FARMERS’ VULNERABILITY TO CLIMATE VARIABILITY AND EXTREME CLIMATE EVENTS IN DIFFERENT AGRO-ECOLOGICAL ZONES IN KITUI COUNTY, KENYA

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DECLARATION

I understand that plagiarism is an offense and I therefore declare that this thesis is my original work and has not been presented in any other institution for any other award.

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DEDICATION

I dedicate this work to my dear parents, John Mutunga and Eunice Wayua and all my siblings for their love, support and encouragement during the entire study period. May the Almighty God bless you immensely.

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ABBREVIATIONS AND ACRONYMS

AC	**:**	Adaptive Capacity
AEZs	**:**	Agro-ecological Zones
ALVI	**:**	Agricultural Livelihood Vulnerability Index
AMCEN	**:**	African Ministerial Conference on the Environment
ANOVA	**:**	Analysis of Variance
ASALS	**:**	Arid and Semi-Arid Lands
ASTGS	**:**	Agricultural Sector Transformation and Growth Strategy
AR3	**:**	Third Assessment Report
AR4	**:**	Fourth Assessment Report
AR5	**:**	Fifth Assessment Report
CCCAF	**:**	County Climate Change Adaptation Fund
CGoK	**:**	County Government of Kitui
CHIRPs	**:**	Climate Hazards group InfraRed Precipitation with Station
CHIRTs	**:**	Climate Hazards group InfraRed Temperature with Station
CIESIN	**:**	Center for International Earth Science Information Network
(CRU TS)	**:**	Climatic Research Unit gridded Time Series
CO_2	**:**	Carbon dioxide
CORDEX	**:**	Coordinated Regional Downscaling Experiment
DAC	**:**	Development Assistance Committee
DFID	**:**	British Department for International Development
ENSO	**:**	El Niño/Southern Oscillation
FAO	**:**	Food and Agriculture Organization
FANRPAN	**:**	Food Agriculture and Natural Resources Policy Analysis Network
FBO	**:**	Farmer Based Organizations
GDP	**:**	Gross Domestic Product
GHGs	**:**	Green House Gas
GtCO2eq	**:**	Gigatonne Carbon dioxide equivalent
GIS	**:**	Geographic Information System
GoK	**:**	Government of Kenya
GCMs	**:**	General Circulation Models

GPS	**:**	Global Positioning System
HVI	**:**	Household Vulnerability Index
HELB	**:**	Higher Education Loans' Board
IPCC	**:**	Intergovernmental Panel on Climate Change
JJAS	**:**	June-July-August-September season
KCIDP	**:**	Kitui County Integrated Development Plan
MK	**:**	Mann-Kendall
MVP	**:**	Multivariate Probit
MAM	**:**	March-April-May
NCCAP	**:**	National Climate Change Action Plan
NAP	**:**	National Adaptation Plan
NDMA	**:**	National Drought Management Authority
OECD	**:**	Organization for Economic Co-Operation and Development
OND	**:**	October-November-December
PERSIANN	**:**	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks
PCA	**:**	Principal Component Analysis
RCM	**:**	Regional Climate Models
RCPs	**:**	Representative Concentration Pathways
SDGs	**:**	Sustainable Development Goals
SEKU	**:**	South Eastern Kenya University
SST	**:**	Sea Surface Temperatures
SLF	**:**	Sustainable Livelihood Framework
SPSS	**:**	Statistical Package for Social Sciences
StARCK+	**:**	The Strengthening Adaptation and Resilience to Climate Change in Kenya Plus
Tmax	**:**	Maximum temperature
Tmin	**:**	Minimum temperature
TRMM	**:**	Tropical Rainfall Measuring Mission
UNCCS	**:**	United Nations Climate Change Secretariat
UNECA	**:**	United Nations Economic Commission for Africa

UNFCCC	**:**	United Nations Framework Convention for Climate Change
UNDP	**:**	United Nations Development Programme
UNISDR	**:**	United Nations International Strategy for Disaster Reduction
VAR	**:**	Variance
VIF	**:**	Variance Inflation Factor

DEFINITION OF TERMS

Adaptation strategies: In this study, an adaptation strategy refers to any action, effort or technology adopted by farmers to reduce the effects of climate variability and extreme climate events on agricultural production.

Adaptive capacity: Adaptive capacity in this study refers to farmers' ability to respond to the effects of climate variability and extreme climate events and was operationalized using the five livelihood capitals from the Sustainable Livelihood Framework.

Climate variability: Climate variability refers to short term variations (usually inter-annual, inter-seasonal or inter-decadal) in the mean values beyond the normal and other statistics (such as standard deviations, the occurrence of extreme climate events, etc.) of climate variables beyond that of individual weather events. In this study, climate variability was measured as the variation in annual and seasonal rainfall and temperature in the different agro-ecological zones.

Extreme climate events: In the present study, extreme climate events refer to occurrence of unusual climate variables above (or below) the normal threshold values such as prolonged dry periods leading to droughts, intense rainfall periods causing flash floods especially along the riparian regions and valleys, strong winds resulting to destruction of property, and livestock disease outbreaks.

Coping strategies: In the present study, coping strategies means actions taken by households to deal with food shortages in times of drought.

Exposure: Exposure in the present study means the number of times households in the study area were faced with climate variability and extreme climate events such as droughts, floods, strong winds and livestock disease outbreaks.

Sensitivity: The term sensitivity in this study refers to the damages households incurred from exposure to climate variability and extreme climate events.

Resilience: Resilience in this study means the ability of farmers to withstand, respond and recover from exposure to climate variability and extreme climate events.

Vulnerability: Vulnerability in this study refers to farmers' predisposition to and inability to cope with the adverse effects of climate variability and its extreme climate events.

ABSTRACT

Vulnerability assessment studies are important in informing the planning of adaptation programmes and strategies, their implementation as well as monitoring and evaluation to assess their effectiveness in increasing farmers' resilience variability and extreme weather events. The present study sought to analyze trends in rainfall and temperature, assess the vulnerability of farmers to climate variability and extreme climate events at the household level as well as coping and adaptation practices adopted by farmers from four different agro-ecological zones, namely; semi-humid, transitional, semi-arid and arid zones in Kitui County. Descriptive research design was used in the study. The sample size comprised of 341 farming households in the four agro-ecological zones which were selected using systematic random sampling method. Mann-Kendall trend analysis results for annual average rainfall in the study area for a period of 30 years (1988-2018) indicated a non-significant negative trend for the average annual rainfall in all the four agro-ecological zones. The results however showed a significant positive trend in average maximum and minimum temperature in all the four agro-ecological zones. Vulnerability results indicated that the arid zone had the highest vulnerability index (17.29) followed by the transitional (1.63) and semi-arid (1.49) zones while the semi-humid zone had the least (-2.65). Additionally, results from one-way Analysis of Variance (ANOVA) indicated a statistically significant difference in the vulnerability index and its components' indices across the four agro-ecological zones. Multinomial logistic regression results showed that different socio-economic characteristics and agro-ecological zones had varying influence of households' vulnerability levels. Regarding the adoption of coping strategies, the results indicated that using off-farm income, selling livestock to buy food, reducing the number of meals taken in a day, selling family assets and seeking off-farm employment in urban areas were the most common coping strategies adopted by households in response to food shortage in the study area. With reference to adaptation strategies, a statistically significant difference in the adoption of mixed farming systems, improved crop varieties, use of fertilizers, irrigation, utilization of manure, agroforestry practice and planting shade trees across the different agro-ecological zones was reported. The study established that the four agro-ecological zones had varying vulnerability indices, adoption of different coping and adaptation strategies was significantly different across the agro-ecological zones and that households' socio-economic characteristics had a varying influence on the farmers' choice of specific coping strategies to food insecurity coping and adaptation strategies to climate variability. The present study thus recommends that projects, programmes and policies initiated by the national and county governments and other non-governmental development agencies aimed at reducing households' vulnerability to climatic variability and occurrence of extreme climate events by increasing their resilience should be informed by households' vulnerability levels in different agro-ecological zones and target specific households' socio-economic characteristics that influence the adoption of the specific adaptation options.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Climate change has been the most complex global environmental challenge affecting many sectors in the 21st Century and has thus been acknowledged as a significant threat to the achievement of several Sustainable Development Goals (SDGs) (IPCC, 2014; UNCCS, 2017; UNECA, 2018). For instance, climate variability and extreme climate events have reduced global agricultural production, threatening food security both at the global and regional levels, especially in Sub-Saharan Africa (IPCC, 2007b; Jones and Thornton, 2003; Thornton *et al.,* 2009). This implies that there is a high risk of falling far short of achieving the SDG target of hunger eradication by 2030 (SDG 2), and even reversing the progress already made (Koubi, 2019). Additionally, since the agricultural sector is a major driver of many economies in Sub-Saharan Africa, the negative effect of climate variablilty and extreme climate events on agricultural production is not only likely to reduce economic growth but also increase poverty, malnutrition and socio-economic inequality thereby hindering the achievement of economic growth (SDG 8), poverty eradication (SDG 1), good health and well-being (SDG 3) and reduced inequalities (SDG 10) (Burke *et al.*, 2018; Koubi, 2019; Pretis *et al.,* 2018).

The vast scientific research and models by the Intergovernmental Panel on Climate Change, (IPCC) support the scientific accord that the Earth's climate is indeed changing (IPCC, 2007b, 2014; Mata *et al.,* 2001). According to Le Treut *et al.* (2007) and McMichael *et al.*(2003) variations in the Earth's climate have been observed throughout history resulting from natural internal variations in the climate system and anthropogenic activities. Scientific evidence has however associated the current warming of the Earth to the increased accumulation of greenhouse gases from fossil fuels as well as the destruction of carbon sinks by humans (IPCC, 2014). According to the IPCC Fifth Assessment Report (AR5), the anthropogenic influence on the climate system is explicit and the recent greenhouse gas emissions from human activities are the highest to be reported in history (IPCC, 2014).

Climate projection models by the IPCC indicate that global mean surface temperature will rise by a range of 1.4°C to 5.8°C from the present to 2100, with the range being influenced by the rate of emissions from fossil fuels combustion between the present and then as well as on different projection models utilized (IPCC, 2001). Stainforth *et al.* (2005) indicated that the rise in temperature by the year 2100 might be larger compared to that recorded in the year 2001. According to the IPCC's Fifth Assessment Report (AR5), warming of the Earth's climate is 'unequivocal' and a successively warmer decade has been recorded from the past thirty years compared to any previous decade from 1850 (IPCC, 2014).

Variations in the Earth's climate in the recent decades have had significant adverse effects on both the natural and human systems across the globe (IPCC, 2014). Studies have recorded that changes in precipitation patterns and snow-melting have caused alterations in most hydrological systems and processes resulting in significant effects on water quality and quantity across the world (IPCC, 2014).

Alterations in rainfall patterns and temperature coupled with increasing concentration of CO_2 levels are likely to cause significant reduction in agricultural production globally owing to the increasing frequency of occurrence of extreme weather events like floods, droughts as well as variations in diseases and pests distribution patterns (IPCC, 2007b).The impacts of the changing climate on agriculture have been reported to vary spatially. According to IPCC (2007), a slight increase in crop productivity is likely to occur if local average temperatures increased with a range of 1–3°C at mid-to-high latitudes while crop productivity at lower latitudes might decrease even with relatively small increases in the local average temperature of up to (1–2°C). Similarly, Jones and Thornton (2003) noted that a 10 to 20% reduction in crop yields is likely to occur by 2050 in the tropics and sub-tropics due to increasing temperatures and consequent reduction in moisture availability with crop failures being more severe in some places compared to others.

According to IPCC (2014), numerous studies on the effects of climate variability on crop productivity in different regions revealed that the adverse impacts of the variability on agricultural productivity outweigh the beneficial impacts. The negative effects of variations in the climate system are more severe in developing countries due to their high dependence on sectors highly sensitive to climate variability such as rain-fed (Belloumi, 2014; Slingo *et al.,* 2005; Thomas *et al.,* 2005). According to IPCC (2007), Africa has been projected to be the most vulnerable continent to climate variability owing to its limited capacity to adapt as a result of high poverty levels, poor governance as well as inadequate infrastructural development.

Agriculture has been reported as one of the highly sensitive sectors to climatic changes since any degree of climate variability can be associated with severe negative impacts on agricultural production and related processes (Lin, 2007). Variations in the intensity and frequency of extreme climate events, such as heavy precipitation, floods and droughts are likely to have adverse impacts on agricultural production with projections showing up to 50% reduction in crop yield and a 90% decline in income from crop production by 2100 (IPCC, 2007b).

The potential for global food production has been projected to increase with a rise in mean local temperatures of up to 1 to 3°C with the slightest increase in mean temperature beyond this range causing a significant decline in food productivity thereby resulting in serious food insecurity (IPCC, 2007b). According to Easterling et *al.* (2007), variations in temperature and precipitation patterns are predicted to increase the number of undernourished people in the world.

For sub-Saharan Africa, changes in precipitation and mean surface temperatures are projected to intensify the occurrence of crop diseases and pests as well as altered soil fertility (Nelson *et al.,* 2007). Further, reducing incomes coupled with increasing unemployment are estimated to increase vulnerability in agricultural zones in addition to deteriorating human health (FAO, 2015). Economic losses resulting from climate variability and extreme climate events have been estimated to rise to 14% of Sub-Saharan Africa's GDP if adaptation measures fail to be implemented (Schaeffer et *al.,* 2014: FAO, 2015). If the projected economic losses were to occur**,** resources that would have been utilized for investments in important development projects in the rural areas would be diverted to short term emergency responses (World Bank, 2010) which would, in turn, undermine the achievement of several sustainable development goals (SDGs) (UNCCS, 2017).

The IPCC's Fourth Assessment Report (AR4) predictions indicated a significant reduction in the land suitable for agriculture, duration of growing seasons as well as agricultural yield potential, especially in the marginalized areas in arid and semi-arid zones where rain-fed crop yields are estimated to decrease by up to 50% by 2020 in some countries (IPCC, 2014). Further, empirical studies have indicated that sources of freshwater upon which agricultural productivity and viability are dependent are highly susceptible to the effects of climate variability and that the present strategies for water resources management are not adequate in coping with the impacts (IPCC, 2014).

A report by World Bank (2008), indicated that the impacts of climate variability on agricultural production were more pronounced in rural households whose livelihoods are largely dependent on rain-fed agriculture. Farmers in developing countries are highly vulnerable to the adverse effects of climate variability and extreme climate events owing to their low adaptive capacity since they are mostly characterized by low levels of education and financial capabilities, limited arable land coupled with inadequate access to markets, credit facilities and technical assistance as well (Harvey *et al.*, 2014; Morton, 2007). According to Harvey *et al.* (2014), many farmers in Africa are located in highly marginalized rural areas characterized by low-quality infrastructure that further limits their access to markets, technical and financial aid as well as emergency disaster relief.

Kenya has been reported to be one of the highly vulnerable countries to the effects of climate variability and extreme climate events in Africa owing to its inadequate ability to adapt as well as its reliance on sectors highly sensitive to climate variability like agriculture and fisheries as the main drivers of the country's economy (FAO, 2011; Herrero *et al.*, 2010; Kabubo-mariara and Karanja, 2007; Kurukulasuriya *et al.*, 2006). Variations in temperature and rainfall patterns are thus projected to have negative effects on the country's economy since recurrent droughts, unpredictable and erratic precipitation patterns as well as floods would continuously cause adverse impacts on the livelihoods of households and communities (Government of Kenya, 2016).

Empirical studies have shown that the impacts of climate variability and extreme climate events have had significant costs implications and resulted in a decline in economic growth in Kenya (SEI, 2009). Being a key livelihood strategy for a majority of rural communities in Kenya, negative developments in agriculture would have adverse effects on livelihoods that are highly dependent on agricultural production (GoK, 2005).The cumulative effects of climate variability and extreme climate events in Kenya therefore pose a significant threat towards the attainment of the country's Vision 2030 (Parry *et al.,* 2012) as well as the implementation of the SDGs (UNCCS, 2017; UNECA, 2018).

To cushion rural communities from the effects of climate variability and have sustainable livelihoods in the advent of a changing climate, implementation of adaptation strategies will be paramount (Akinnagbe and Irohibe, 2014; Schipper *et al.,* 2008; IPCC, 2007). Adaptation, which involves adjustments in both human and natural systems, helps systems respond to the already experienced or projected climatic changes and their impacts (IPCC, 2007). In practical and operational terms, adaptation involves changing structures, actions and procedures to moderate, offsetting anticipated damages or maximizing opportunities resulting from climate variability (IPCC, 2007b). Adaptation therefore includes the process of altering practices, livelihood strategies and infrastructure as well as legal and institutional frameworks in response to actual or projected climate events to reduce the system's susceptibility (Schipper *et al.,* 2008). According to AMCEN (2008), adaptation is a process that begins with understanding the present vulnerability of a system, strengthening the system's capacity for adaptation planning and execution, evaluation of pilot interventions and adoption of strategies to implement climate variability adaptation in susceptible areas.

The government of Kenya acknowledges the impact of climate variability on the livelihoods of communities and the overall country's economy and has been in the forefront to address them through the development of a policy framework to spearhead adaptation both at the national and county levels. The Ministry of Environment and Natural Resources developed the National Climate Change Response Strategy in 2010, the National Climate Change Action Plan (NCCAP 2013-2017) in 2012, the National Adaptation Plan (NAP 2015-2030) in 2016 and the Climate Change Act of 2016 in order to address the nation's susceptibility to climate variability (Government of Kenya, 2016). Additionally, the Ministry of Agriculture, Livestock, Fisheries and Irrigation developed the Agricultural Sector Transformation and Growth Strategy (ASTGS 2019-2029) to enhance food security, improve farmers' income and increase employment opportunities which are critical in reducing households' vulnerability to climate variability and extreme climate events (Government of Kenya, 2019).

The Strengthening Adaptation and Resilience to Climate Change in Kenya Plus (StARCK+) programme which is funded by the Government of the United Kingdom, has supported the National Drought Management Authority (NDMA) through the Adaptation Consortium to assist county governments and communities in Garissa, Isiolo, Kitui, Makueni and Wajir to mainstream climate change adaptation planning in county development (Orindi *et al.,* 2018). The programme intended to provide technical support and strengthen adaptive capacity for households in the five counties through identification and implementation of climate-resilient livelihood strategies at the local levels through the formation of County Climate Change Adaptation Fund (CCCAF) kits to aid prioritization of climate variability adaptation investments in the communities (Crick *et al.,* 2019; Murphy and Orindi, 2017). In that regard, the County Government of Kitui established the Kitui County Climate Change Fund in 2018 to finance climate change adaptation and resilience-building in the County (CGoK, 2018).

At the local level, farmers in Kenya's rural areas are also aware of the effects of climate variability and some have implemented several adaptation strategies in efforts to lower associated agricultural losses (Mutunga *et al.,* 2017; Ndambiri *et al.,* 2012; Oremo, 2013). However, the farmers have been faced with several challenges in the adoption of options such as inadequate financial and technological capacity, inadequate access to credit services as well as weather and climate change-related information (Mutunga *et al.,* 2018; Ndambiri *et al.,* 2012).

Adaptation needs vary significantly between different locations, people and sectors, and thus effective and strategic adaptation planning should target the most vulnerable systems (Fritzsche *et al.,* 2014). Vulnerability assessment studies are therefore important in the planning phase of adaptation programmes, in the identification of the impact of climate variation on farming systems as well as prioritization of adaptation options with regard to farmers' vulnerability levels (Fritzsche *et al.,* 2014). Since adaptation interventions aim to raise the resilience of farmers and their ability to adapt to climate variability consequently reducing their vulnerability (Vincent and Cull, 2010). Vulnerability assessment serves as an important tool in evaluating the effectiveness of adaptation programmes and strategies in reducing vulnerability (Craft and Fisher, 2016; Fritzsche *et al.,* 2014). The few vulnerability studies in Kenya have however been conducted at either regional or national scale (Marigi, 2017; Mutimba *et al.,* 2010; Mwangi *et al.,* 2020; Vincent, 2004) with less attention given to farmers at the local level. According to Ludena and Yoon (2015), vulnerability assessments should emphasize the local level context since even neighboring communities respond differently to the effects of climate variability and extreme climate events depending on their ability to adapt. Therefore, there exists a knowledge gap on the distribution of vulnerability levels of households in the study area. The present study thus sought to assess the integrated vulnerability of farmers to climate variability and extreme climate events at the household level in different agro-ecological zones in Kitui County.

1.2 Statement of the problem

Anthropogenic induced variations in the climate system have been reported to cause adverse effects on global agricultural production due to the increased frequency in occurrence of extreme weather events such as droughts and floods and changes in patterns of pests and diseases resulting from variability in temperature and rainfall patterns (IPCC, 2007b). Kenya has been rated as one of the highly susceptible countries to climate variability and extreme climate events in Africa owing to its reliance on sectors such as agriculture and fisheries that are highly sensitive to climatic changes as the main drivers of the economy coupled with limited ability to adapt (FAO, 2011; Herrero *et al.,* 2010; Kabubo-mariara and Karanja, 2007) and therefore recurring droughts, erratic rainfall patterns and floods are likely to have disastrous impacts on community livelihoods. According to FAO (2011b), rising temperatures and increased drought occurrences have exacerbated the fragility of farmers in the Arid and Semi-arid Lands (ASALs) whose livelihoods are dependent on agricultural production thus increasing incidences of food insecurity and malnutrition.

Since farmers in the rural areas are directly dependent on agriculture and have inadequate adaptive capacity, any decrease in agricultural productivity would have adverse effects on their livelihoods. With changes in precipitation patterns, increased temperatures and recurring droughts, farmers in ASALs will be faced with rising possibilities of losses in crop yields, increased diseases and mortality of livestock, increased livelihood insecurity and dependency on food aid as well as a downward spiral on human development indicators such as health and education (Ching, 2010; Easterling *et al.,* 2007).

Just like other farmers in ASALs, farmers in Kitui County are highly vulnerable to the effects of increased temperature, unreliable and erratic rainfall patterns and increased frequency of droughts (NDMA, 2017). As previously mentioned, although farmers in the county have implemented several adaptation options in efforts to reduce the associated agricultural losses they are still faced with several challenges in the implementation of the adaptation strategies. In order to achieve effective adaptation to climate variability, understanding the vulnerability of farmers to climate variability and extreme climate events would be paramount. The present study therefore sought to assess the integrated vulnerability of farmers to climate variability and extreme climate events as well as coping and adaptation strategies adopted at the household level in different agro-ecological zones in Kitui County.

1.3 Objectives of the study

1.3.1 Overall objective

The overall objective of the study was to assess farmers' vulnerability and adaptation to climate variability and extreme climate events in Kitui County.

1.3.2 Specific objectives

i. To analyse rainfall and temperature trends and variability in different agro-ecological zones in Kitui County.
ii. To assess the spatial vulnerability of farmers to climate variability and extreme climate events in the study area.
iii. To develop a predictive model for assessing farmers' vulnerability to climate variability and extreme climate events in the study area.
iv. To examine determinants of households' choice of specific coping strategies to food insecurity resulting from climate variability and extreme climate events in the study area.
v. To assess determinants of farmers' choice of specific adaptation strategies to climate variability and extreme climate events in the study area.

1.4 Hypotheses

The study sought to test the following hypotheses;

1. H_0-There is no significant trend in rainfall and temperature in different agro-ecological zones in Kitui County.

   H_1 - There is a significant trend in rainfall and temperature in different agro-ecological zones in Kitui County.
2. H_0-There is no significant difference in the vulnerability of farmers to climate variability and extreme climate events in the study area.

   H_1- There is a significant difference in the vulnerability of farmers to climate variability and extreme climate events in the study area.
3. H_0- Socio-economic characteristics and agro-ecological zones do not influence farmers' vulnerability to climate variability and extreme climate events in the study area.

H_1- Socio-economic characteristics and agro-ecological zones influence households' choice of specific adaptation strategies to climate variability and extreme climate events in the study area.

4. H_0- Socio-economic characteristics do not influence households' choice of specific coping strategies to food insecurity in the study area.

   H_1- Socio-economic characteristics influence households' choice of specific coping strategies to food insecurity in the study area.

5. H_0- Socio-economic characteristics do not influence households' choice of specific adaptation strategies to climate variability and extreme climate events in the study area.

   H_1- Socio-economic characteristics influence households' choice of specific adaptation strategies to climate variability and extreme climate events in the study area.

1.5 Justification of the study

Assessment of the vulnerability of systems to climate variability and extreme climate events is vital in building an understanding of why systems are vulnerable, assessing how effective past coping options are in the context of past and present climatic changes as well as identifying and targeting feasible and practical adaptation strategies to systems that are highly vulnerable (Craft and Fisher, 2016; Fritzsche *et al.,* 2014; Gleeson *et al.,* 2011; Smit and Wandel, 2006).

Although several climate variability and extreme climate events related studies in Kenya have been conducted in the recent past, their main focus has been on the effects of increasing temperatures and changing rainfall patterns on agricultural (Kabubo-mariara and Karanja, 2007; Omoyo *et al.,* 2015) and adaptation strategies by farmers (Mutunga *et al.,* 2017; Ndambiri *et al.,* 2012; Oremo, 2013) with little focus on how vulnerable farmers are to climate variability. Thus, the present study sought to bridge the knowledge gap on the extent to which farmers in Kitui County are exposed to, their sensitivity to the effects of climate variability and extreme climate events, and their adaptive capacity.

Further, the few vulnerability studies have been conducted at either regional or national scale (Mutimba *et al.,* 2010; Parry *et al.,* 2012; UNFCCC, 2007; Vincent, 2004) with less attention given to farmers at the local level. According to Ludena and Yoon (2015), vulnerability assessments should emphasize the local level context since even neighboring communities respond differently to the effects of climate variability and extreme climate events depending on their ability to adapt. This is because vulnerability levels are different among households, even those in the same community (Bobadoye *et al.*, 2019; Giller *et al.,* 2011; Westerhoff and Smit, 2009) due to the differences in resource endowments, livelihood options as well as institutional and social arrangements in a locality (Chinwendu *et al.,* 2017; Herrera *et al.,* 2018).The variation implies that the farmers would have different sensitivity levels thus varying vulnerability levels (Rurinda *et al.,* 2014). The present study therefore sought to assess the vulnerability of farmers to climate variability and extreme climate events at the household level in different agro-ecological zones in Kitui County.

1.6 Significance of the study

Adoption and effective implementation of adaptation strategies is of paramount importance in order to cushion farmers from negative impacts of climate variability and extreme climate events. Understanding the vulnerability of farmers to hazards of climate variability is thus essential in planning for adaptation. The results of the present study would therefore be important to policymakers in both the Central Government and the County Government of Kitui as well as other non-governmental entities in planning, resources allocation and implementation as well as monitoring of adaptation plans, projects and programmes that target specific groups at the community level based on their vulnerability levels. Academically, the study would add to the present vulnerability assessment literature and provide suggestions for further studies.

1.7 Scope of the study

Vulnerability assessment studies in all households in Kitui County are vital for planning and prioritizing adaptation interventions in the County. The study was however limited to selected households from the four agro-ecological zones in Kitui County. The respondents for the study were drawn purely from farmers, who are mainly agro-pastoralists, in the study area. Even though there are several elements of climate, the study focused on temperature and rainfall as the main elements of climate which define climate variability since the two are the essential direct inputs for agricultural production (Deschênes and Greenstone, 2011) and according to IPCC (2007b), variation in rainfall and temperature, as well as extreme climate events, are the main indicators of exposure to climate variability. In regard to extreme climate events, the present study only examined droughts, flash floods especially along the riparian regions and valleys resulting from intense rainfall periods, strong winds and livestock disease outbreaks. Further, the study only assessed households' socio-economic characteristics as the determinants of farmers' vulnerability and their ability to adopt different coping and adaptation strategies. According to Smit *et al.* (2001), adaptation occurs in socio-economic settings and therefore households' socio-economic characteristics are the main features that determine a household's adaptive capacity.

1.8 Assumptions of the study

The study was based on the following assumptions;

1. All households in the study area practised agro-pastoral farming.
2. The household heads were the main decision-makers in regards to coping and adaptation to climate variability and extreme climate events.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rainfall and temperature trends and variability

Niang et *al.* (2014) studied climate trends and projections in Africa and reported that most regions in Africa had inadequate observed precipitation data for concrete conclusions on annual rainfall trends over the last century and that there were discrepancies between different observed precipitation data sets in many regions of the continent. The study however reported that in regions with adequate data, '*very likely'* reductions in annual rainfall were reported in most parts of Africa with a general decrease in the 20th century being experienced over the Sahel. Regarding temperature trends, the authors reported a 0.5°C rise in near-surface temperatures over the past century in most African countries. Further, the authors noted that minimum temperatures were rising faster compared with maximum temperatures. The study further noted that there was a high likelihood that there was an increase in the average annual temperature over the last century across several regions of Africa and that was substantial proof of an anthropogenic influence on the increasing temperatures across the continent.

Williams and Funk (2010) analyzed climate data using principal component analysis (PCA) to confirm a westward extension of the tropical Walker circulation contrary to its weakening during the long rainfall season in the East African region. The study confirmed a westward extension tropical Walker circulation which was suggested to be caused by the expansion of the edge at the west of the Indian Ocean's tropical warm pool. The study suggested that the western expansion of the Walker circulation could have resulted in the reduction in the long rain season precipitation in the East African region. The results of this study were however contrary to the Fourth Assessment Report (AR4) findings where most of the models indicated an increase in rainfall across the East African region (Christensen *et al.*, 2007).

Lyon and Dewitt (2012) used observed data and climate model simulations to proof that the sudden reduction in rainfall in the "long rains" season was associated with sudden variations in sea surface temperatures (SST), primarily in the tropical Pacific basin. The study revealed that there had been a sudden decrease in “long rains” across Eastern Africa in 1999 which have been linked to the repeated occurrence of abnormal rainfall patterns in the region to date. Further, the study noted that the reduction in the “long rains” seemed to have been largely caused by broad variations in sea surface temperatures especially in the tropical Pacific and that the continuous occurrence of the present sea surface temperatures inconsistencies identified in the tropical Pacific indicates a progressive reduction as well as unpredictability in “long rains” over eastern Africa.

While working on trends of extreme temperature and rainfall indices for Arid and Semi-Arid Lands of South Eastern Kenya, Marigi et *al.* (2016) used the RClimDex software to derive climate extreme indices for five stations in the ASALs of South-Eastern Kenya, namely Makindu, Katumani, Kitui, Mutomo and Mwingi, using climate data from 1961 to 2009. The indices derived from the study showed declining patterns in annual precipitation, the intensity of precipitation, successive moisture periods and increasing trends in successive days without moisture as well as constant rising temperature trends for both the maximum and minimum temperature index values.

Additionally, Aduma et *al.* (2018) carried out a trend analysis for precipitation and temperature in the Amboseli ecosystem of Kenya using historical Climate Hazards group InfraRed Precipitation with Station (CHIRPS) and Climate Hazards group InfraRed Temperature with Station (CHIRTS) data for the period 1960-2014 and the period 2006-2100 for the simulations. The study used Regional Climate Models (RCM) from Coordinated Regional Downscaling Experiment (CORDEX) for simulations of precipitation and warming in the Amboseli ecosystem as well as Mann– Kendall’s statistical test and linear trend to analyze periodic patterns in precipitation and temperature. Between 1960 and 2014, there was a non-significant decrease in annual and seasonal precipitation, according to the study's findings. In terms of temperature trends, the study found that the annual minimum (1.23°C) increased more than the annual maximum (0.79°C), with maximum temperatures during the October-November-December (OND) season increasing by 0.88 °C and the March-April-May (MAM) season increasing by 0.69 °C.

The scientists also found that the June-July-August-September (JJAS) season had the largest increase in minimum temperature (1.35°C), while the MAM season had the lowest increase (1.04°C). Pertaining future projections, the study reported a decrease in predicted precipitation for the four seasons based on Representative Concentration Pathways (RCPs) for the years 2006-2100, as well as a minimal increment in annual and OND precipitation with reductions in the MAM and JJAS, while projections for maximum and minimum temperatures showed less than 1°C increments for the years 2030, 2050, and 2070. The study acknowledged that rising temperatures and changing precipitation patterns could have a significant influence on Eastern Africa's natural resources in the arid and semi-arid lands upon which wildlife, livestock and agricultural production are dependent.

2.2 Farmers' vulnerability to climate variability and extreme climate events

Owusu *et al.* (2021) assessed the vulnerability of farming households utilizing data from agricultural households in three distinct agro-ecological zones in Ghana. The empirical results suggested that farmers in the Guinea Savannah zone had high vulnerability levels, while the Forest-Savannah Transition zone had households with low vulnerability levels. The study also found that agro-ecological zones have a major impact on household vulnerability, and it recommended that policymakers and key stakeholders develop and implement tailored intervention measures that target the most susceptible households in the zones studied.

Bobadoye *et al.* (2019) conducted a study to analyze how vulnerable Maasai pastoralist communities were to climate variability in Kajiado County, Kenya. The study measured vulnerability as a function of exposure, sensitivity and adaptive capacity using data collected from 305 households in five different wards in Kajiado East Sub-county. Vulnerability indices for the households were calculated using weights assigned to the vulnerability indicators from Principal Component Analysis (PCA). The findings revealed that Kitengela ward had the least vulnerable households owing to the high infrastructural and socio-economic development in the ward. Further, the study reported that areas with access to basic facilities such as water, education and health centers had low vulnerability levels to climatic extremes and concluded that there was a variation in susceptibility levels of households in the same locality. The authors recommended that climate change intervention measures should therefore target particular households in wards and within counties based on their vulnerability levels.

Ndungu *et al.* (2015) examined how vulnerable the rural people of the Mid-Hills of Himachal Pradesh in India are to climatic changes and established that natural disasters such as floods and droughts elevated the exposure levels of the households in the study area while snow occurrences reduced their exposure, possibly due to snow's good ground water recharge and reduced surface run-off due to slow infiltration. Regarding sensitivity, the study indicated that livestock fatalities and property damage, a decreasing trend in availability of water resources and the proportion of income from natural resources had a positive influence on the sensitivity index whereas the proportion of income from non-natural resources influenced the sensitivity index negatively. Further, the study revealed that among the five groups of indicators for adaptive capacity, the physical capital had the highest influence on adaptive capacity while the human and social capitals ranked second and third, respectively. The authors concluded that adaptive capacity had direct policy implications and recommended that enhancing the adaptive capacity of the households in the study area could be achieved by the creation of irrigation facilities, improvement of infrastructure and investments in off-farm income generation opportunities.

Piya *et al.* (2012) analyzed the vulnerability levels of households using survey data collected from 221 households in four distinct administrative units (districts) in Chepang area in Nepal. The study established that exposure to variations in climatic variables and extreme climate events was the key determinant of the integrated vulnerability of an area and that out of the three constituents of vulnerability, adaptive capacity had a direct influence on policy and therefore enhanced households' ability to adapt to climate variability could greatly decrease their sensitivity levels consequently decreasing their vulnerability climate variability and extremes. The authors recommended that priority policy intervention should aim at investing in off-farm livelihood strategies for enhanced financial capital as well as reduction of communities' reliance on natural resources.

Tesso *et al.* (2012) conducted a survey using 452 households to analyze how vulnerable and resilient farming households in North Shewa, Ethiopia are to environmental change. The study used an integrated vulnerability analysis approach where indices for socio-economic and biophysical indicators were calculated using PCA. The results of the study indicated that highland farmers were more susceptible to environmental changes as opposed to their counterparts in the lowlands. The results further showed that farmers who had higher education levels, savings, investments in environmental conservation, easily accessed the market, irrigation and credit facilities and good social networks were more resilient compared to those without.

2.3 Determinants of households' vulnerability to climate variability and extreme climate events

Azumah *et al.* (2020) used cross-sectional data from 300 farmers to examine factors that determine the vulnerability of households to climate variability in two Ghanaian districts (South Tongu and Zabzugu) using ordered probit regression. The results indicated that education, credit, Farmer Based Organizations' (FBO) membership, number of unemployed household members, non-farm income, early warning and drought significantly influenced the vulnerability levels of farming households in the study area. The study however indicated that contrary to the *a priori* expectation of the research, the number of unemployed household members and receiving early warnings weather information decreased the probability of households having low vulnerability levels.

Ghosh and Ghosal (2020) used ordinal logistic regression to assess how different socio-economic characteristics influenced the vulnerability of households' livelihoods to climatic change in the Himalayan hillocks of West Bengal, India. The study revealed that specific factors like the agricultural land size, household heads' occupation, caste, self-help groups' membership, perception of precipitation trends and housing type were key determinants of income loss in maximum households. Moreover, the study observed that increasing work opportunities, understanding early warning information on floods and other climatic disasters as well as access to higher education reduced households' susceptibility to climate variability in the study area. Additionally, the study noted that households with larger agricultural land were able to survive the climatic changes despite immense crop loss compared to those with smaller agricultural lands while increasing distances to the local markets and agricultural extension centers increased the probability of households' crop and income loss in the study area. The authors suggested an urgent need to develop physical infrastructures like bridges over rivers, proper roads, housing infrastructure as well as strengthening the existing flood management strategy in the sub-Himalayan area.

Bobadoye *et al.* (2019) examined determinants of Maasai pastoralist communities' susceptibility to climate change in Kajiado County, Kenya, using data collected from 305 households in five different wards in Kajiado East Sub-county. Using ordered logit regression analysis, the study examined how different variables influenced vulnerability levels of households in the different wards. The results indicated that household heads' gender, level of education, access to extension services, diversity of livestock and size of land were among the significant determinants of how vulnerable households were to climatic change.

In their study, Opiyo *et al.* (2014a) assessed determinants of households' vulnerability to climate change among pastoralists in Kenya. The study analyzed data from 302 households using ordinal logistic regression to assess how various variables influenced households' vulnerability. The findings revealed that household head's gender and age, family size, marital status, social networks, access to agricultural extension and weather emergency alerts, alternative income sources, number of livestock owned, livestock diversification, proximity to markets, job status were the major predictors of susceptibility levels among the pastoralists. According to the authors, measures that address the factors of vulnerability, with a focus on women's empowerment, education, and income diversification, are likely to improve pastoral households' resilience.

Notenbaert *et al.* (2013) explored predictors of agro-pastoralists' vulnerability to climatic pressures in Mozambique's Gaza area. The findings revealed that the household head's gender, age, capacity to save income and availability of emergency financial lending all had a role in determining a household's vulnerability to climatic changes and variability.

The results, however, indicated that the cumulative impact of determinants such as proximity to water sources, farm income, forest resources' access, crop diversification index, food assistance and the size of herds owned did not have a significant effect on the households' social vulnerability to climatic changes.

2.4 Spatial vulnerability to climate variability and extreme climate events

Mwangi *et al.* (2020) used an indicator approach to vulnerability assessment to understand the distribution of vulnerability trends in Kitui County. The researchers employed additive approach to index construction to generate constituent maps for exposure, sensitivity and adaptive capacity where the three main elements of vulnerability were averaged to create an integrated vulnerability map. The findings revealed a west to east vulnerability slope across Kitui County, with lower vulnerability levels in the western and central regions and higher vulnerability values in the eastern and northern areas.

Hoque *et al.* (2019) while working on agricultural livelihood vulnerability to climate change in Coastal Bangladesh analyzed the spatial distribution of vulnerability patterns in the study area. The study applied a weighted sum of sub-indices technique for aggregation of indicators of exposure, sensitivity and adaptive capacity. The categorization of exposure, sensitivity, adaptive capacity and overall vulnerability indices into five classes of attributes (very low, low, moderate, high, and very high) at the spatial scale was accomplished by employing the equal interval approach under an ArcGIS environment. The results showed varying spatial distribution of exposure, sensitivity, adaptive capacity and overall vulnerability across the coastal districts.

While assessing agricultural livelihood vulnerability to climate change in Coastal Bangladesh, Hoque *et al. (*2019) looked at the geographic variation of susceptibility trends of households to climate change in the area. For the aggregation of variables of exposure, sensitivity, and adaptive capacity, the researchers used a weighted sum of sub-indices approach. The equal interval approach was used in an ArcGIS context to categorize exposure, sensitivity, adaptive capacity and total vulnerability indices into five classes of attributes (very low, low, moderate, high, and very high) at the spatial scale. The study found that vulnerability hotspots were dominant in the rural farming regions where livelihood strategies are primarily dependent on growing crops and are constantly threatened by various climatic hazards, while low vulnerability zones were spread along the Sundarbans which provide numerous livelihood options thereby decreasing the sensitivity of neighboring towns safeguarding them from numerous climatic hazards. The authors stated that assessing the agricultural livelihood vulnerability index (ALVI) and mapping out patterns of vulnerability is critical in supporting those who are vulnerable. The study established that the 'hot' spot of vulnerability distribution was concentrated in the rural agricultural districts where livelihoods are mainly dependent on crop-based farming and are continuously threatened by multiple climatic disasters while the vulnerability 'cold' spots were distributed along the world's largest mangrove forest, the Sundarbans, which offers numerous livelihood opportunities and reduces the vulnerability of surrounding districts by providing an ecological buffer against climatic disasters. The authors stated that assessing the agricultural livelihood vulnerability index (ALVI) and mapping out vulnerability patterns in communities is critical for decision-makers and key stakeholders to prioritize funding for climate change intervention.

Bobadoye *et al.* (2019) studied the spatial vulnerability of pastoral households to climatic changes in Kajiado County, Kenya. Vulnerability indices were generated for 305 pastoral households in the study area using 28 variables as measures for adaptive capacity, exposure and sensitivity. Using the Geographical Information System (GIS) software package ArcGIS 10.2, vulnerability maps depicting the spatial distribution of vulnerability patterns (highly vulnerable, moderately vulnerable, and less vulnerable) in the study area were generated. The research reported disparities in the spatial distribution of vulnerability levels of pastoral households to climatic changes in the region.

Marigi (2017) used climate and socio-economic data to examine the spatial distribution of climate change vulnerability in different parts of Kenya. The study used point precipitation data from 1960 to 2014 to create exposure indicators while socio-economic population data was used to create indicators for sensitivity and adaptive capacity for all the 47 counties in Kenya, which were analyzed using GeoClim software to produce geographical distribution of exposure, sensitivity and adaptive capacity indices. To create a vulnerability map, composite layers of the vulnerability attributes were overlaid. The findings showed that the whole nation was susceptible to climatic changes, where high vulnerability levels were concentrated in the northern regions with the southern edge of the coastal line being the most vulnerable.

2.5 Households' coping strategies to food insecurity and determinants of choice of specific coping strategies

Sani and Kemaw (2019) analyzed information from 276 households' survey on food insecurity and its drivers in Assosa zone, western Ethiopia. The findings of the research revealed that reduction in meal quantity, times of meal service, doing daily casual jobs, using livestock sales to buy food, harvesting and selling forest products were the main strategies adopted by households in response to food shortage in the zone. Additionally, results from Tobit model indicated household head's age, the number of family members and off-farm earnings had a positive impact on the level of families' food insecurity, but access to irrigation, farm revenue, proximity to market and loans had a negative impact. Future interventions, according to the authors, should focus on increasing households' resilience by improving their access to human, financial and physical assets.

Tsegaye *et al.* (2018) conducted a study to investigate food shortages and coping strategies in Dabat district, northwest Ethiopia. The Household Food Insecurity Access Scale (HFIAS) was used to assess the extent of food shortages and insecurity while logit regression was utilized to analyze the influence of different variables on meal reduction as a strategy to cope with food insecurity. The results of the study established that households adopted a variety of survival strategies, including reducing meal frequencies as well as quantities (55.96 percent), lending money and food (38.11 percent) and receiving food and financial assistance (26.67 percent). Furthermore, when presented with food stress, city inhabitants, mid-altitude (weyina-dega), high-land (dega) residents and single people were more likely to eat less. Additionally, the study found that households living in lower altitudes (Kola) were more likely to use lending as a coping technique while households residing in mid-altitude (Weyina-dega) and high-altitude (dega) had a higher probability of reducing meal quantities and frequencies as a strategy to cope.

Berlie (2015) used questionnaire surveys from 201 households chosen from three rural kebele administrations (RKAs) using a commensurate stratified random sampling method, to examine households' responses to food insecurity. The study revealed that the most common coping strategies used by the respondents were minimizing the number of meals consumed (69%), postponing celebrations (78%), selling small bullock stock (64%) harvesting juvenile agricultural products (58%) as well as selling large bullock stock to buy food (54%) to meet the deficit in food requirements.

In Kwale County, Kenya, Makoti and Waswa (2015) investigated households' coping strategies in the face of drought-related food shortages. The study assessed data from 120 families chosen through stratified random sampling and 20 key informants chosen based on their expertise. Households used short-term coping techniques such as the adoption of diverse income streams, salaried employment, livestock sales, minimization of meals consumed and seeking financial assistance from family and friends and family in response to food shortage. Further, the study found that building water reservoirs, soil and water conservation technologies, diversifying income sources, planting drought-resilient crops, obtaining decent jobs and expanding livestock diversity are all important long-term techniques for adjusting to droughts and food insecurity. To help households address their financial constraints, the authors recommended training for alternative livelihoods opportunities as well as improved availability of affordable rural financial institutions.

Wabwoba *et al.* (2016) examined measures adopted by households in response to food shortages in Bungoma County, Kenya. Focus group discussions revealed that the majority of the people worked as informal workers to earn money for food, while others cut back on the number and regularity of meals they ate each day. Further, the findings revealed that in severe instances, household properties such as bicycles, chickens, shoats, woods and cell phones were sold for low prices. Additionally, while the aged got food and supplies from families and monies from their offspring, individuals with good credit worthiness had to loan money to pay for food or buy food on credit. However, the respondents stated that the surviving techniques employed were ineffective and proposed that farmers' ability to adopt long term adaptation strategies should be enhanced through training focus group discussions revealed that most people worked as casual laborers to earn money to buy food while others reduced the amount and frequency of meals eaten per day. Further, the results revealed that in extreme cases, assets like bicycles, poultry, shoats, trees and mobile phones were disposed of at cheap prices. Additionally, while elderly persons received food donations from relatives while those credit worthy borrowed cash to purchase food or bought food items on credit. The respondents however noted that the coping mechanisms were ineffective and proposed that farmers' ability to adopt long-term adaptation strategies should be enhanced through training on the adoption of quick maturing crop varieties, improved techniques for management of harvest, sustainable dairy farming and enhanced access to affordable agricultural inputs.

2.6 Farmers' adaptation to climate variability and extreme climate events and determinants of choice of specific adaptation strategies

Dasmani *et al.* (2020) used a structured questionnaire to interview 622 farmers from 18 villages in Ghana's three major agro-ecological zones to obtain information on determinants of measures adopted by farming households in response to climate fluctuations in the region. In response to variations in climate and other associated circumstances, households reported using measures such as irrigated agriculture, mixed cropping, investment in off-farm activities, adjusting sowing periods and hybrid crop seeds. In addition, the study found that characteristics such as the farmer's gender, level of education, seniority, levels of precipitation and warming, insect infestations, flooding and incidences of droughts had a substantial influence on the adoption of various response techniques by farmers. The authors recommended that climate change programmes should take into account socio-economic characteristics that influence farmers' selection of different adjustment techniques.

Arun and Yeo (2020) surveyed 300 agricultural households to examine farmers' adaptation practices and determinants of their adoption using the multivariate probit model in five agro-ecological zones in Nepal. The study's findings revealed that the most prevalent response technique to variations in temperatures and droughts recurrence was investing in irrigated agriculture whereas the most popular response strategy to variations in rainfall was changing sowing dates. Modification in crops grown on the other hand was reported as the least desirable climate change response technique in the research area. Results from the multivariate probit regression model revealed that the number of schooling years, gender of the household head, accessibility of loans, seniority, land size, land ownerships and non-irrigated agriculture were all significant factors in determining farmers' choice of various climate variability response techniques.

Using household survey data from 194 respondents, Dumenu and Tiamgne (2020) investigated the susceptibility and response techniques of farming households to climate variability in two Zambian districts (Chirundu and Masaiti). Growing drought-resilient crop varieties, altering planting dates, mixed cropping, relying on governmental aid and engaging in off-farm activities were the most common responses to changes in climate, according to the findings of the study. The authors recommended enhancing accessibility to and enhancing early warning weather information and services as well as strengthening the socioeconomic characteristics of susceptible farmers, strengthening climatic monitoring skills and facilities, and sustainable climate-resilient farming as pragmatic suggestions for enhancing small-scale farmers' ability to adapt to climatic changes in the research area.

Fagariba *et al*. (2018) investigated determinants of farming households' ability to adapt to climate variability and the measures adopted in response to the effects of climate variability in Sissala West District in northern Ghana. The results of the study indicated that agroforestry techniques, planting drought-resilient seed varieties and composting were the most popular adaptation strategies in the research area. Further, the study findings revealed that showed that erratic precipitation, increasing temperatures, availability of information, and rising evapotranspiration rates highly influenced households' adaptation to climatic changes. Additionally, the education level of the household head, family size as well as the availability of agro-extension facilities had a positive influence on farmers' adaptation while the availability of loans reduced the probability of adaptation.

Ojo and Baiyegunhi (2018) analyzed factors influencing the adoption of different measures in response to climatic changes among rice farmers in Southwestern Nigeria using a multi-stage sample selection approach to obtain information from 360 rice farming households. The dependent variables for the study were the five main selected response options while household characteristics, climatic factors, availability of facilities and locality were used as the predictors in the multi-variate regression analysis. The research findings indicated a reduction of the probability of adopting intercropping and hybrid crop varieties with a unit increase in age while a high number of family members increased the probability of adopting water and soil conservation technologies. According to the study, non-farm investments significantly influenced the choice of soil and water management techniques, agrochemicals and hybrid crops. Additionally, the authors highlighted the influence of climate variables on the choice of adaptation strategies indicating that while rising temperatures increased the probability of adopting soil and water management techniques while average precipitation significantly increased the probability of adopting mixed cropping as an adaptation strategy.

2.7 Literature overview and gaps

From the reviewed literature, it has been noted that there has been increasing temperature and decreasing rainfall trends across eastern Africa (Lyon and Dewitt, 2012; Niang *et al.*, 2014; Williams and Funk, 2010) which are likely to cause negative impacts on the livelihood of farmers in the region due to its dependency on climate-sensitive sectors. Further, the reviewed literature has highlighted differences in spatial and seasonal variation in temperature and rainfall variability in Kenya implying that location and season-specific analysis of temperature and rainfall trends are crucial for effective preparation and operationalization of climate variability interventions (Aduma *et al.*, 2018; Marigi *et al.*, 2016). This therefore informed the need to analyze temperature and rainfall trends and variability in the study area for effective planning of adaptation measures to climate variability and extreme climate events. Regarding vulnerability assessments, the literature has emphasized the importance of vulnerability studies in identifying and targeting feasible and practical response strategies to sectors and individuals exhibiting high susceptibility to climatic changes. Although several climate variability related studies in Kenya have been conducted in the recent past, their emphasis has been on the impacts of increasing temperatures and erratic precipitation on agricultural production (Kabubo-mariara *et al.,* 2016; Kabubo-mariara and Karanja, 2007; Omoyo *et al.,* 2015) and adaptation strategies by farmers (Mutunga *et al.,* 2017; Ndambiri *et al.,* 2012; Oremo, 2013) with little focus on farmers' vulnerability to climatic variations and extreme climate events.

The importance of understanding farmers' vulnerability distribution at the local level has also been highlighted since the vulnerability levels are different among households and within communities due to the varying availability of different livelihood assets in a region (Bobadoye *et al.,* 2019; Mwangi *et al.,* 2020; Opiyo *et al.,* 2014a; Owusu *et al.,* 2021).The limited research on farmers' susceptibility to climatic variations in Kitui County has been done on regional scales (Marigi *et al.,* 2016; Mwangi *et al.,* 2020) with little focus on household-level vulnerability assessment. The present study, therefore, aimed at assessing the integrated vulnerability of farming households to climate variability and extreme climate events at the household level in Kitui County, Kenya.

Additionally, the empirical studies reviewed revealed that agro-ecological zones play an important role in determining households' susceptibility to climate variability and thus planners and other key stakeholders should formulate and execute tailored interventions targeting susceptible farmers in distinct agro-ecological zones. The present study therefore sought to compare the vulnerability patterns across different agro-ecological zones in Kitui County.

2.8 Conceptual Framework

Various intellectual communities have defined vulnerability in a variety of ways. For example, according to Fussel and Klein (2006), vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with the adverse impacts of climate change whereas Adger (2006) viewed vulnerability as the condition of how susceptible to damage a system is from exposures to shocks resulting from variations in the society and the environment coupled with its inability to adapt.

From the IPCC Fourth Assessment Report (AR4), vulnerability is defined in two ways, one *as* "the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change including climate variability and extreme climate events" and the other as "a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity" (IPCC, 2007a pg.89).

Vulnerability can be classified as contextual (or starting-point) vulnerability, which focuses on the prevailing conditions of the system before any disaster impacts it (O'Brien *et al.*, 2007) or outcome (or end-point) vulnerability, which refers to the remaining degree of susceptibility after adjustment measures are implemented (Hinkel, 2011).

According to Piya *et al.* (2012), preceding climate change research has often followed the end-point analysis, which hypothesizes vulnerability as the effect on the system after a disaster has occurred, making the disaster the central unit of assessments and focusing on physical and biological drivers like temperature, rainfall and adverse climate occurrences that policymakers cannot influence. Nelson *et al.* (2010) noted that the 'end- point' approach of vulnerability is based on estimates from biophysical models which contain a lot of uncertainty.

Since vulnerability to climate variability and extreme climate events is described not only by the features of the hazards but also by the relationships between the biophysical and socio- economic systems to adapt to the changing climate, recent research has associated both system exposure and sensitivity (biophysical vulnerability) to adaptive capacity (social vulnerability) for effective characterization of prevailing vulnerability (Vincent, 2004; Vincent and Cull, 2010) which is the 'starting-point' or contextual vulnerability (O'Brien *et al.*, 2007). Until the IPCC's Third Assessment Report (AR3), vulnerability was defined as the risk of a system being exposed to disasters (McCarthy *et al.*, 2001) assuming people to be passive receivers of the climatic changes and thus neglecting their versatile capacity to moderate the disasters, either through their capacity to withstand or adapt once a disaster has occurred (Stonich, 2000). Rather than being passive recipients of climatic changes, the social vulnerability concept according to Vincent (2004), emphasizes that physical phenomena are linked to and moderated by the societal environment in which they happen.

Although biophysical vulnerability (climate variability exposure and sensitivity) define the prospective impacts of climate change on a system, it does not always imply that a system that has high exposure and/or sensitivity levels to climate variability is highly susceptible, because neither exposure nor sensitivity acknowledges the ability of the system to adapt (Fellmann, 2012). Therefore, there has been a growing need to recognize that vulnerability is defined not only by the features of a disaster, but also by the dynamic attribute of biophysical-social system interactions that allow them to adjust to the variations (Piya *et al.* 2012). The above realization has led to the emergence of an integrated approach which combines both the biophysical (exposure and sensitivity) and social (adaptive capacity) vulnerability in determining the overall susceptibility of systems to climate variability and extreme climate events (Bobadoye *et al.,* 2019; Nelson *et al.*, 2010; Opiyo *et al.,* 2014a; Piya *et al.*, 2012; Vincent and Cull, 2010).

Since vulnerability is highly dependent on the context and components that determine a system's susceptibility to a disaster, the condition of the system, and the kind of disaster in discussion (Brooks *et al.,* 2005), the (IPCC, 2007a) definition of vulnerability as a function of the identity, severity, and frequency of climate variability to which a system is exposed to, how sensitive a system is to climate variability and extreme climate events as well as its adaptive capacity was used in the present study.

In order to illustrate the relationship between exposure, sensitivity and adaptive capacity, the study adopted the Sustainable Livelihood Framework (SLF) by British Department for International Development (DFID, 1999) as shown in Figure 2.1. In this framework, the vulnerability contextual approach defines the physical conditions in which people live, as well as crucial patterns, stresses and seasonality, all of which have a significant impact on community livelihoods and asset availability (DFID, 1999).

The five types of livelihood capitals upon which livelihoods are built play a critical role in determining the vulnerability of farming households to the climate fluctuations (Huai, 2016). The livelihood capitals help households to achieve positive livelihood outcomes thus defining the adaptive capacities of households in the face of climatic variability and extreme climate events (DFID, 1999). According to Huai (2016), natural capital are resources from the natural environment that provide a steady supply of products or services. Since the natural capital is a key resource in the livelihoods of most farmers, the natural resource base's ability to retain productivity even after occurrence of climatic stressors is a key measure of farmers' adaptive capacity (Dulal *et al.*, 2010).

The human capital, which refers to the availability of expertise, competence, education, and labor (Gupta *et al.*, 2010; Nelson *et al.*, 2010) as well as wellbeing and physical capacity to work (Ellis, 1999) influence the resources and workforce returns for farmers that boost manpower performance and farm management capacity, enhancing farmers' adaptive capacity to climate stressors.

The social capital on the other hand represents a collection of linkages, commitments, and information flows that promote collaborative partnerships between resident and non-resident players during periods of crisis, as well as timely implementation of management efforts to deal with risks to resources and their users (Adger, 2006). According to Pelling and High (2005), social capital is essential in providing resources needed in increasing resilience to climatic shocks and modifying institutions to address the shocks.

The financial capital is critical in influencing available livelihood opportunities (Hammill *et al.*, 2008; Lockwood *et al.*, 2015) and thus according to Dulal *et al.* (2010), access to basic financial services improves the households' ability to adapt thereby reducing their susceptibility to climatic shocks.

Physical capital, which includes assets such as land, roads, machinery, and instruments that support the process of production (Ellis, 1999; Lockwood *et al*., 2015) enable households to establish livelihood strategies aimed at improving their adaptability to climatic pressures, hence reducing their vulnerability (Dulal *et al.*, 2010).

The Sustainable Livelihoods Framework has been used to investigate the multi-dimensional and contextual nature of vulnerability (O'Brien *et al.,* 2007; Reid and Vogel, 2006; Vincent and Cull, 2010).

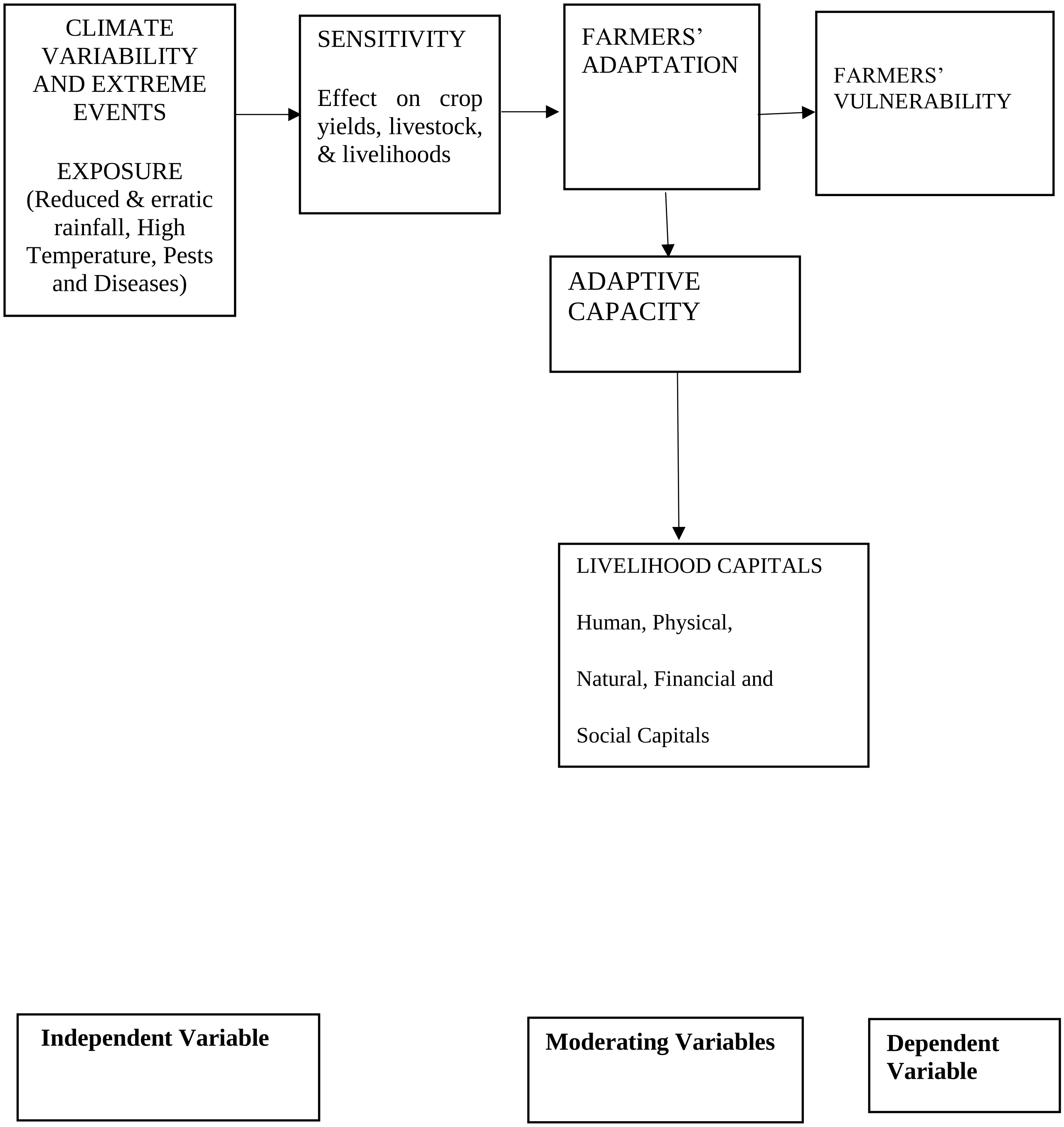

Figure 2.1 Conceptual Framework

Source: Modified from the Sustainable Livelihood Framework, DFID (2000), IPCC, (2007) and Nelson et al. (2010).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study area

The study was carried out along a transect line (in a buffer zone of 5km radius on both sides of the line) in four agro-ecological zones namely; Arid, Semi-arid, Transitional (semi-arid to semi-humid) and Semi-Humid, in Kitui County. The study sites are shown in Figure 3.1.

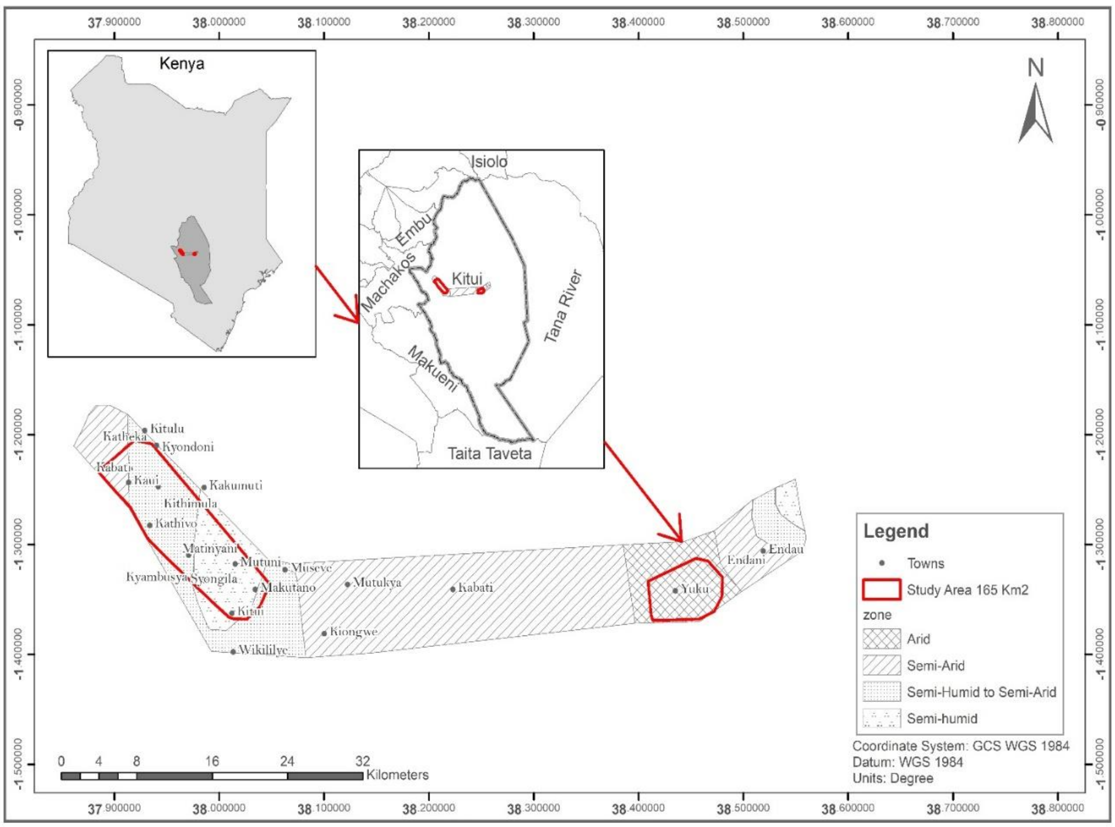

Figure 3.1: Map of Kitui County showing the study area in four agro-ecological zones
Source: ILRIS GIS Database

3.1.1 General topography and climate of Kitui County

Kitui County lies between 400m to 1,830m above sea level and generally slopes from the west to east with the highest regions being Kitui Central and Mutitu Hills (KCIDP, 2018). The climate of the area is semi-arid with very erratic and unreliable rainfall. The area is hot and dry throughout the year with temperatures ranging from a minimum of 14-22° centigrade to a maximum of 26-34° centigrade.

February and September are the hottest months in the year (KCIDP, 2018). Rainfall is distributed within two seasons annually locally referred to as “long rains” and “short rains” that varies from 500-1050mm with about 40% reliability. The “long rains” are experienced between March and May and “short rains” between October and December. The “short rains” are considered more reliable than the “long rains” since it is during the “short rains” that farmers get their main food production opportunity (NDMA, 2017). The area consists of a variety of soil types ranging from sandy to black cotton which are generally low in fertility rates (GoK, 2005).

The agro-ecological features of the study area are shown in Table 3.1.

Table 3.1: Description of the study area

Agro-ecological Zone	Sub-location	Population (No. of Households)	Altitude (m above sea level)	Mean annual Temperature (^oC)	Mean annual Rainfall (mm)	Main Crops Grown
Semi-humid	Kaveta	950	1340-1620	20.2-18.6	900-1050	Maize, beans, peas,
Transitional	Kasaini	380	1110-1150	21.0-19.0	850-1000	Maize, beans, peas, green grams,
Semi-arid	Kauwi	1600	760-1280	24.0-20.9	720-1000	Maize, cowpeas, green grams, sorghum,
Arid	Yuku	360	550-760	25.3-23.2	500-720	millet, sorghum, cowpeas, green grams

Source: (GoK, 2019; Jaetzold *et al.*, 1983; KCIDP, 2018; NDMA, 2017)

3.2 Study design and sampling techniques

3.2.1 Study design

The descriptive survey design was used in the present study. The study's target population was the agro-pastoralists in the study area, the household served as the study unit while the respondent was the household's head.

3.2.2 Sampling techniques

The study locations were classified using the stratified sampling technique according to four agro-ecological zones. Along a transect line (in a buffer zone of 5km radius on either side), one sub-location in each agro-ecological zone was randomly selected. The systematic random sampling procedure was then utilized to identify respondents in the identified sub-locations, with a beginning point conveniently chosen from the local shops and every tenth household interviewed.

3.2.3 Sample size determination

The study's sample size was determined by calculating 10% of the number of households in the chosen sub-location. According to Mugenda and Mugenda, (2003) in descriptive research, a sample size of 10% gives a sufficient representation of the target population.

Table 3.2: Sample size of the study

Agro-ecological zone	Selected sub-location	Number of households	Sample size
Arid	Yuku	390	39
Semi-arid	Kauwi	1600	160
Transitional	Kasaini	380	38
Semi-humid	Kaveta	1040	104
Total sample size			**341**

Source: (GoK, 2019)

3.2.4 Operationalization of variables

The study's independent variables were climate variability and extreme climate events, while the dependent variable was the farmers' vulnerability to climate variability and extreme climate events. Explanatory (moderating) variables included vulnerability sensitivity and adaptive capacity indicators, as well as the socio-economic characteristics of households. Table 3.3 shows how the variables were operationalized.

Table 3.3: Operationalization of variables

Variables	Criteria	Source/Tools	Outcome	Attribute
Climate variability and extreme climate events (Independent variables)	Trends on climatic variables such as minimum and maximum annual temperature, total annual and seasonal rainfall and extreme climate events	Meteorological data Interview schedules Key Informants Interviews	Trend in rainfall and temperature, extreme climate events established	Household-level
Farmers' vulnerability to climate variability and extreme climate events (Dependent variable)	Identification of farmers' exposure, sensitivity and adaptive capacity to climate variability and extreme climate events	Interview schedules Key Informants Interviews	Farmers' vulnerability to climate variability and extreme climate events established	Household-level
Vulnerability indicators (Moderating variables)	Identification of climatic and socio-economic factors that influence farmers' vulnerability to climate variability and extreme climate events	Interview schedules Key Informants Interviews	A predictive model for farmers' vulnerability to climate variability and extreme climate events developed	Household-level
Coping and adaptation strategies adopted by farmers (Moderating variables)	Farmers' identification of coping and adaptation strategies and adopted	Interview schedules, Key Informants Interviews	Differences in the adoption of coping and adaptation strategies by farmers established	Household-level

3.3 Data collection methods

3.3.1 Primary data

Primary data was obtained through household and key informant interviews in the selected sub-locations in the arid, semi-arid, transitional and semi-humid agro-ecological zones in Kitui County. Geospatial technology was used to collect spatial data where a Global Positioning System (GPS) was used to obtain the geographic location of households. In the acquisition, basic information on the household such as the name of the respondent was incorporated in the collected point. More detailed information was also recorded for further input as attributes during the data entry into a Geographic Information System (GIS).

3.3.2 Validity and reliability test

The household interview schedule, which was the main data collection instrument for the study was pre-tested by randomly interviewing 30 households in conveniently selected Kyambiti village, in Kaveta sub-location, Kitui County. Expert review of the household interview schedule was done to assess the effectiveness and accuracy of the instrument in measuring the intended variables as suggested by (Stoner *et al.*, 2011). Cronbach's Alpha was used to test the internal consistency of the instrument where Cronbach's Alpha based on standardized items was 0.80 indicating high reliability of the household interview schedule. According to Cronbach (1951), values above 0.80 indicate very good reliability of the instrument.

3.3.3 Secondary data collection

The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS; CHIRPS v2.0 at 0.05° horizontal resolution; 1981–near present; Funk *et al*. 2015) rainfall dataset was used. CHIRPS database is a useful set of precipitation data for studying precipitation patterns and drought monitoring, with a long-time series (more than 30 years) and high spatial resolution and provides a practical alternative in the absence of ground precipitation data (Bai *et al.*, 2018; Funk *et al.*, 2015; Habitou *et al.*, 2021; Zambrano *et al.*, 2016). CHIRPS database comprises a quasi-global (50°S-50°N, 180°E-180° W), 0.05° resolution, 1981 to near present gridded precipitation time series and merges three types of information: global climatology, satellite estimates, and in situ observations generating several precipitation products with time steps from 6-hourly to 3-monthly aggregates (Bai *et al.,* 2018; Funk *et al.,* 2015).

In comparison with other precipitation data sets such as the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN-CDR), which provides daily rainfall estimates at a spatial resolution of 0.25 degrees in the latitude band 60S - 60N from 1983 to the near-present and Tropical Rainfall Measuring Mission (TRMM3B43), which provides a "best" precipitation estimate by merging merged microwave-infrared precipitation rate (in mm/hr) and root-mean-square (RMS) precipitation-error estimates, Zambrano *et al.* (2016) reported that CHIRPS datasets showed the best agreement with ground precipitation measurements in Chile.

Similarly, Le and Pricope (2017) reported that CHIRPS dataset had a greater temporal correlation with the in situ station data in Nzoia Basin, Western Kenya. CHIRPS datasets have been used to analyze precipitation trends in similar studies in East Africa (Aduma *et al.,* 2018; Cattani *et al.,* 2021; Gebrechorkos *et al.,* 2019; Kerandi *et al.,* 2017).

The gridded Climate Research Unit (CRU v3.24, monthly at 0.5° horizontal resolution, 1901 to 2014; Harris *et al*. 2014) temperature dataset was used. The CRU dataset provides a high-resolution resolution (0.5° × 0.5°), a monthly grid of land-based observations for several climate variables including minimum and maximum temperature (Harris et *al.*, 2014, 2020). Harris et *al.* (2020) reported a high correlation of the majority of interpolated global monthly temperature anomalies with station observations. In addition, Mahmood and Jia (2017) reported a high correlation between CRU data and in situ observed data using different statistical indicators indicating that CRU data could be utilized with high certainty. Similar studies have used CRU TS data to analyze temperature trends in Kenya (Ayugi *et al.,* 2018; Kerandi *et al.,* 2017; Ouma *et al.,* 2018).

3.3.4 Data requirement per objective

Table 3.4 shows the required data for each objective.

Table 3.4: Data requirements per objective

Objective	Required data	Source/Tool
1. To analyze rainfall and temperature trends and variability in Kitui County.	✓ Minimum and maximum temperature, annual rainfall, frequency of extreme climate events	• Meteorological data
2. To assess the spatial vulnerability of farmers to climate variability and extreme climate events in the study area	✓ Exposure, sensitivity and adaptive capacity indicators GPS co-ordinates for households	• Household survey Interview schedule, Key Informants Interviews, GPS
3. To develop a predictive model for assessing farmers' vulnerability to climate variability and extreme climate events in the study area.	✓ Vulnerability indices	✓ Household survey Interview schedule, Key Informants Interviews
4. To assess households' food shortage coping strategies and determinants of the choice of specific strategies in the study area	✓ Coping strategies adopted by farmers	✓ Household survey Interview schedule, Key Informants Interviews
5. To assess farmers' climate variability adaptation strategies and determinants of the choice of specific strategies in the study area	✓ Adaptation strategies adopted by farmers	✓ Household survey Interview schedule, Key Informants Interviews

3.3.5 Choice of vulnerability indicators

Since the variables that are used to represent components of vulnerability may not be directly measurable, it is important to develop indicators that can be aggregated to form a vulnerability index with a more comprehensive model of reality (Vincent, 2004). According to Hammond *et al.* (1995) indicators are measurable constructs that give information on issues that are more important than the one being tested, or on a procedure or pattern that would otherwise go unnoticed. The best way to choose appropriate indicators is to employ theories that give information about the nature and sources of vulnerability (Vincent, 2004). Thus, indicators for this study were derived from the (IPCC, 2007b) definition of vulnerability as a function of exposure, sensitivity and adaptive capacity.

3.3.5.1 Indicators for exposure

According to IPCC (2007b), exposure is the type and extent to which a system is subjected to substantial climatic fluctuations and shocks. For this study, the historical rates of change in climate variables, represented by rate of variation in the mean annual maximum and minimum temperatures, and rainfall for the last 30 years and incidences of extreme climatic events recorded in the last 10 years were taken as the indicators of exposure and their relationship with vulnerability index hypothesized as shown in Table 3.5.

Table 3.5: Indicators of farmers' exposure to climate variability and extreme climate events

Components	Description of indictors	Unit	Hypothesized relation
	Indicators for Exposure		
Historical change in climate variables	Rate of change in average annual minimum temperature (1988-2018)	Coefficient of trend	+
	Rate of change in average annual maximum temperature (1988-2018)	Coefficient of trend	+
	Rate of change in average annual precipitation (1988-2018)	Coefficient of trend	+
Extreme climate events	Frequency of climate-related natural disasters (droughts, floods, storms, forest fires, livestock diseases, conflicts) over the last 10 years (2008-2018)	Number	+

Source: Modified from Ludena and Yoon (2015); Piya *et al.* (2012); Vincent and Cull, 2010)**.**

3.3.5.2 Indicators for sensitivity

IPCC (2007b) defined sensitivity as the extent to which perturbations either internal or external, modify or affect a system. The impacts of climate-related disasters on farmers' livelihoods such as loss of crop yields, livestock and drying of water sources were used as indicators of sensitivity in the present study. The study hypothesized that the sensitivity of households would be increased by higher effects of past climate-related disasters as indicated in Table 3.6 (IPCC, 2007b; Piya *et al.*, 2012; Vincent and Cull, 2010).

Income structure was also used to determine the sensitivity of the households, where it was hypothesized that larger proportions of earnings from natural resources (farming, farm animals, forestry products, honey, and arts and crafts) would increase the sensitivity of households since the sources are more climate-dependent, whereas a larger proportion of none natural resource revenue streams (salaries, non-farm technical labor, and remittances from aboriginal people) would decrease sensitivity (Piya *et al.*, 2012).

3.3.5.3 Indicators for adaptive capacity

Adaptive capacity refers to a system's ability to adapt to climate extreme climate events and it is determined by physical assets, availability of technologies and knowledge, infrastructural diversity, institutional competency and resource distribution (Ludena and Yoon, 2015). Given that adaptive capacity is a reflection of households' asset ownership (Nelson *et al.*, 2010; Smit and Wandel, 2006) adaptive capacity indicators were derived from the five livelihood capitals described in the DFID sustainable livelihoods framework (DFID, 1999) as presented in Table 3.7.

The livelihood diversification index, which was considered as an indicator for financial assets, was calculated using the Herfindahl-Hirschman index of diversification as applied by (Piya *et al.*, 2012).

$$D_k = 1 - \sum_{i=k}^{N} S_{ik}{}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 1$$

where, D_k = diversification index, i = the specific livelihood activity, N=the total number of activities analyzed, k = the specific household, and S_{ik} = the proportion of i^{th} activity to the total household income for the k^{th} household.

Table 3.6: Indicators of farmers' sensitivity to climate variability and extreme climate events

Components of Indicators	Description of indictors	Unit	Hypothesized relation
	Indicators for Sensitivity		
Livestock fatalities	Number of cows and goats deaths due to droughts over the last 10 years	Number	+
Crop losses	Number of acres of crops damaged by droughts over the last 10 years	Acres	+
Income Structure	Share of natural resource based income (agriculture, livestock, charcoal, timber, wood, honey, sand and handicraft) to total income	%	+
	Share of non-natural based income (salaried job, remittance, skilled non-farm job) to total income	%	-
Water sources sub-composite index	Number of times different water sources dried due to droughts over the last 10 years	Number	+

Source: Modified from Ludena and Yoon (2015); Piya *et al.* (2012); Vincent and Cull (2010)

Table 3.7: Indicators of farmers' adaptive capacity to climate variability and extreme climate events

Components of Indicators	Description of indictors	Unit	Hypothesized relation
Indicators for Adaptive Capacity			
Physical Assets	Gadgets owned and used to access information	Number	+
	Access to extension services	No. of times in the past 1 year	+
	Sources of timely early warning weather information	Number of times in the past 1 year	+
	Distance to the nearest motorable road	Km	-
	Distance to the nearest water source	Km	-
	Distance to the nearest health facility	Km	-
	Distance to the nearest market	Km	-
Human Assets	Highest level of education of qualification in the family	Number of schooling years	+
	Persons in the HH with formal employment?	Number	+
	Trainings or vocational course attended	Number	+
Natural Assets	Size of total land owned	Acres	+
	Size of productive land	Acres	+
	Size of unproductive land	Acres	+
	Land size under crops	Acres	+
	Land size under pasture	Acres	+
	Large stock livestock (cows, camels, donkeys)	Number	+
Financial Assets	Monthly Gross household income	Ksh.	+
	Monthly household savings income	Ksh.	+
	Livelihood diversification index	Number	+
	Credit facilities accessed in the last 10 years	Number of times	+
Social Assets	Highest amount of credit accessed in the last 10 years	Number of times	+
	Extension services accessed in the past 1 year	Number of times	+

Source; Modified from DFID, (1999); Ludena and Yoon, (2015); Piya *et al.*(2012); Vincent and Cull (2010)

3.3.6 Data analysis procedure

Both descriptive and inferential statistics were done using the Statistical Package for Social Sciences (SPSS version 20), Stata version 12 and MS Excel. Data was analyzed per objective as follows;

3.3.6.1 Objective One; to analyze rainfall and temperature trends and variability in the study area

Annual and seasonal rainfall and temperature trends for a period of 30 years (1988-2018) in the study area were analyzed using the Mann-Kendall (MK) statistical test.

The Mann-Kendall Statistic (S) is a non-parametric statistical process for assessing the trends of data sets over time, with positive (+) values indicating an increase in element concentration over time and negative (-) values indicating a drop in element values in a given period (Kendall, 1975; Khambhammettu, 2005; Mann, 1945; Opiyo *et al.*, 2014b). The Mann-Kendal Test was used for this study for trend analysis since it does not require the assumption of residual normality as it is the case in linear regression method (Kendall, 1975; Mann, 1945). According to Viessman *et al.* (1989), hydrological variables show a pronounced right skewedness and do not adopt a normal distribution due to the influence of natural phenomena. The non-parametric test is preferred for trend analysis in time series over parametric tests since it evades the problem caused by data skewness (Aditya *et al.*, 2021; Mondal *et al.*, 2012; Opiyo, *et al.*, 2014b).

The MK statistic (S) refers to the overall outcome of all the increases and decreases i.e the summation of all the positive differences excluding the aggregate negative variances (Khambhammettu, 2005) as shown in the following equation;

$$S = \sum_{k-1}^{n-1} \sum_{k=j+1}^{n} Sign(x_j - x_k) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Equation\ 2$$

Where, $x_1 \ldots x_n = n\ data\ values,\ J_x = data\ value\ at\ time_j,$ $sign\ (x_j - x_k) = 1\ if\ (x_j - x_k) > 0\ , = 0\ if (x_j - x_k) = 0\ and -1\ if\ (x_j - x_k) < 0$

The Kendall Test (Kendall, 1975) was used to predict a normal-approximation assessment for large amounts of data with more than ten values to account for the non-monotonic identity of patterns in the data; the testing is applied using a normal distribution (Helsel and Frans, 2006; Khambhammettu, 2005) with the mean and variance by first determining S as described in Equation 2 and then

The variance of S is calculated, $VAR(S)$ using Equation 3:

$$VAR(S) = \frac{1}{8}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)\right] \ldots\ldots\ldots Equation\ 3$$

Where $n =$ number of data points,

g = the number of tied groups,

(a tied group is a set of sample data having the same value) and

$p\ t =$ the number of data points in the p[th] group.

In the sequence {2, 3, non-detect, 3, non-detect, 3}, we have $n = 6$, $g = 2$, $1t = 2$ for the non-detects, and $2t$=3 for the tied value 3.

The standard normal deviate (Z statistics) is then computed as (Khambhammettu, 2005) follows:

$$Z = \frac{S-1}{\left[VAR(S)^{\frac{1}{2}}\right]}\ if\ S > 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 4$$

$$= 0\ if\ S = 0$$

$$= \frac{S+1}{\left[VAR(S)^{\frac{1}{2}}\right]}\ if\ S<0$$

To calculate the probability linked with the normalized test statistics, the probability density function for a normal distribution is expressed in Equation 5:

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-Z^2}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 5$$

From the above equations, a negative Z score with a calculated probability greater than the significant level indicates a declining trend, whereas a positive Z score with a calculated probability larger than the significant level indicates an increasing trend. If the estimated probability is lower than the significant level of significance, then there is no trend in the data points (Khambhammettu, 2005; Opiyo *et al.,* 2014b).

3.3.6.2 Objective Two; to assess the spatial vulnerability of farmers to climate variability and extreme climate events in the study area

3.3.6.2.1 Calculation of Vulnerability Index; to assess the vulnerability of farmers to climate variability and extreme climate events in selected agro-ecological zones in Kitui County

From the (IPCC, 2007b, 2014) expression of vulnerability as a function of exposure, sensitivity and adaptive capacity, where the potential impact is represented by exposure and sensitivity while adaptive capacity denotes the extent to which the impact would be averted, the vulnerability of a farmer to climate variability and extreme climate events (V) can be defined mathematically as shown in Equation 6;

$$V = f(I - AC) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Equation\ 6$$

Where, V is vulnerability, I is potential impact and AC is adaptive capacity.
From the above equation, vulnerability indices for individual households were calculated from the selected vulnerability indicators. Since the indicators were in different units and scales, normalization was done using the formula in Equation 7;

$$x' = {(x - \mu)}/{\sigma} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Equation\ 7$$

Where, x' is normalized value, x is observed value, μ is mean and σ is standard deviation.
Weights for the various indicators were calculated using the Principal Component Analysis (PCA) where loadings of principle components (PC) which were highly correlated to the indicators were used as the weights for the indicators as described by Abson *et al.*(2012) and (Jolliffe, 2002). Using Equation 8, the standardized variables were multiplied by the allocated weights to get the indices for exposure, sensitivity and adaptive capacity.

$$I_j = \sum_{i=1}^{k} b_i [\frac{a_{ji-x_i}}{si}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 8$$

Where, $I =$ respective index value for the jthhousehold ,

$b =$ weighted value for the i^{th} indicator, $a_i =$ the i^{th} indicator value for j^{th}household, x = the mean value for the j^{th}indicator and s = the standard deviation for the i^{th} indicator value.

The overall vulnerability index for individual households was then computed using Equation 9;

$$\mathrm{V} = \mathrm{E} + \mathrm{S} - \mathrm{AC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation 9}$$

Where, V =the vulnerability index, E = the exposure index, S= the sensitivity index and AC =the adaptive capacity index for each household.

To compare the mean values of vulnerability and its component indices across the four agro-ecological zones, one-way analysis of variance (ANOVA) was used.

3.3.6.2.2 Vulnerability mapping; to assess the vulnerability of farmers to climate variability and extreme climate events in selected agro-ecological zones in Kitui County

Spatial profile maps on farmers' vulnerability to climate variability and extreme climate events were generated using the following procedure as outlined by (CIESIN, 2015). Household geospatial data obtained was downloaded into a GIS system and converted to a point map. The attributes previously recorded during the data collection were added to those existing in the point map for each household describing clusters of exposure, sensitivity, and adaptive capacity and vulnerability indices of households generated from the Principle Component Analysis. The resulting outputs provided the spatial distribution of exposure, sensitivity, adaptive capacity and vulnerability of households to climate variability and extreme climate events in the study area. Other layers of data such as the Kitui County maps were overlaid on these points for visualization and further analysis. The spatial pattern of these variables was generated and interpreted into zonation maps of the various factors. Overlays with other variables such as agro-ecological zones were done to establish the relationship between these biophysical factors and the generated vulnerability maps.

3.3.6.3 Objective Three; Predictive modelling of farmers' vulnerability to climate variability and extreme climate events in the study area

The multinomial logistic regression model was used to predict farmers' vulnerability to climate variability and extreme climate events in the study area. The model was expressed as follows (Dragoş and Vereş, 2007; Nkondze *et al.*, 2013).

$$p(y_i = j) = p_{ij} = \frac{\exp(x_i \beta_{j)}}{\Sigma \exp(x_i \beta_k)} \;\; Where\; 0 < p_{ij} < 1 \quad \ldots\ldots\ldots\ldots. Equation\ 10$$

$$p(y_i = j) = p_{ij}(\beta_0 + \beta_1 x_1 + \cdots \beta_k x_k) = p_{ij}(\beta_0 + x\beta) \ldots\ldots\ldots\ldots. Equation\ 11$$

Where:

p_{ij} *is the* the probability of a household i to be moderate or highly vulnerable with respect to,

x_i *is low vulnerability vector of the independent variables associated with household* i

and

β_j *is* the vector of parameters associated with the alternative j.

For this study, the dependent variable consisted of the three vulnerability quartiles which were classified according to FANRPAN (2011) categorization of Household Vulnerability Index (HVI) as shown in Table 3.8. Socio-economic characteristics of the farmers were used as the explanatory variables for the model as described in Table 3.9. Variance inflation factor (VIF) was used to test for multicollinearity among the explanatory variables as described by (Yoo et *al.*, 2015) in Equation 12.

$$VIF = {}^{1}\!\big/_{1 - R_j^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Equation\ 12$$

where ${R^2}_j$ is the R^2 value obtained by regressing the j^{th} predictor on the remaining predictors.

Table 3.8: Household vulnerability categorization

Vulnerability Category	Quartile Range	Description
Low Vulnerability	0 - 33.3	The household is in a vulnerable situation, but still able to cope
Moderate Vulnerability	33.4 - 66.7	Household has been hit so hard that it needs urgent but temporary assistance for it to recover
High Vulnerability	66.8 - 100	Household is in a situation of almost a point of no return but could be resuscitated only with the best possible expertise. Emergency response required

Source: Modified from FANRPAN (2011)

Table 3.9: Description and summary statistics of explanatory variables used in the multinomial logistic regression model

Variable	Description	Mean	SD	Expected sign
X_1	Gender of household head (1= male; 0= female)	1.29	0.46	+/-
X_2	Age of the household head (number of years of the household head)	55.86	15.11	+/-
X_3	Household size (number of family members in the household)	5.88	2.64	+/-
X_4	Highest education level attained in the household (number of schooling years)	12.43	4.41	-
X_5	Access to credit (1= yes; 0= otherwise)	0.35	0.48	-
X_6	Access to extension services(1= yes; 0= otherwise)	0.16	0.37	-
X_7	Distance from the market (how far the household is from the market in Km)	2.79	3.24	+
X_8	Land size (number of acres owned by the household)	5.82	8.07	+/-
X_9	Agro-ecological zone (Arid)	0.10	0.84	+
X_{10}	Agro-ecological zone (Semi-humid)	0.30	0.84	-

Source: Modified from Bobadoye *et al.* (2019); Nkondze *et al.* (2013); Notenbaert *et al.* (2013); Opiyo *et al.* (2014a)

3.3.6.4 Objective Four: to assess coping strategies to food insecurity and determinants of households' choice of specific coping strategies in the study area

Chi-square test of independence was used to test for differences in the adoption of different food insecurity coping strategies across the agro-ecological zones. To analyze determinants of households' choice of different food insecurity coping mechanisms in the study region, multivariate Probit (MVP) regression analysis was done using Stata version 12. The random utility theoretical model, which depicts a choice decision in which a person has a set of various techniques to choose from, guides the MVP decision model (McFadden, 1977). The utility model is based on the assumption that each option has unique features that influence a household's decision to choose one option over another. It is also built on the assumption that utility is obtained by selecting numerous options. The random utility model is expressed below as applied by (Feleke *et al.*, 2016).

Assuming that U_j is the expected utility that a farmer will gain from adopting coping strategy j whereas U_k is the expected utility for not choosing coping strategy j but rather k. The linear random utility model of coping with food insecurity by choosing j^{th} coping strategy U_j can be expressed as a function of explanatory variables x_i as shown below;

$$U_{ij} = x_i\beta_j + \mu_j \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. Equation\ 13$$

The linear random utility equation for the i^{th} household, which does not adopt the j^{th} but instead, the k^{th} coping technique, is as follows:

$$U_{ik} = x_i\beta_k + \mu_k \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. Equation\ 14$$

Where x_i = a vector of predictor variables, β_j and β_k = vectors of parameters for selecting j^{th} and k^{th}coping techniques, respectively, while μ_j and μ_k= error terms for selecting j^{th} and k^{th} coping techniques, respectively.

The error terms in Equations 13 and 14 are assumed to be normally distributed independently and identically as noted by (Gujarati, 2006). According to Falco *et al. (*2011) a household selects coping technique j over technique k only if the anticipated benefits from coping technique j is greater than anticipated benefits from coping technique k, as indicated in Equation 15.

$$U_{ij} = x_i\beta_j + \mu_j > U_{ik} = x_i\beta_k + \mu_k \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Equation\ 15$$

The MVP model requires that each subject has J different binary responses, as applied by Mihiretu *et al.* (2019) and Piya *et al.* (2012). Let i=1,...n be the number of independent variables, j=1,...J be the number of binary response options, and x_i be a covariate matrix made up of any continuous or discrete factors.

Let $Y_{ij} = Y_{i1} \dots Y_{ij}$ indicate the J-dimensional vector of observed binary responses taking values {0;1} on the ith household and ;

$Z_{ij} = Z_{i1} \dots Z_{ij}$ indicate a J-variate normal vector of latent factors such that:

$$Z_{ij} = X_{i\beta} + \varepsilon_i 1 = 1 \dots n \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . Equation\ 16$$

where $\beta = \beta_1 \dots \beta_j$ is a matrix of unknown regression coefficient, ε_i is a vector of residual error distributed as a multivariate normal distribution with zero means and unitary variance;

$\varepsilon_i \sim N(0, \sum)$, where Σ is the variance-covariance matrix.

The off-diagonal elements in the correlation matrix, $\rho_{kj} = \rho_{jk}$ represent the unobserved correlation between the stochastic components of $k^{th}$and j^{th} options (Cappellari and Jenkins, 2003).

The relationship between Z_{ij} and Y_{ij} is:

$$Y_{ij} = \{1\ if >\ 0; 0\ otherwise\} i = 1 \dots n\ and\ j = 1 \dots J \dots\dots\dots\dots\dots Equation\ 17$$

The probability of the observed discrete data is then obtained by integrating over the latent variables

$$Z: P(Y_{ij} = {}^{1}/_{X_i\beta\sum}) \int A_{i1}\Phi_T\,(Z_{ij} = {}^{1}/_{X_i\beta\sum}) dZ_{ij} \dots\dots\dots\dots\dots\dots .. Equation\ 18$$

Where, A_{i1} is the interval (0, ∞) if Y_{ij}=1 and the interval (-∞, 0) otherwise and $A_{i1}\Phi_T(Z_{ij} = {}^{1}/_{X_i\beta\sum}) dZ_{ij}$ is the probability density function of the standard normal distribution.

Since the estimated coefficients from the multivariate probit regression reveal the direction of effect instead of the size (Mullahy, 2016) marginal effects were calculated to explain the influence of predictor variables on the dependent variables as shown in Equation 19: The marginal effects quantify the anticipated variation in the likelihood of a specific choice when the predictor variable is changed by a unit (ATPS, 2013).

$$\partial_{ij} = \frac{\partial P_{ij}}{\partial x_i} Pij \left[\beta j - \sum_{k=0}^{j} P_{kj}\, \beta_k \right] = P_{ij}[\beta j - \beta] \dots\dots\dots\dots\dots\dots Equation\ 19$$

Where ∂_{ij}= the marginal effect of the predictors on the likelihood that option j is selected.

The multivariate probit (MVP) regression model was appropriate for this study because it models the influence of several explanatory variables on every coping technique while allowing unobserved factors (error terms) to be freely associated (Belderbos *et al.*, 2004; Lin *et al.*, 2005).

The dependent variables for the model comprised of selected techniques employed by households in response to food insecurity whereas the socio-economic characteristics of households were used as the predictor variables as shown in Table 3.10 and Table 3.11, respectively.

Table 3.10: Description and summary statistics of households' coping strategies to food insecurity used as dependent variables for the multivariate probit model

Dependent variables (Coping Strategies)	**Description of Variables**	**Mean**	**SD**
Reduce food consumption	Dummy=1 if household adopts reduce food consumption 0=otherwise	0.41	0.49
Sell livestock to buy food	Dummy=1 if household adopts sell of livestock to buy food 0=otherwise	0.62	0.47
Use off-farm income to buy food	Dummy=1if household adopts the use of off-farm income 0=otherwise	0.64	0.48
Sell family assets	Dummy=1if household adopts selling of family assets 0=otherwise	0.35	0.48
Sell forest products	Dummy=1if household adopts sell of forest products, 0= otherwise	0.11	0.31

Table 3.11: Description and summary statistics of explanatory variables for households' choice of specific coping strategies to food insecurity in the study area

Variable	Description	Mean	SD	Expected sign
X_1	Gender of household head (1= male; 0= female)	1.29	0.46	+/-
X_2	Age of the household head (no. of years of the HH head)	55.86	15.11	+/-
X_3	Household size (no. of family members)	5.88	2.64	+/-
X_4	Education level of the household head (years of schooling of the household head)	12.43	4.41	+
X_5	Access to credit (1= yes; 0= otherwise)	0.35	0.48	+
X_6	Distance from the market (Km)	2.79	3.24	+
X_7	Land size (number of acres owned by the household)	5.82	8.07	+/-

Source: Modified from Ajao *et al.* (2010); Awotide *et al.*(2015); Kirimi *et al.* (2013); Maziya *et al.* (2017)

3.3.6.5 Objective Five: to assess adaptation strategies to climate variability and extreme climate events and determinants of farmers' choice of specific adaptation strategies in the study area

To test if there was a significant difference in the adoption of adaptation strategies by farmers' in the four agro-ecological zones, the chi-square test of independence was used. Multivariate Probit (MVP) regression analysis was done using Stata version 12 to examine the influence of different socioeconomic characteristics of farmers on the choice of specific adaptation strategies in the study area.

The random utility theoretical model, which depicts a choice decision in which a person has a set of various strategies to choose from, guides the MVP decision model (McFadden, 1977). The utility model is based on the assumption that each option has unique features that influence a farmer's decision to choose one strategy over another. It is also built on the assumption that utility is obtained by selecting numerous options.

The model was used as expressed in Equations 13-19 in section 3.3.3.4 as applied by Feleke *et al.* (2016). The dependent variables for the model were selected adaptation strategies adopted by farmers while the predictor variables comprised of different socio-economic characteristics of the farmers as shown in Table 3.12 and Table 3.13, respectively.

Table 3.12: Description and summary statistics of farmers' adaptation strategies to climate variability and extreme climate events used as dependent variables for the multivariate probit model

Dependent variables (Adaptation Strategies)	Description of Variables	Mean	SD
Crop diversification	Dummy=1 if household adopts crops diversification, 0=otherwise	0.70	0.46
Planting drought-resilient crops	Dummy=1 if household adopts planting drought-resilient crops, 0=otherwise	0.66	0.47
Planting hybrid crop varieties	Dummy=1if household adopts planting hybrid crop varieties, 0=otherwise	0.60	0.49
Use of soil conservation techniques	Dummy=1if household adopts soil conservation techniques, 0=otherwise	0.72	0.45
Use of inorganic fertilizers	Dummy=1if household adopts use of fertilizers, 0= otherwise	0.27	0.46
Use of manure	Dummy=1if household adopts use of manure, 0=otherwise	0.81	0.40
Agroforestry	Dummy=1if household adopts agroforestry, 0=otherwise	0.47	0.50
Use pesticides	Dummy=1if household adopts use of pesticides, 0=otherwise	0.72	0.45

Table 3.13: Description and summary statistics of explanatory variables explanatory variables for farmers' choice of specific adaptation strategies to climate variability and extreme climate events in the study area

Variable	Description	Mean	SD	Expected sign
X_1	Gender of household head (1= male; 0= female)	1.29	0.46	+/-
X_2	Age of the household head (number of years of the household head)	55.86	15.11	+/-
X_3	Household size (number of family members in the household)	5.88	2.64	+/-
X_4	Membership in a farmers' cooperative/group (1= yes; 0= otherwise)	0.20	0.40	+
X_5	Farming experience (number of years household head involved in farming)	25.66	16.52	+
X_6	Education level of the household head (years of schooling of the household head)	12.43	4.41	+
X_7	Access to credit (1= yes; 0= otherwise)	0.35	0.48	+
X_8	Access to extension services (1=yes, 0=otherwise)	0.20	0.40	+
X_9	Distance from the market (how far the household is from the market in Km)	2.79	3.24	+
X_{10}	Access to early warning weather information (1=yes, 0=otherwise)	0.74	0.44	+
X_{11}	Land size (Number of acres owned by the household)	5.82	8.07	+/-

Source: Modified from Feleke *et al. (*2016); Kinuthia *et al.*(2018); Maddison, (2007); Obayelu *et al*.(2014).

3.3.7 Ethical considerations

The researcher briefed the respondents about the purpose of the research and highlighted that it was intended for academic work. It was also made clear that respondents' participation was entirely voluntary, and that they had the choice to opt-out of the interviews. The responders' privacy was also safeguarded.

CHAPTER FOUR

4.0 RESULTS

The study findings are presented in tables, percentages, maps and graphs in relation to the study objectives.

4.1 Rainfall and temperature trends and variability in the study area

4.1.1 Rainfall trends and variability in the study area

4.1.1.1 Annual rainfall trend in the study area

Mann-Kendall statistical test results for total annual rainfall for a period of 30 years (1988–2018) had a negative Z-statistics value implying a decreasing trend in the annual precipitation in the four agro-ecological zones as shown in Table 4.1. The findings however indicated that the trend was not significant at 5% significance level. Further, the results revealed that the arid zone had the highest coefficient of variation (30.16%) for the 30-year period annual rainfall followed by semi-humid (30.13%) and semi-arid (29.91%) zones while the transitional zone had the lowest (29.70%).

The distribution of the total annual rainfall for the 30-year period (1988–2018) in the four agro-ecological zones is shown in Figure 4.1. The total annual rainfall was highest in the semi-humid zone (968.82 mm), followed by the transitional zone (891.00 mm). Further the results indicated that the semi-arid zone had the second lowest mean (833.98 mm) for the total annual rainfall while the arid zone had the lowest (718.08 mm). Additionally, the results showed that the highest total annual rainfall in all the agro-ecological zones was recorded in 2006 while the lowest was recorded in 2005.

Table 4.1: Trend in 30-year period (1988-2018) total annual rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D.	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	718.08	1282.75	347.92	216.60	30.16	-1.53	.13
Semi-arid	833.98	1563.97	457.62	249.48	29.91	-1.34	.18
Transitional	891.00	1593.79	513.21	264.60	29.70	-1.16	.25
Semi-humid	968.82	1756.99	554.58	291.24	30.13	-0.73	.48

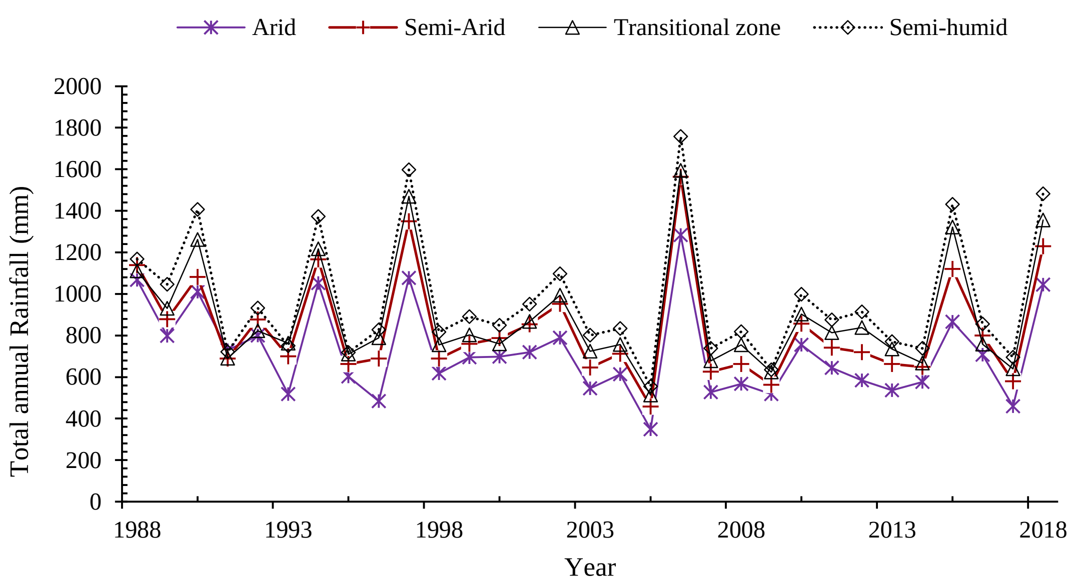

Figure 4.1 Total annual rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

4.1.1.1.2 Seasonal rainfall trends and variability in the study area

Results from Mann-Kendall statistical test indicated a decreasing trend in March-April-May (MAM) seasonal rainfall for a period of 30 years (1988–2018) in the arid and semi-arid zones. The trend was however not significant at 95% confidence level. The Z-statistic values in the semi-humid and transitional zones were however positive indicating an increasing trend in MAM seasonal rainfall in the zones as shown in Table 4.2. Regarding MAM seasonal rainfall variability, the results revealed that the arid zone had the highest coefficient of variation (41.97%) followed by semi-arid (41.69%) and semi-humid (41.29 %) zones while the transitional zone had the lowest (39.74%).

Table 4.2: Trend in 30-year period (1988-2018) MAM seasonal rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	232.02	593.94	88.46	97.39	41.97	-2.27	.79
Semi-arid	289.89	724.00	113.97	120.84	41.69	-2.27	.79
Transitional	348.36	835.49	165.25	138.45	39.73	0.14	.89
Semi-humid	377.23	930.74	167.91	155.77	41.29	0.38	.71

The MAM seasonal rainfall distribution for the 30-year period in the four agro-ecological zones is shown in Figure 4.2. The results showed that the MAM seasonal rainfall was highest in the semi-humid zone (377.23 mm), followed by the transitional zone (348.36 mm) while the semi-arid and arid zones had the second lowest (289.89 mm) and lowest (232.02 mm) means, respectively. The highest MAM seasonal rainfall in all the agro-ecological zones was recorded in 2018 while the lowest was recorded in 2009.

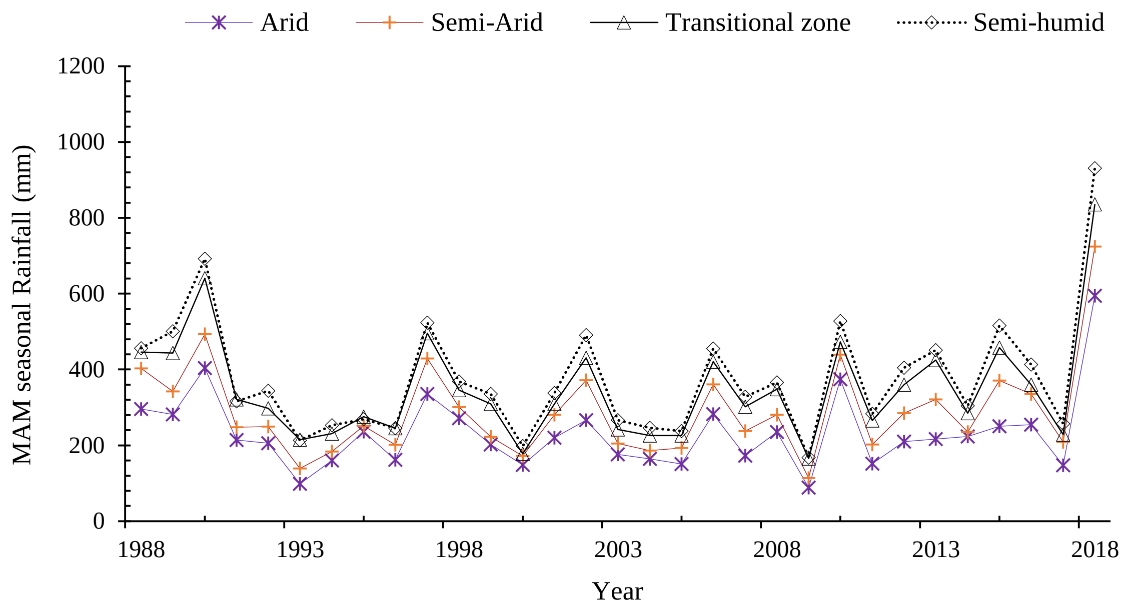

Figure 4.2: MAM seasonal rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

With regard to the October-November-December (OND) rainfall season, the Z-statistics values from Mann-Kendall statistical test were negative implying a decreasing trend in OND average rainfall in the four zones in the study area as shown in Table 4.3. The trend was however not statistically significant at 5% significant level. Additionally, the results indicated that the semi-humid zone had the highest coefficient of variation (44.70%) for OND rainfall for the 30-year period followed by transitional (43.25%) and semi-arid (42.56%) zones while the arid zone had the lowest (41.67%).

Table 4.3: 30-year period (1988-2018) trend in OND seasonal rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	425.50	955.87	160.94	177.31	41.67	-1.84	.07
Semi-arid	473.01	1145.03	194.52	201.32	42.56	-1.67	.09
Transitional	474.84	1111.10	191.53	205.37	43.29	-1.29	.20
Semi-humid	512.92	1222.33	200.04	229.25	44.69	-1.43	.15

The OND seasonal rainfall distribution for the 30-year period in the four agro-ecological zones is shown in Figure 4.3. The OND seasonal rainfall was highest in the semi-humid zone (512.92 mm), followed by the transitional zone (473.01 mm). Further the results indicated that the semi-arid zone had the second lowest mean (473.03 mm) for OND seasonal rainfall while the arid zone had the lowest (425.50 mm). Additionally, the results showed that the highest OND seasonal rainfall in all the agro-ecological zones was recorded in 2006 while the lowest was recorded in 2005.

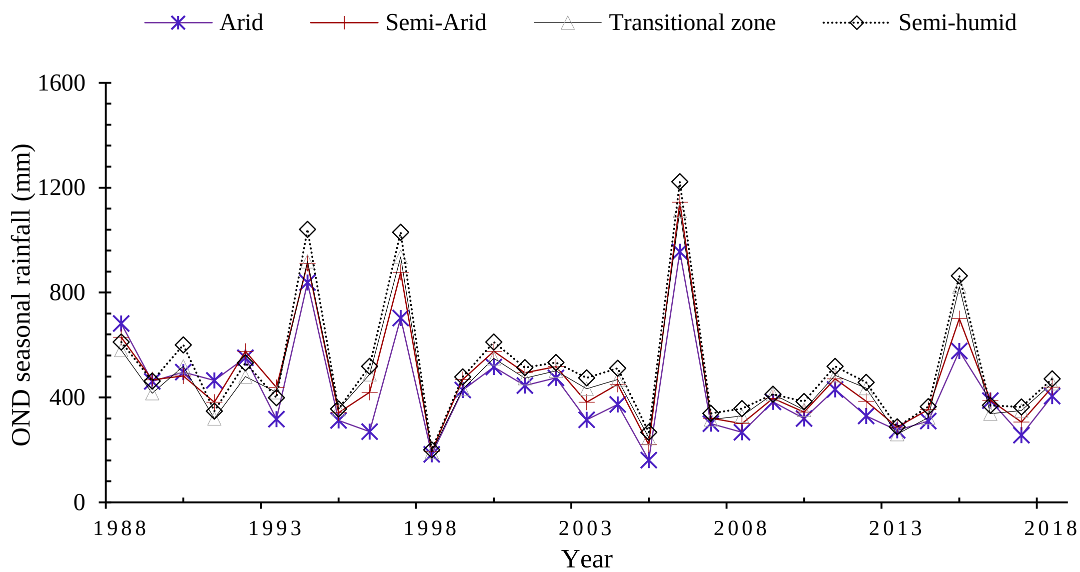

Figure 4.3: OND seasonal rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

4.1.2 Temperature trends and variability in the study area

4.1.2.1 Annual temperature trends and variability in the study area

Mann-Kendall statistical test results showed a significant increasing trend (p<.001) in a 30-years period (1988-2018) annual mean temperature in the four agro-ecological zones as shown in Table 4.4. Further scrutiny of the results revealed that the semi-humid zone had the highest coefficient of variation (2.40%) for the annual mean temperature for the 30 years followed by arid and semi-arid zones with a similar coefficient of variation (2.34%) and lastly the transitional zone (2.13%).

Table 4.4: Trend in 30-year period (1988-2018) annual mean temperature in the study area

Agro-ecological Zone	Mean (ºc)	Max (ºc)	Min (ºc)	S.D. (ºc)	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	24.34	24.94	23.64	0.27	1.10	3.98	<.001
Semi-arid	24.34	24.94	23.64	0.27	1.10	3.98	<.001
Transitional	22.18	22.80	21.10	0.33	1.47	3.88	<.001
Semi-humid	24.34	24.94	23.64	0.27	1.10	3.98	<.001

The annual mean temperature for the 30-year period in the different agro-ecological zones is presented in Figure 4.4. The highest mean temperature was recorded in the arid, semi-arid and semi-humid zones (24.34°C) while the transitional zone had the lowest mean temperature (22.18°C). Further, the results indicated that the highest mean annual temperature in all the agro-ecological zones was recorded in 2003 and 2009 while the lowest was recorded in 1989.

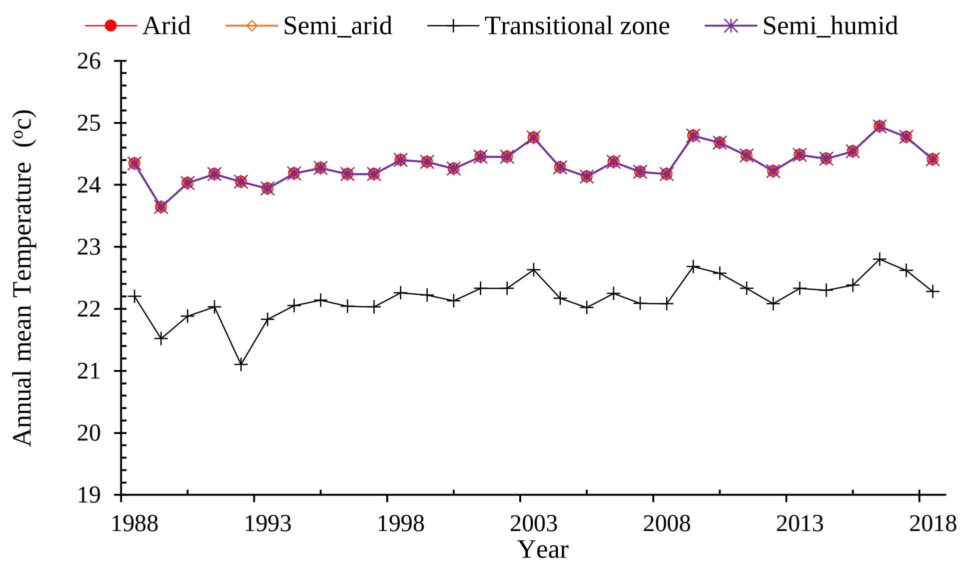

Figure 4.4: Average annual mean temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

Results from Mann-Kendall statistical test results for average annual maximum temperature for a period of 30 years (1988-2018) indicated significant positive Z-statistics values implying that there was a statistically significant upward trend ($p<.001$) in average maximum temperature in all the four agro-ecological zones as shown in Table 4.5. Similarly, the results indicated that there was a statistically significant increasing trend in the average annual minimum temperature at 95% confidence level in all the four agro-ecological zones as presented in Table 4.6.

Table 4.5: Trend in 30-year period (1988-2018) average annual maximum temperature in the study area

Agro-ecological Zone	Mean (ºc)	Max (ºc)	Min (ºc)	S.D. (ºc)	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	30.28	30.90	29.50	0.29	0.96	3.42	<.001
Semi-arid	30.28	30.90	27.30	0.29	0.96	3.56	<.001
Transitional	28.15	28.80	27.30	0.29	1.05	3.10	<.001
Semi-humid	30.28	30.90	29.50	0.29	0.96	3.32	<.001

Table 4.6: Trend in 30-year period (1988-2018) average annual minimum temperature in the study area

Agro-ecological Zone	Mean (ºc)	Max (ºc)	Min (ºc)	S.D. (ºc)	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	18.36	18.85	17.87	0.27	1.47	2.05	.04
Semi-arid	18.29	18.85	16.08	0.49	2.68	2.32	.02
Transitional	16.22	16.72	15.60	0.28	1.74	2.30	.02
Semi-humid	18.39	18.85	17.87	0.27	1.47	2.06	.04

The results further revealed that the transitional zone had the highest coefficient of variation (1.05%) for average annual maximum temperature for the 30-year period followed by arid, semi-arid and semi-humid zones which had a similar coefficient of variation (0.96 %). With regard to average annual minimum temperature, the semi-arid zone had the highest coefficient of variation (2.68 %) followed by the transitional zone (1.74%) and lastly the arid and semi-humid zones which had a similar coefficient of variation (1.47%).

The annual mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are shown in Figures 4.5 and 4.6, respectively. The highest mean annual maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (30.28°C) while the transitional zone had the lowest annual maximum temperature (28.15°C). Further, the results indicated that the highest annual maximum temperature in all the agro-ecological zones was recorded in 2003 and 2009 while the lowest was recorded in 1989.

In regard to annual minimum temperature (Tmin), the results showed that highest mean was recorded in semi-humid (18.39°C), followed by arid (18.36°C) and semi-arid (18.29°C) zones while the transitional zone had the lowest annual minimum temperature (16.22°C). Further, the results indicated that the highest annual minimum temperature in all the agro-ecological zones was recorded in 2010 while the lowest was recorded in 1989.

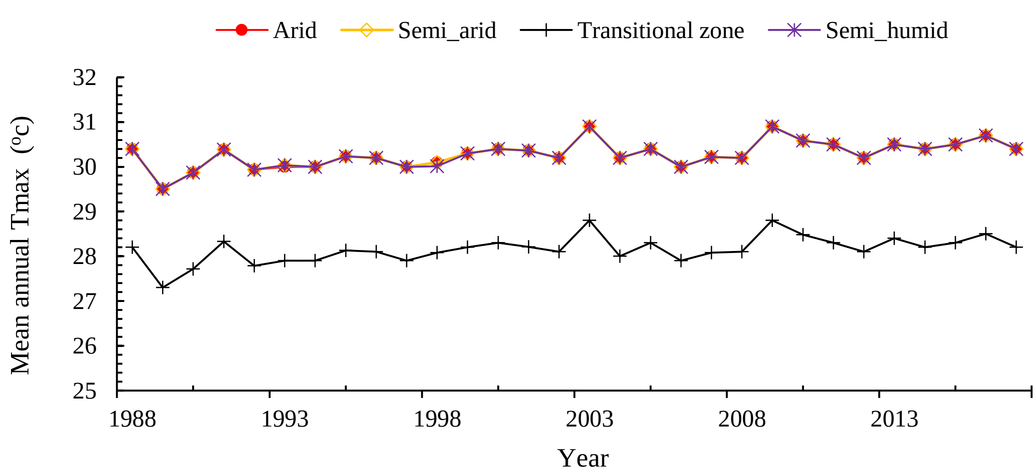

Figure 4.5: Mean annual maximum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

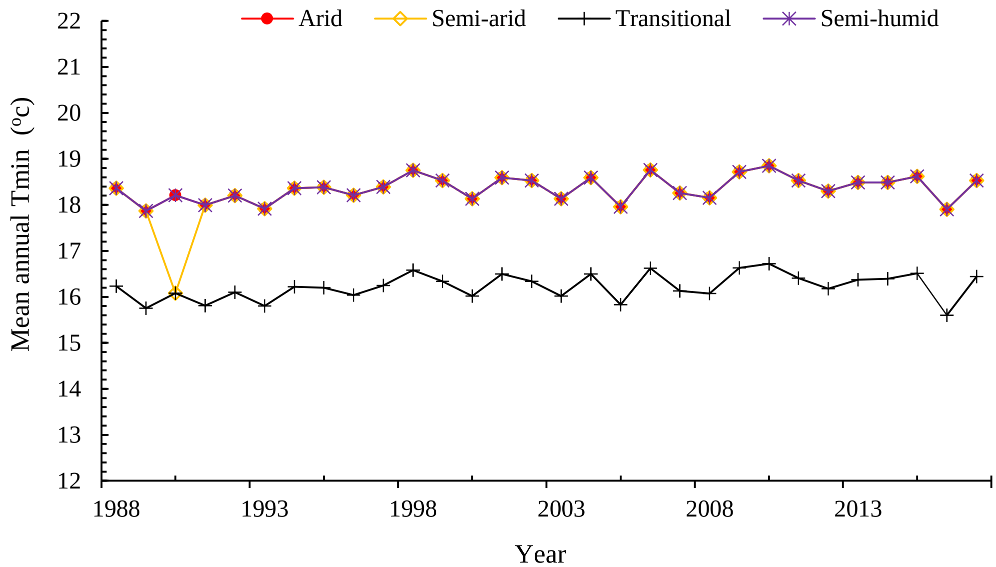

Figure 4.6: Mean annual minimum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

4.1.2.2 Seasonal temperature trends and variability in the study area

Mann-Kendall statistical test results for average MAM maximum temperature for a period of 30 years (1988-2018) had positive Z-statistics values implying that there was an upward trend in average MAM maximum temperature in all the four agro-ecological zones as shown in Table 4.7. The trend was however not significant at 95% confidence level. Similarly, the results showed a non-significant increasing trend in average MAM minimum temperature at 95% confidence level in all the four agro-ecological zones as shown in Table 4.8.

Additionally, the results indicated that the transitional zone had the highest coefficient of variation (2.21%) for average MAM maximum temperature for the 30 years followed by arid, semi-arid and semi-humid zones which had a similar coefficient of variation (1.55%). Regarding average MAM minimum temperature, the transitional zone had the highest coefficient of variation (2.44 %) followed by the semi-humid zone (2.35%) and lastly, the arid and semi-humid zones which had a similar coefficient of variation (2.14%).

Table 4.7: Trend in 30-year period (1988-2018) average MAM maximum temperature in the study area

Agro-ecological Zone	Mean (ºc)	Max (ºc)	Min (ºc)	S.D. (ºc)	Coefficient of Variation	Mann-Kendall test Z-Stat	P-Value
Arid	31.20	32.50	30.30	0.48	1.55	0.75	.45
Semi-arid	31.20	32.50	30.30	0.48	1.55	0.75	.45
Transitional	29.04	31.30	28.00	0.64	2.21	0.43	.69
Semi-humid	31.20	32.50	30.30	0.48	1.55	0.75	.45

Table 4.8: Trend in 30-year period (1988-2018) average MAM minimum temperature in the study area

Agro-ecological Zone	Mean (ºc)	Max (ºc)	Min (ºc)	S.D. (ºc)	Coefficient of Variation	Mann-Kendall test Z-Stat	P-Value
Arid	19.51	20.40	18.60	0.42	2.14	1.48	.14
Semi-arid	19.51	20.40	18.60	0.42	2.14	1.48	.14
Transitional	17.49	18.40	16.57	0.43	2.44	1.43	.15
Semi-humid	19.49	20.40	18.30	0.46	2.35	1.48	.14

The MAM mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are shown in Figures 4.7 and 4.8, respectively. The highest mean MAM maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (31.20°C) while the transitional zone had the lowest mean value (29.04°C). Further, the results indicated that the highest MAM maximum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

In regard MAM minimum temperature (Tmin), the results showed that the arid and semi-arid zones had the highest mean (19.51°C) followed by the semi-humid zone (19.49°C) while the transitional zone had the lowest MAM minimum temperature (17.49°C). Further, the results indicated that the highest MAM minimum temperature in all the agro-ecological zones was recorded in 2010 while the lowest was recorded in 1989.

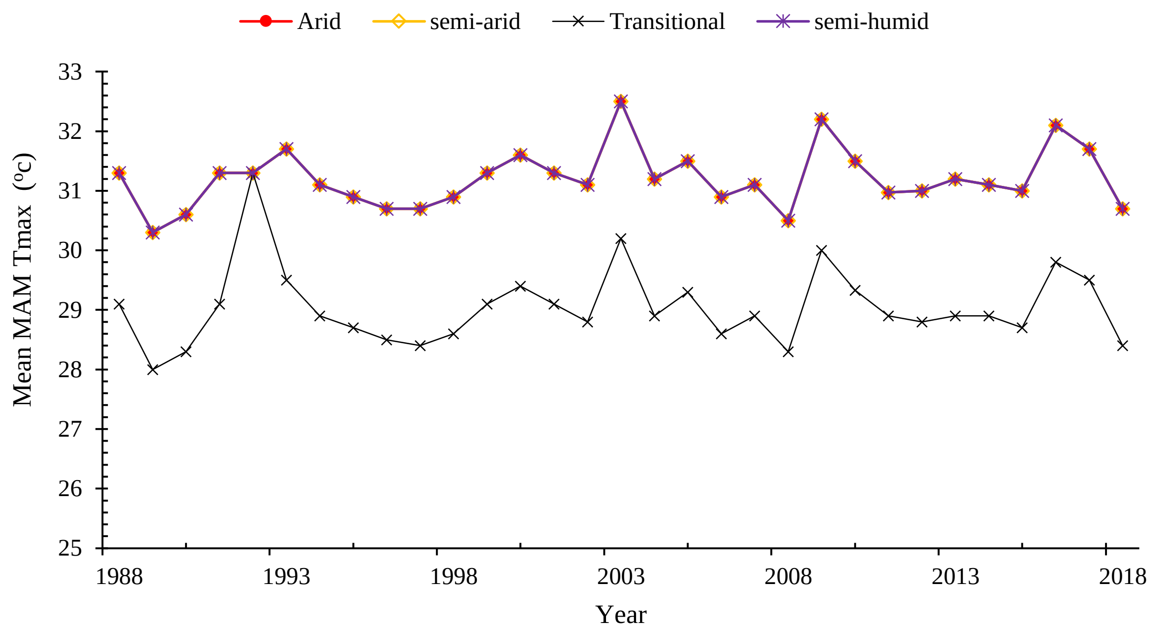

Figure 4.7: Mean MAM maximum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

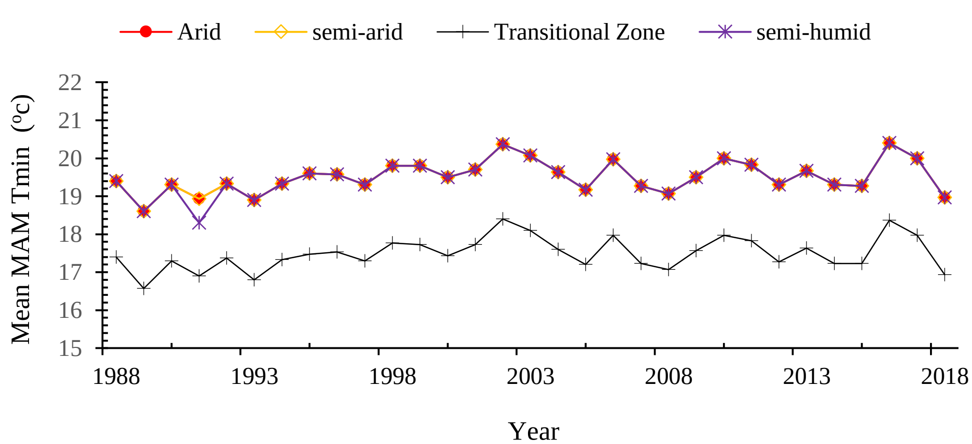

Figure 4.8: Mean MAM minimum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

Results from Mann-Kendall statistical test showed a significant increasing trend at 95% confidence level in the 30-years period (1988-2018) average OND maximum and minimum temperatures in the four zones as indicated in Tables 4.9 and 4.10, respectively. In addition, the results indicated that the coefficient of variation for average OND maximum temperature for the 30-year period was highest in the semi-humid zone (2.40%) followed by arid and semi-arid zones with a similar coefficient of variation (2.34%) and lastly the transitional zone (2.13%). With regard to average OND minimum temperature, the transitional zone had the highest coefficient of variation (3.68 %), the semi-arid zone had the second highest (3.03%) while the arid and semi-humid zones had the lowest with a similar coefficient of variation (2.28%).

Table 4.9: Trend in 30-year period (1988-2018) average OND maximum temperature in the study area

Agro-ecological Zone	Mean (°c)	Max (°c)	Min (°c)	S.D. (°c)	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	30.18	31.10	29.10	0.59	2.34	2.34	.02
Semi-arid	30.18	31.10	29.10	0.58	2.34	2.34	.02
Transitional	28.13	29.00	27.10	0.55	2.13	2.13	.03
Semi-humid	30.18	31.20	29.10	0.59	2.40	2.40	.02

Table 4.10: Trend in 30-year period (1988-2018) average OND minimum temperature in the study area

Agro-ecological Zone	Mean (°c)	Max (°c)	Min (°c)	S.D. (°c)	Coefficient of Variation	Mann-Kendall test	
						Z-Stat	P-Value
Arid	18.74	19.73	18.03	0.43	2.28	3.49	<.001
Semi-arid	18.74	19.73	16.63	0.57	3.03	3.37	<.001
Transitional	16.85	18.73	18.07	0.62	3.68	3.11	<.001
Semi-humid	18.74	19.73	18.03	0.43	2.28	3.49	<.001

The OND mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are presented in Figures 4.9 and 4.10, respectively. The highest mean OND maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (30.18°C) while the transitional zone had the lowest mean value (28.13°C). Further, the results indicated that the highest OND maximum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

In regard OND minimum temperature (Tmin), the results showed that the arid, semi-arid and semi-humid zones had the highest mean (18.74°C) while the transitional zone had the lowest OND minimum temperature (16.85°C). Further, the results indicated that the highest OND minimum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

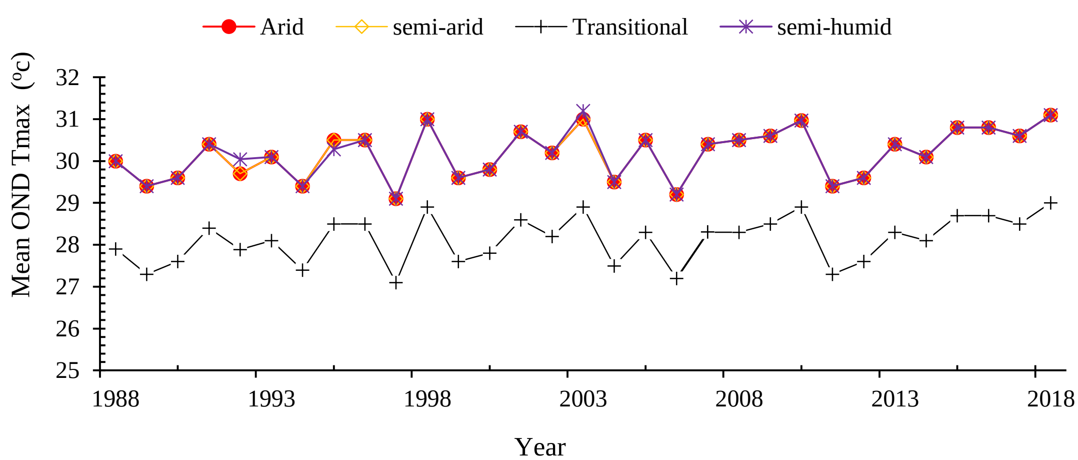

Figure 4.9: Mean OND maximum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

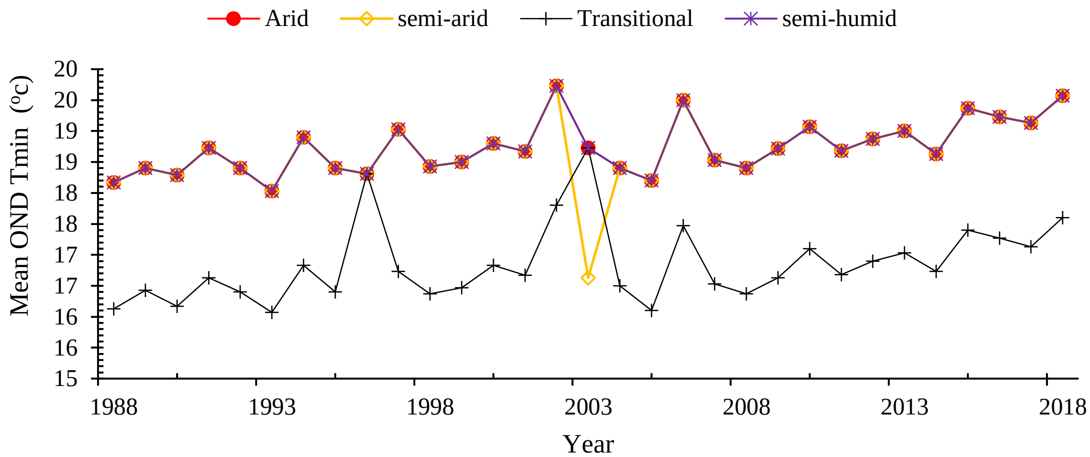

Figure 4. 10: Mean OND minimum temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

4.2 Spatial vulnerability of farmers to climate variability and extreme climate events in the study area

Farmers' vulnerability to climate variability and extremes in the study area was calculated using the indicator-based approach. As presented in Chapter 3, indicator variables for exposure, sensitivity and adaptive capacity were weighted using the Principal Component Analysis (PCA).

4.2.1 Exposure indicators

Weights from the Principle Component Analysis and mean values for exposure indicators are presented in Table 4.11. From the results, the weights for all the indicators of exposure had a positive sign implying a positive relationship with the exposure index except floods which had a negative weight thus indicating a negative relationship with exposure index. The coefficient of variation for average annual maximum temperature had the highest influence on the exposure index (0.82) followed by the coefficient of variation for average annual maximum temperature (0.72), droughts (0.60), strong winds (0.58), floods (-0.54) and livestock disease outbreaks (0.31). Results from one-way analysis of variance indicated that the average scores for all exposure indicators were statistically significant at 5% significance level across the four agro-ecological zones.

The findings further indicated that the coefficient of variation for average annual maximum temperature (1988-2018) was highest in the transitional zone (1.05%) followed by the semi-humid zone (0.97%) while the arid and semi-arid zones had the least (0.96%). The semi-arid zone had the highest coefficient of variation (2.68%) for average annual minimum temperature (1988-2018) followed by the transitional zone (1.74%) while the arid and semi-humid zones ranked third with the same rate of change (1.47%). In regards to annual rainfall, the coefficient of variation was highest in the arid zone (30.16%) followed by the semi-humid (30.13%), semi-arid (29.91%) and transitional (29.70%) zones.

In addition, the number of floods were highest in the arid zone (1.03) followed by semi-humid (0.71), transitional (0.37) and semi-arid (0.08) zones. Drought incidences were highest in the arid zone (8.28) followed by semi-arid (5.11) and transitional zones (3.45) and the lowest in the semi-humid zone (2.97). Similarly, incidences of strong winds were highly recorded in the arid zone (7.36) followed by semi-arid, transitional and semi-arid zones (4.34, 2.50 and 1.92, respectively). Additionally, the number of livestock disease outbreaks were highest in the arid zone (4.15) followed by semi-arid (2.54) and transitional zones (2.45) and the lowest in the semi-humid zone (1.74).

Table 4.11: Weights and mean values of exposure indicators in the study area

Exposure Indicator	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
Rate of change in average annual maximum temperature (1988-2018)	0.82	0.96 (0.00)	0.96 (0.00)	1.05 (0.00)	0.97 (0.00)	<.001***
Rate of change in average annual minimum temperature (1988-2018)	0.72	1.47 (0.00)	2.68 (0.00)	1.74 (0.00)	1.47 (0.00)	<.001***
Rate of change in average annual rainfall (1988-2018)	0.53	30.16 (0.00)	29.91 (0.00)	29.70 (0.00)	30.13 (0.00)	.03**
Floods	-0.54	1.03 (2.07)	0.08 (0.34)	0.37 (1.65)	0.71 (1.17)	<.001***
Droughts	0.60	8.28 (1.88)	5.11 (3.10)	3.45 (1.52)	2.97 (1.56)	<.001***
Strong winds	0.58	7.36 (3.65)	4.34 (4.66)	2.50 (4.09)	1.92 (3.13)	.01***
Livestock diseases	0.31	4.15 (3.48)	2.54 (4.09)	2.45 (3.78)	1.74 (3.02)	.04**

Note: Figures in parenthesis indicate standard deviation; ******* and ****** indicate significant at 1% and 5% levels of significance, respectively.

4.2.2 Sensitivity indicators

4.2.2.1 Water sources sensitivity sub-composite index

Results from Principal Component Analysis (PCA) are presented in Table 4.12. The results showed that the weights for all the indicators of water sources sub-composite index were positive implying a positive influence on the sensitivity index. The results further indicated that the number of times shallow wells dried due to droughts had the highest weight (0.82) followed by the number of times springs dried (0.81), the number of times earth dams dried (0.80), the number of times rivers dried (0.73), number of times water pans dried (0.72) and the number of times boreholes dried (0.71) due to droughts.

Further, the results revealed that the arid zone (4.72) had the highest mean value for the number of times shallow wells dried due to droughts followed by the transitional (3.69), semi-arid (3.69) and semi-humid (2.47) zones. The number of times springs dried due to droughts were highest in the arid zone (3.82), followed by semi-arid, transitional and semi-humid zones (3.82, 1.91, 1.58 and 1.43, respectively). Similarly, number of times water pans dried due to droughts were highest in the arid zone (4.67), followed by semi-arid (2.65), transitional (2.16) and semi-humid (1.99) zones.

Further scrutiny of the results showed that the number of times earth dams dried due to droughts followed a decreasing order of arid (4.82), semi-arid (3.55), transitional (2.53) and semi-humid (1.73) zones. In addition, the semi-arid zone (5.76) had the highest mean value for the number of times rivers dried due to droughts followed by the transitional (5.44), semi-arid (5.32) and semi-humid (4.31) zones. Further, the number of times boreholes dried due to droughts were highest in the arid zone (2.85), followed by semi-humid (1.53), semi-arid (1.08) and transitional (1.05) zones.

Table 4.12: Weights and mean values of indicators for sensitivity of water sources to droughts

Water source sensitivity indicator	Weight	Agro-ecological zone				P-Value
		Arid (Yuku)	Semi-arid (Kauwi)	Transitional (Kasaini)	Semi-humid (Kaveta)	
No. of times rivers dried due to droughts	0.73	5.44 (4.79)	5.76 (4.53)	5.32 (5.23)	4.31 (4.48)	.09*
No. of times boreholes dried due to droughts	0.71	2.85 (4.72)	1.08(3.04)	1.05(3.11)	1.53(3.25)	<.001***
No. of times shallow wells dried due to droughts	0.82	4.72 (4.85)	3.69(4.46)	3.82 (4.49)	2.47 (4.00)	.03**
No. of times springs dried due to droughts	0.81	3.82 (5.38)	1.91 (3.86)	1.58 (3.70)	1.43 (3.45)	.01***
No. of times water pans dried due to droughts	0.72	4.67 (8.79)	2.65 (4.23)	2.16 (3.95)	1.99 (3.94)	.03**
No. of times earth dams dried due to droughts	0.80	4.82 (4.50)	3.55 (4.65)	2.53 (4.28)	1.73 (3.41)	<.001***

Note: Figures in parenthesis indicate standard deviation, ******* and ** indicate significant at 1% and 5% significance levels, respectively.

4.2.2.2 Overall sensitivity indicators

With regard to the overall sensitivity, PCA analysis results indicated that all the weights for overall sensitivity indicators were positive except the percentage off-farm income thereby implying a positive relationship with the sensitivity index as shown in Table 4.13. The negative weight of the percentage share of off-farm income implies that it has a negative influence on the sensitivity index. The number of cows and number of goats dead due to droughts had the highest influence on sensitivity with a similar weight of 0.92, followed by the proportion of on-farm and off-farm income with weights of 0.92 and -0.92, respectively. The water sources sensitivity sub-composite index ranked third in its influence on sensitivity with a weight of 0.87 followed by the number of goats dead due to livestock disease outbreaks, the number of acres of crops destroyed by droughts and the number of cows killed by livestock disease outbreaks with respective weights of 0.84, 0.61 and 0.02.

One-way analysis of variance indicated that there was a statistically significant difference, at 5% level of significance, in the means values for all the indicators of sensitivity across the four agro-ecological zones. The arid zone had the highest number of cows killed by droughts (34.62) followed by the semi-arid (1.98), transitional (0.63) and semi-humid (0.46) zones. The arid zone had the highest number of cows killed by droughts (34.62) followed by the semi-arid (1.98), transitional (0.63) and semi-humid (0.46) zones. The number of goats killed by droughts had the highest mean in the arid zone (12.08) followed by the transitional (1.32), semi-arid (1.03) and semi-humid (0.37) zones.

Regarding the percentage share of on-farm income, the arid zone had the highest mean value (69.14%) followed by the transitional (55.92%), semi-arid (50.14%) and semi-humid (22.64%) zones. Conversely, the percentage share of off-farm income followed a decreasing order of semi-humid (77.36%) followed by the semi-arid (49.86%), transitional (44.07%) and arid (30.86%) zones. Further, the results indicated that the arid zone had the highest mean value for water sources sensitivity sub-composite index in the arid zone (1.59) followed by the semi-arid (0.15) transitional (-0.22) and semi-humid (-0.74) zones. Additionally, the results revealed that the mean values for the number of goats dead due to livestock disease outbreaks were highest in the arid zone (12.00) followed by the semi-arid (1.39), transitional (1.16) and semi-humid (0.63) zones. For the number of cows dead due to livestock disease outbreaks, the arid zone had the highest mean (66.77) followed by the semi-arid (0.54), semi-humid (0.48) and transitional (0.37) zones. Similarly, the mean values for the number of acres of crops destroyed by droughts were highest in the arid zone (2.38) followed by the semi-arid (0.80), semi-humid (0.36) and least in the transitional (0.22) zones.

Table 4.13: Weights and mean values of sensitivity indicators in the study area

Sensitivity Indicators	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
No. of cows dead due to droughts	0.97	34.62 (112.12)	1.98 (3.86)	0.63 (1.87)	0.46 (1.68)	<.001***
No. of goats dead due to droughts	0.97	12.08 (16.41)	1.03 (3.65)	1.32 (5.66)	0.37 (3.02)	<.001***
No. of cows dead due to livestock diseases	0.02	66.77 (385.53)	0.54 (1.95)	0.37 (1.05)	0.48 (1.22)	.03**
No. of goats dead due to livestock diseases	0.84	12.00 (19.46)	1.39 (4.82)	1.16 (2.72)	0.04 (0.24)	<.001***
No. of acres of crops destroyed by drought	0.61	9.08 (3.54)	2.03 (3.22)	1.26 (1.64)	0.95 (1.37)	<.001***
Percentage share of on-farm income	0.92	51.28 (32.11)	40.10 (39.89)	39.46 (41.02)	23.56 (32.43)	<.001***
Percentage share of off-farm income	-0.92	27.67 (28.63)	42.10 (41.91)	47.01 (42.44)	53.09 (39.72)	.01***
Water sources sub-composite index	0.87	1.57 (4.44)	0.15 (3.45)	-0.22 (0.99)	-0.74 (2.99)	.01***

Note: Figures in parenthesis indicate standard deviation, ******* and ** indicate significant at 1% and 5% significance levels, respectively.

4.2.3 Indicators for adaptive capacity

A 2-step PCA was done to calculate the adaptive capacity index. Weights and mean values for the indicators of adaptive capacity were calculated separately for each of the five livelihood assets in the First-step PCA.

4.2.3.1 Indicators for physical livelihood assets

Weights and average values for the indicators of physical livelihood assets are presented in Table 4.14. The number of gadgets used to assess information and the number of sources for timely weather forecasts had positive weights thereby implying a positive relationship with the adaptive capacity index. Conversely, the weights for proximity to the nearest motorable roads, markets, permanent water sources and health facilities were negative indicating a negative relationship with the adaptive capacity index.

Additionally, one-way analysis of variance results indicated that there was a statistically significant difference, at 95% confidence level, in the mean scores for the indicators of physical livelihood assets except for the distance to the nearest mortorable road across the four agro-ecological zones. The number of gadgets used to assess information was highest in the semi-humid zone (3.20) followed by semi-arid (2.39) and arid (2.08) zones and the lowest in the transitional zone (2.05). On the other hand, the semi-arid zone had the lowest number of sources of timely weather forecasts (1.18) while the semi-humid zone had the highest number (1.47).

Moreover, the results revealed that the distance to the nearest motorable road was longest in the arid zone (2.53 Km) followed by semi-humid (2.26 Km), semi-arid (0.98 Km) and the transitional (0.62 Km) zones in that order. Similarly, the longest distance to the nearest market was registered by the arid zone (4.83 Km) followed by the transitional zone (3.00 Km) and the semi-arid zone (2.54 Km) while the semi-humid zone had the shortest distance to the market (2.34 Km). Distance to the nearest permanent water source was the longest in the arid zone (4.23 Km) followed by the semi-humid (1.20 Km), semi-arid (1.09 Km) and transitional (1.04 Km) zones. On the other hand, the semi-humid zone had the shortest distance to the nearest health centre (2.61 Km) followed by the semi-arid (2.92 Km), the transitional (3.51 Km) zones with the arid zone recording the longest (8.31 Km).

Table 4.14: Weights and mean values for physical livelihoods assets' indicators in the study area

Physical assets Indicators	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional zone (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
No. of gadgets used to assess information	0.80	2.08 (1.75)	2.39 (1.68)	2.05 (1.37)	3.20 (2.84)	<.001***
No. of sources of timely early warning weather information	0.76	1.18 (0.86)	1.09 (0.85)	1.24 (1.03)	1.47 (1.22)	.03**
Distance to the nearest motorable road (Km)	-0.14	2.53 (3.32)	0.98 (1.90)	0.62 (0.88)	2.26 (0.53)	.22
Distance to the nearest market (Km)	-0.91	4.83 (7.36)	2.53 (2.32)	3.00 (2.38)	2.34 (1.57)	<.001***
Distance to the nearest permanent water source (Km)	-0.79	4.23 (5.53)	1.09 (1.30)	1.04 (1.22)	1.21 (1.19)	<.001***
Distance to the nearest health facility (Km)	-0.93	8.31 (7.44)	2.92 (2.59)	3.51 (2.08)	2.61 (2.01)	<.001***

Note: Figures in parenthesis indicate standard deviation; ******* and ** indicate significant at 1% and 5% levels of significance, respectively.

4.2.3.2 Indicators for human livelihood assets

Results presented in Table 4.15 indicated that the weights for all indicators of human livelihood assets were positive thereby implying a positive relationship with the adaptive capacity index. The number of persons with formal employment had the highest weight (0.73) followed by the highest educational level (0.69) and the number of vocational courses attended (0.65).

In addition, one-way analysis of variance results indicated that there was a statistically significant difference across the four agro-ecological zones (p=.01) in mean values for the number of persons with formal employment in the family and the number of vocational courses attended by family members. However, the mean values for the highest level of education in the family were not significantly different across the four study areas (p=.07). Further, the results indicated that the semi-humid zone registered the highest mean values for all the indicators of human livelihood assets while the arid zone registered the lowest. The transitional zone had the second highest mean values for all the indicators of human livelihood assets while the semi-arid zone registered the third-highest mean values.

Table 4.15: Weights and mean values for human livelihoods assets' indicators in the study area

Human assets Indicators	**Weight**	**Agro-ecological zone**				**P-Value**
		Arid (Yuku; n=39)	**Semi-arid (Kauwi; n=160)**	**Transitional (Kasaini; n=38)**	**Semi-humid (Kaveta; n=104)**	
Highest level of education in schooling years	0.69	10.85 (3.98)	12.40 (4.18)	12.42 (4.68)	13.06 (4.71)	.07
No. of persons with formal employment	0.73	0.44 (0.85)	0.50 (0.85)	0.66 (1.26)	0.91 (1.30)	.01***
No. of vocational courses attended	0.65	0.44 (0.85)	0.45 (0.85)	0.50 (0.76)	0.84 (1.18)	.01***

Note: Figures in parenthesis indicate standard deviation; ******* indicate significant at 1% significance levels, respectively.

4.2.3.3 Indicators for natural livelihood assets

Weights and mean values for the indicators of natural livelihood assets are presented in Table 4.16. The weights for all the indicators of natural livelihood assets except the size of unproductive land were positive thereby indicating a positive influence on the adaptive capacity index. The negative weight for the size of unproductive land implied that it had a negative relationship with the adaptive capacity index.

Additionally, the results indicated that total land size had the highest weight (0.86) followed by productive land size under crops and productive land size pasture with a common weight of 0.85. The number of large bullock stocks had the third-highest weight (0.75) while unproductive land size had the lowest weight (-0.44). Results of one-way analysis of variance indicated that mean values for all indicators of natural livelihood assets were significantly different across the four agro-ecological zones ($p<.001$).

From the results, it was noted that the mean values for all indicators of natural livelihood assets were highest in the arid zone, followed by the semi-arid, transitional and finally the semi-humid zones except for the productive land size under crops and pasture. The mean values for productive land size under crops were highest in the semi-arid (5.31 acres), followed by the arid (5.14 acres), transitional (4.04 acres) and semi-humid (2.15 acres) zones. For the productive land size under pasture, the mean values were highest in the arid zone (6.54 acres), followed by transitional (1.78 acres), semi-arid (1.71 acres) and the least in semi-humid (0.34 acres) zones.

Table 4.16: Weights and mean values for natural livelihoods assets' indicators in the study area

Natural assets Indicators	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
Total land size (acres)	0.86	15.77 (15.63)	5.43 (5.93)	4.75 (4.12)	3.08 (4.32)	<.001***
Productive land size (acres)	0.85	8.72 (10.83)	4.72 (5.09)	3.80 (3.67)	2.35 (2.76)	<.001***
Unproductive land size (acres)	-0.44	6.00 (10.70)	0.58 (1.82)	0.57 (1.21)	0.62 (1.77)	<.001***
Land size under crops in current season (acres)	0.82	5.14 (1.95)	5.31 (5.02)	4.04 (2.87)	2.15 (1.94)	<.001***
Land size under pasture (acres)	0.82	6.54 (8.86)	1.71 (6.09)	1.78 (2.93)	0.34 (0.88)	<.001***
Number of large bullock stock	0.75	6.15 (6.85)	2.32 (2.74)	2.13 (2.22)	1.26 (1.74)	<.001***

Note: Figures in parenthesis indicate standard deviation and ******* indicate significant at 1% significance level.

4.2.3.4 Indicators for social livelihood assets

Results presented in Table 4.17 indicated that all the indicators for social assets had a positive sign thereby implying a positive relationship with the adaptive capacity index. The highest amount of credit accessed in the past ten years had the greatest influence on the adaptive capacity index (0.81) followed by the number of credit facilities accessed (0.78) and the number of extension services accessed over the past one year (0.23).

Results from one-way analysis of variance indicated that there was a significant difference in the mean values for the number of extension services accessed in the past year (*p*=.01) across the four agro-ecological zones. However, the mean values for the highest amount of credit accessed in the past ten years (*p*=. 42) and the number of credit facilities accessed in the last year (*p*=.51) were not significantly different across the four agro-ecological zones. The highest amount of credit accessed over the past ten years was highest in the transitional zone (Kshs.15, 657.89) followed by the semi-humid (Kshs.11, 894.23), arid (Kshs.10, 871.79) and finally the semi-arid (Kshs.6, 962.50) zones. On the other hand, the arid zone had the least mean values for the number of facilities accessed in the past year (0.26) followed by the transitional (0.39), semi-arid (0.46) and semi-humid (0.53) zones. Similarly, the mean values for the number of extension services accessed in the past year followed an increasing order of transitional (0.18), arid (0.26), semi-arid (0.33) and semi-humid (0.76) zones.

Table 4.17: Weights and mean values for social livelihoods assets' indicators in the study area

Social assets Indicators	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Semi-humid to semi-arid (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
No. of extension services accessed in the last one year	0.23	0.26 (0.68)	0.33 (0.81)	0.18 (0.46)	0.76 (1.75)	.01***
No. of credit facilities accessed in the last ten years	0.78	0.26 (0.68)	0.46 (0.98)	0.39 (0.68)	0.53 (1.20)	.52
Highest amount of credit accessed in the last ten years (Kshs)	0.81	10,871.79 (37,271.54)	6,962.50 (16,798.06)	15,657.89 (65,058.92)	11,894.23 (31,689.00)	.41

Note: Figures in parenthesis indicate standard deviation and *** indicate significant at 1% level of significance.

4.2.3.5 Indicators for financial livelihood assets

Weights and mean values for the indicators for financial livelihood assets are presented in Table 4.18. Weights for all the financial livelihood assets' indicators were positive, implying a positive influence on the adaptive capacity index. In terms of magnitude, the weights followed a decreasing order of estimated gross monthly income (0.78), estimated monthly savings (0.71) and livelihood diversification index (0.38). Results from one-way analysis of variance indicated that mean values for the livelihood diversification index were significantly different ($p < .001$) across the four agro-ecological zones. However, the mean values for estimated gross monthly income (p=.51) and estimate monthly savings (p=.45) were not significantly different.

The estimated gross monthly income was highest in the semi-humid zone (Kshs.26, 343.27) followed by semi-arid (Kshs.19, 583.45), transitional (Kshs.15, 944.74) and arid (Kshs.3, 095.49) zones. Similarly, estimated monthly savings were highest in the semi-humid zone (Kshs.2, 914.42) followed by semi-arid (Kshs.2, 121.37), transitional (Kshs.1, 592.11) and the least in arid (Kshs.843.85) zones. The mean values for the livelihood diversification index were however highest in arid (0.41) followed by semi-arid (0.25), semi-humid (0.24) and the lowest in the transitional (0.19) zones.

Table 4.18: Weights and mean values for financial livelihoods assets' indicators in the study area

Financial assets Indicators	Weight	Agro-ecological zone				P-Value
		Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
Estimated gross monthly income (Kshs)	0.78	13095.49 (19727.95)	19583.45 (52978.26)	15944.74 (24359.54)	26343.2 (67726.19)	.51
Estimated monthly savings (Kshs)	0.71	843.85 (2516.05)	2121.37 (6440.46)	1592.11 (6532.51)	2914.42(9549.13)	.45
Livelihood diversification index	0.38	0.41 (0.21)	0.25 (0.26)	0.19 (0.25)	0.24 (0.26)	<.001 ***

Note: Figures in parenthesis indicate standard deviation and ******* indicate significant at 1% significance level.

Results from the Second-step PCA indicated the relative significance of the five types of livelihood capitals that influence the overall adaptive capacity as shown in Figure 4.1. Physical assets had the greatest influence on adaptive capacity with a weight of 0.94 followed by financial assets (0.73), social assets (0.40) and human assets (0.29) while the natural assets had the least (0.03).

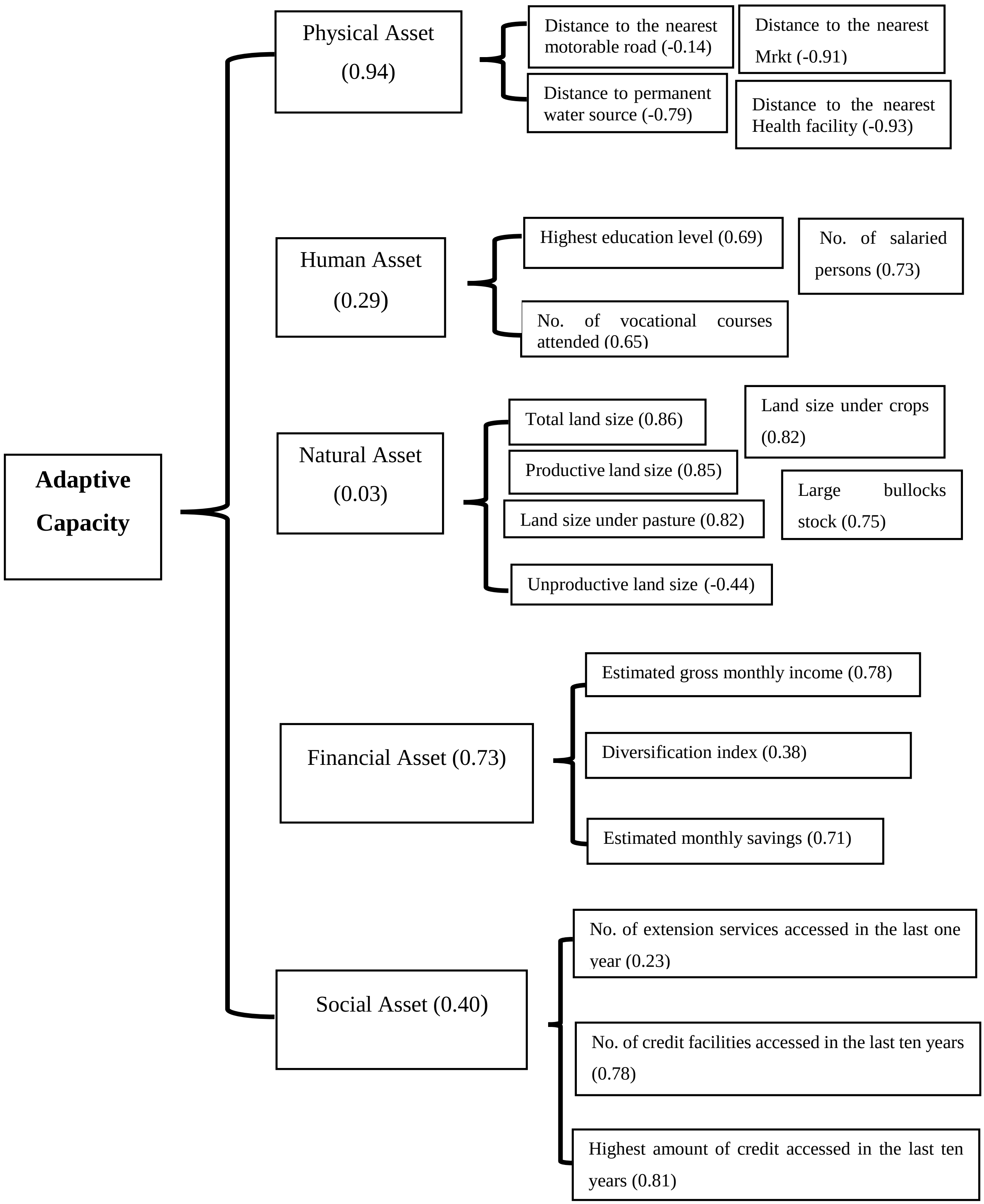

Figure 4.11: Structure of aggregate adaptive capacity index, sub-composite indices and component indicators

Note: Figures in parenthesis are PCA loadings taken as weights for the respective indicator

4.2.3.6 Adaptive capacity sub-composite indices

The five livelihood assets' sub-composite indices are presented in Table 4.19. Results from one-way analysis of variance indicated that the mean values for physical, natural and human assets' sub-composite indices were significantly different ($p < .001$) across the four agro-ecological zones. However, the mean values for social (p=.36) and financial (p=.44) assets' sub-composite indices were not significantly different.

Further scrutiny of the results revealed that the physical assets' sub-composite index score was highest in the semi-humid zone (0.85) followed by semi-arid (0.19), transitional (-0.08) and arid (-2.91) zones. Additionally, the human assets' sub-composite index score was highest in the semi-humid zone (0.46) followed by transitional (-0.04), semi-arid (-0.18) and the lowest in arid (-0.48) zones. The natural assets' sub-composite index on the other hand was highest in the arid zone (1.78) followed by semi-arid (1.58), transitional (0.38) and the lowest in the semi-humid (-0.35) zones. Further, the social assets sub-composite index had the highest score in the semi-humid zone (0.18) followed by transitional (0.05), semi-arid (-0.09) and the lowest in the arid (-0.16) agro-ecological zones. Regarding financial assets, the sub-composite index score was highest in the semi-humid zone (0.14) followed by arid (-0.02) and semi-arid (-0.03) zones and the lowest in the transitional zone (-0.22).

Table 4.19: Mean scores for adaptive capacity sub-composite indices in the study area

Livelihood assets	Agro-ecological zone				P-Value
	Arid (Yuku; n=39)	Semi-arid (Kauwi; n=160)	Transitional (Kasaini; n=38)	Semi-humid (Kaveta; n=104)	
Physical asset	-2.91 (5.20)	0.19 (1.89)	-0.08 (1.52)	0.85 (2.18)	<.001***
Human asset	-0.48 (1.05)	-0.18 (1.22)	-0.04 (1.39)	0.46 (1.72)	<.001***
Natural asset	1.78 (3.88)	1.58 (5.40)	0.38 (1.81)	-1.35 (1.51)	<.001***
Social asset	-0.16 (1.38)	-0.09 (1.06)	0.05 (1.81)	0.18 (1.45)	.36
Financial asset	-0.02 (0.47)	-0.03 (1.11)	-0.22 (0.79)	0.14 (1.58)	.44

Note: Figures in parenthesis indicate standard deviation and *** indicate significant at 1% level of significance.

4.2.4 Vulnerability index

The overall vulnerability index was calculated by adding exposure and sensitivity indices then subtracting the adaptive capacity index. The mean index values for vulnerability and its constituents in the four agro-ecological zones are presented in Figure 4.12. Additionally, results from one-way analysis of variance indicated that there was a statistically significant difference (p<.001) in the vulnerability index and its components' indices across the four agro-ecological zones.

A close examination of the results showed that the arid agro-ecological zone had the highest vulnerability index score (17.29) followed by the transitional (1.63) and semi-arid (1.49) zones while the semi-humid zone had the lowest score (-2.65). In terms of exposure, the results indicated that the transitional zone had the highest exposure index (0.87) followed by arid (0.51), semi-arid (0.45) and lastly the semi-humid (-0.93) zones. The sensitivity index mean score followed a decreasing order of arid (11.23), semi-arid (1.12), transitional (0.52) and semi-humid (-6.63) zones. Regarding adaptive capacity, the results showed that the highest adaptive capacity index mean score was registered in the semi-humid zone (1.09) followed by semi-arid (0.09) and transitional (-0.23) zones while the arid zone registered the lowest adaptive capacity index.

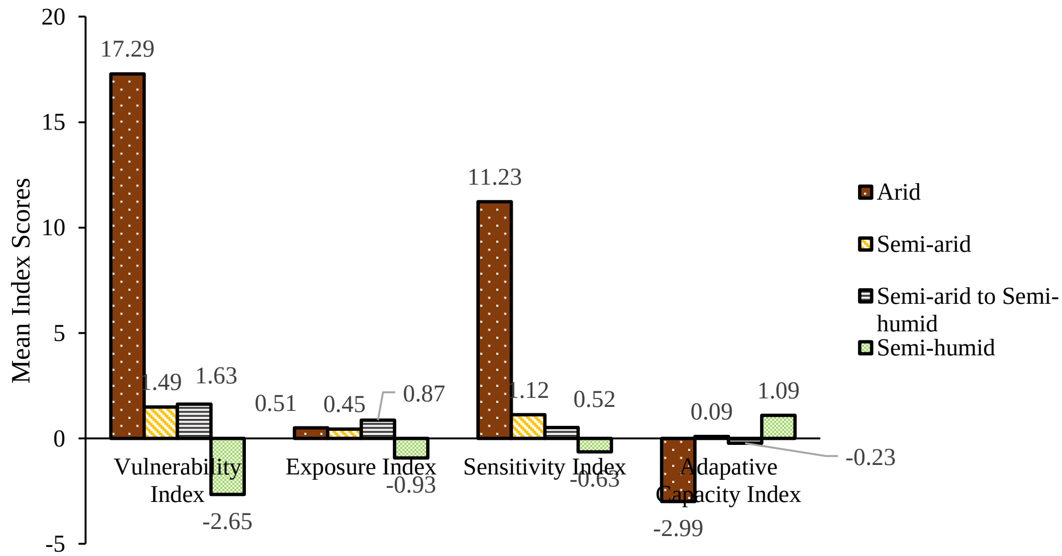

Figure 4.12: Mean index scores for vulnerability and its components in the study area

4.2.5 Vulnerability index quartiles

Inter-house quartile analysis of vulnerability indicated a descending order for the high vulnerability quartile of arid, transitional, semi-arid and semi-humid zones with respective values of 82%, 42%, 37% and 8% as shown in Figure 4.13. Conversely, the moderate vulnerability quartile had an ascending order of arid (15%), semi-arid (33%), transitional (34%) and semi-humid (41%). With regard to the low vulnerability quartile, the arid zone registered the lowest percentage (3%) followed by transitional (24%) and semi-arid zones while the semi-humid zone had the highest percentage (53%).

Further, the Chi-square test of independence results showed a statistically significant difference in the vulnerability quartiles across the four agro-ecological zones (X^2 (6, N = 341) = 83.40, p<.001).

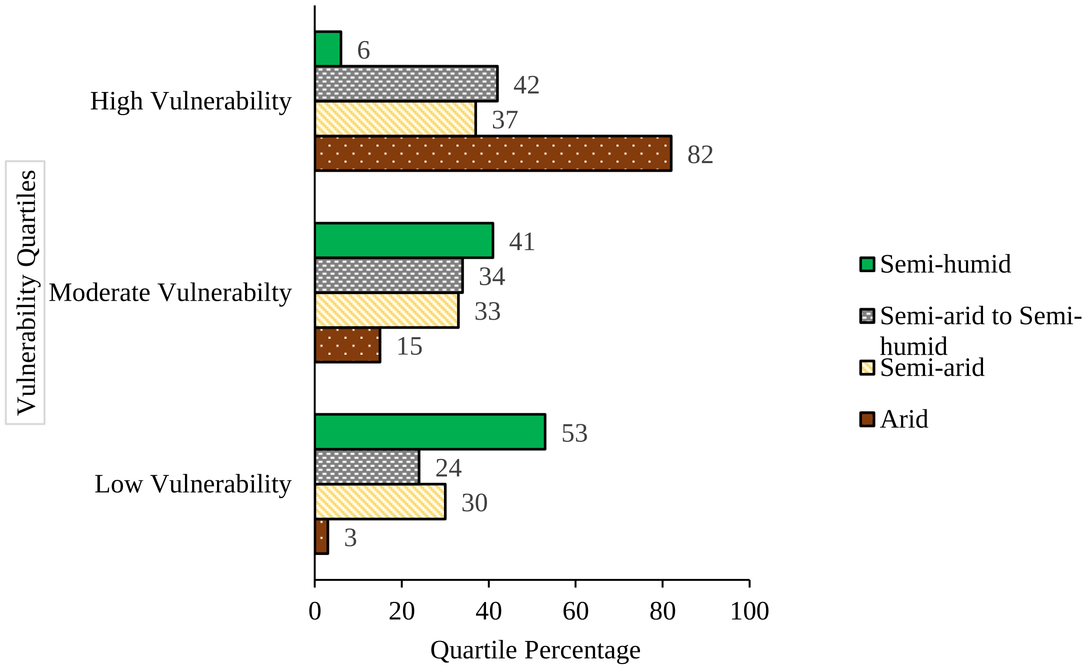

Figure 4.13: Vulnerability quartiles percentages in different agro-ecological zones in the study area

4.2.6 Spatial vulnerability of households to climate variability and extreme climate events in the study area

Maps were generated to show the spatial distribution of exposure, sensitivity and adaptive capacity and the total vulnerability indices in the different agro-ecological zones in the study area.

4.2.6.1 Exposure index map

The exposure map in Figure 4.14 indicated that the largest proportion of households in the transitional zone had high exposure levels followed by the arid and semi- arid zones while most households in the semi-humid zone had low exposure levels.

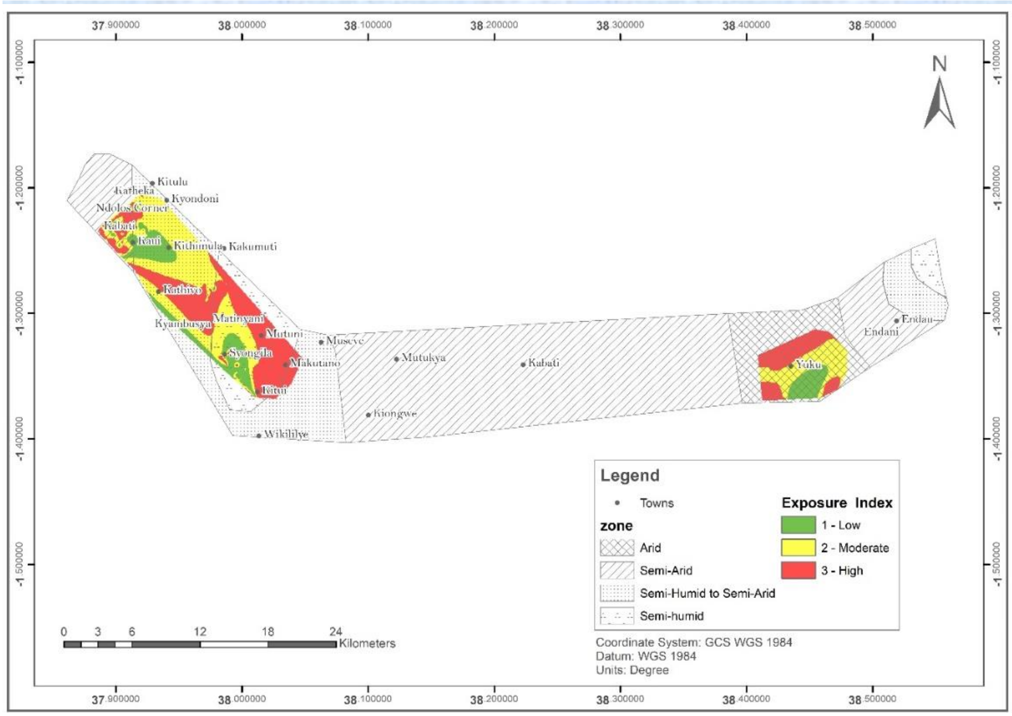

Figure 4.14: Spatial distribution of exposure index in different agro-ecological zones in the study area

Note: The uncolored region at the central part of the transect (between Makutano and Yuku) was not part of the study area.

4.2.6.2 Sensitivity index map

Examination of the sensitivity map revealed that the largest proportion of households with high sensitivity levels was in the arid zone followed by semi-arid and transitional zones while the semi-humid zone had the least proportion of households with high sensitivity levels and the largest proportion in the low sensitivity category as shown in Figure 4.15.

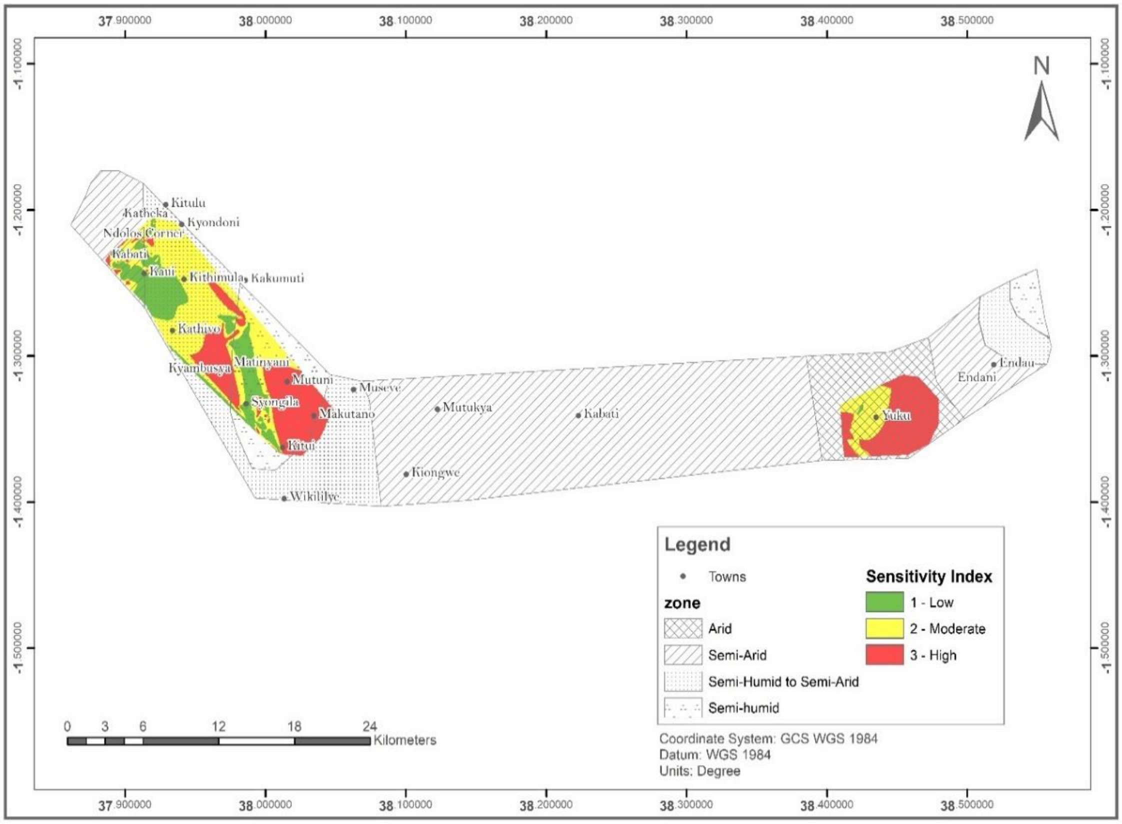

Figure 4.15: Spatial distribution of sensitivity index in different agro-ecological zones in the study area

Note: The uncolored region at the central part of the transect (between Makutano and Yuku) was not part of the study area

4.2.6.3 Adaptive capacity index map

Analysis of the adaptive capacity index map revealed that the semi-humid zone had the largest proportion of households with high adaptive capacity followed by the semi-arid and transitional zones while the arid zone had the largest proportion of households with low adaptive capacity as presented in Figure 4.16.

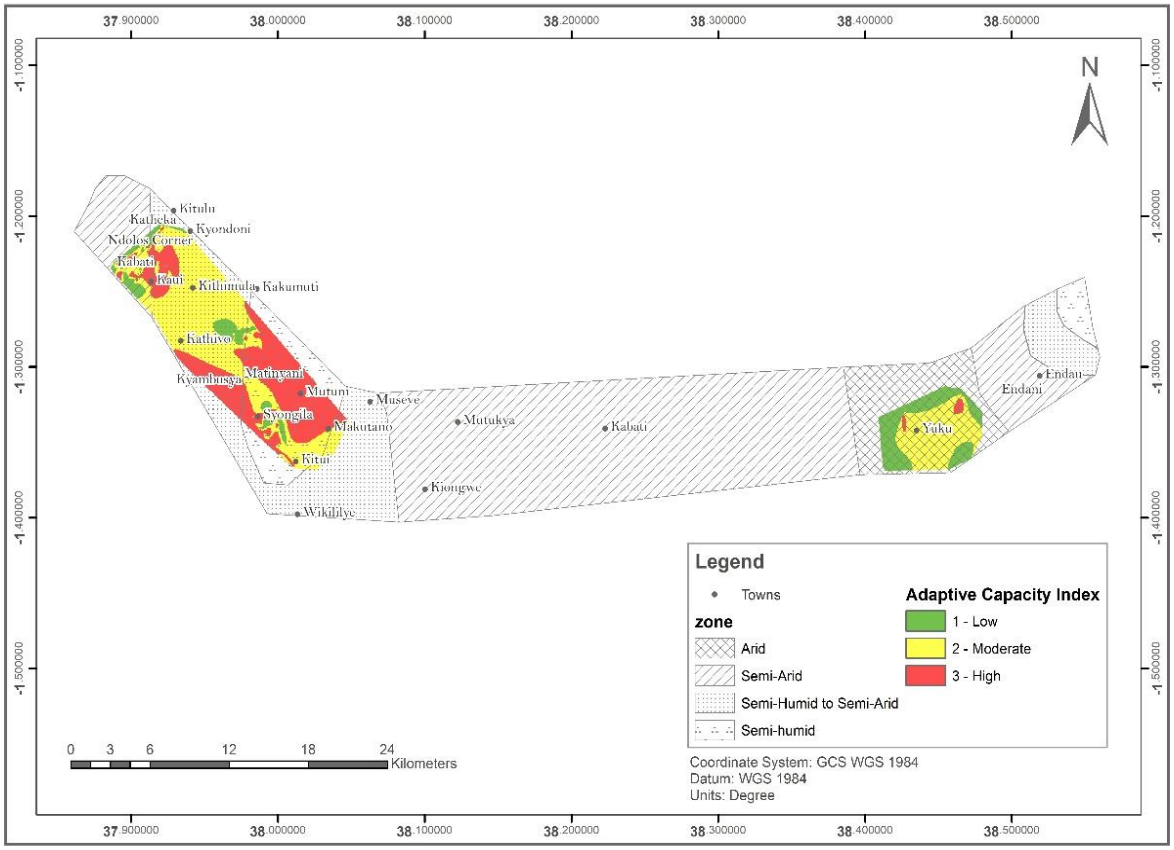

Figure 4.16: Spatial distribution of adaptive capacity index in different agro-ecological zones in the study area

Note: The blank region in the central part of the transect (between Makutano and Yuku) was not part of the study area.

4.2.6.4 Overall vulnerability index map

The overall vulnerability map of the study area is presented in Figure 4.17. A closer examination of the map highlighted that most households in the arid zone were highly vulnerable to climate variability and extreme climate events while the largest proportion of households in the semi-humid zone had low and moderate vulnerability levels. Additionally, the map indicated that a larger percentage of households in the moderately vulnerable category were from the semi-humid zone followed by the transitional and semi-arid zones. Further scrutiny of the map revealed some differences in the vulnerability categories of households even in the same agro-ecological zone.

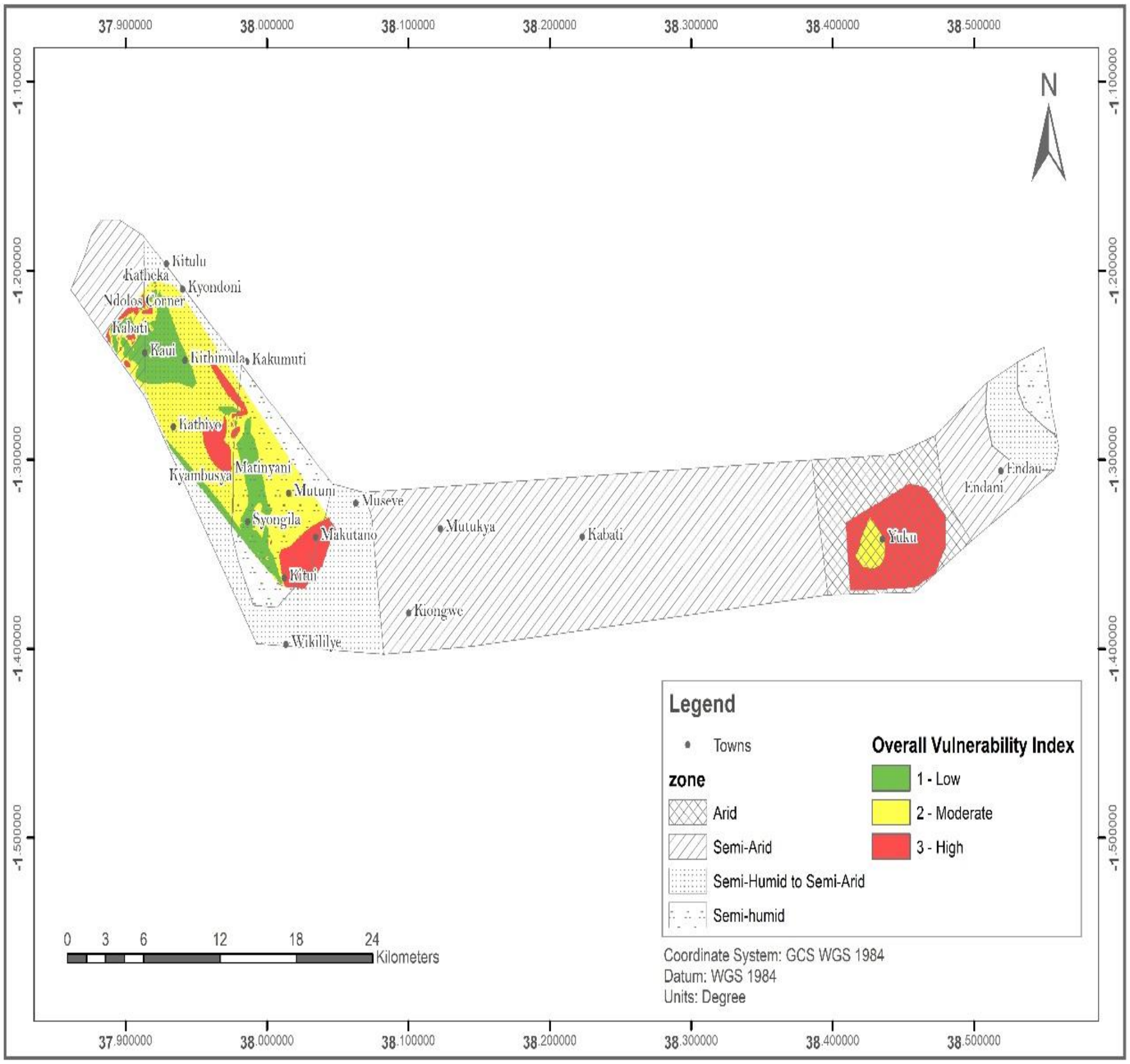

Figure 4.17: Spatial distribution of overall vulnerability index in different agro-ecological zones in the study area

Note: The uncolored region at the central part of the transect (between Makutano and Yuku) was not part of the study area

4.3 Predictive modeling of farmers' vulnerability to climate change and extreme climate events in the study area

Table 4.20 shows the results of the multinomial logistic regression analysis. As indicated in Appendix 3, the variance inflation factor (VIF) values for all explanatory variables were between 1 and 3, indicating that multicollinearity was not a worry. Multicollinearity concerns develop when the VIF value is larger than 10 (Yoo *et al.,* 2015). The results showed that household head's age ($p<.001$), proximity to market ($p<.001$) and arid agro-ecological zone ($p=.05$) significantly reduced the odds of a household belonging to the low vulnerability category relative to the high vulnerability category. On the other hand, the highest level of education in the household and semi-humid zone significantly ($p<.001$) increased the probability of a household belonging to the low vulnerability category relative to the high vulnerability category.

The results further showed that a unit increase in household head's age and distance from the nearest market significantly decreased the odds of a household belonging to the low vulnerability category relative to the high vulnerability category by 5% and 45%, respectively, while a unit increase in the number of schooling years increased the odds of a household belonging to the low vulnerability category by a factor of 0.20. This finding implied that households with elderly household heads and located far from the market were highly susceptible to climatic shocks compared to those with younger household heads and nearer to the market.

Additionally, the results revealed that the arid agro-ecological zone reduced the probability of a household belonging to the low vulnerability category relative to the high vulnerability category by a factor of 0.35 while the semi-humid agro-ecological zone reduced the probability of household belonging to the low vulnerability category by a factor of 2.93. The results imply that households in the arid agro-ecological zone are highly susceptible to climatic stressors as opposed to their counterparts in the semi-humid zone.

Further, the results indicated that the regression coefficients for household heads' gender (0.06), access to extension services (0.01) as well as access to credit facilities (0.04) were positive implying that they increased the odds of a household belonging to the low vulnerability category by 6%, 1% and 4%, respectively, while household size (-0.05) and land size (-0.07) had negative regression coefficients implying that they reduced the probability of a household belonging to the low vulnerability category by 5% and 7%, respectively. The influence of gender of the household head, access to extension services, access to credit facilities, household size and land size on households belonging to the low vulnerability category was however not significant at 5% significance level.

The second model results indicated that distance from the market ($p<.001$) and the arid agro-ecological zone ($p=.04$) significantly reduced the odds of households belonging to the moderate vulnerability category relative to the high vulnerability category by a factor of 0.28 and 1.36, respectively. Access to credit facilities ($p=.02$) and semi-humid agro-ecological zone ($p<.001$) on the other hand significantly increased the odds of a household belonging to the moderate vulnerability category relative to the high vulnerability category by a factor of 0.81 and 2.51, respectively.

Additionally, the results revealed that household head's gender and the highest level of education attained increased the probability of a household belonging to the moderate vulnerability category relative to the high vulnerability category by 20% and 6%, respectively. Further, access to extension services and household size increased the odds of a household belonging to the moderate vulnerability category relative to the high vulnerability category by a factor of 0.81 and 0.04, respectively. Moreover, the results indicated that household head's age and land size reduced the odds of a household belonging to the moderate vulnerability category relative to the high vulnerability category by 1%.

The influence of household head's gender, the highest level of education attained, access to extension services, household head's age, size of the household and land size on the moderate vulnerability category was however not significant at 5% significant level.

Table 4.20: Coefficient estimates of multinomial logistic regression model results on determinants of farmers' vulnerability to climate variability and extreme climate events in the study area

Explanatory Variables	Dependent Variable	
	Low Vulnerability	**Moderate Vulnerability**
Age	-0.05	-0.01
	(0.01)***	(0.01)
Gender	0.06	0.20
	(0.40)	(0.36)
Household size	-0.05	0.04
	(0.07)	(0.06)
Market distance	-0.45	-0.28
	(0.10) ***	(0.08) ***
Highest education level	0.20	0.06
	(0.05) ***	(0.04)
Land size	-0.07	-0.01
	(0.04)	(0.02)
Access to extension	0.01	0.50
services	(0.48)	(0.48)**
Access to credit facilities	0.04	0.81
	(0.37)	(0.35)**
Agro-ecological zone	-0.35	-0.36
(Arid)	(1.18) **	(0.66) **
Agro-ecological zone	2.93	2.51
(Semi-humid)	(0.37) ***	(0.63) ***

Note: Figures in parentheses are standard errors; ***, ** significant at 99% and 95% confidence levels, respectively.

4.4 Households' coping strategies to food insecurity and the determinants of households' choice of specific coping strategies in the study area

4.4.1 Households' coping strategies to food insecurity in the study area

Results from the study showed that majority of households in the study area had adopted several strategies to cope with food shortages resulting from the effects of climatic changes and extreme climate events as depicted in Table 4.21. Chi-square test results showed a statistically significant difference, at 99% confidence level, in households' use of off-income to buy food, food for work programmes, receiving relief food, selling livestock to buy food, selling forest products and reducing the number of meals per day across the four agro-ecological zones.

From the results, it was noted that most households from the arid (85%) and semi-arid (66%) zones used off-farm income to buy food compared to those in the transitional (58%) and semi-humid (53%) zones. The results also indicated that most households in the arid (90%) and semi-arid zones (68%) sold livestock to buy food as opposed to those in the transitional and semi-humid zones (43% and 66%, respectively).

Further scrutiny of the results revealed that a larger proportion of households in the arid and semi-arid zones (67% and 47%, respectively) reduced the number of meals per day to cope with food shortages compared to their counterparts in the semi-humid (37%) and transitional (32%) zones. Additionally, it was noted from the results that a larger proportion of households in the arid (49%) and semi-arid (34%) zones benefited from food assistance for assets programmes compared to their counterparts in the transitional (32%) and semi-humid (20%) zones. The results further indicated that a greater percentage of households in the arid zone (28%) were selling forest products such as charcoal, timber and firewood to cope with food shortage compared to the other zones.

Table 4.21: Households' coping strategies to food insecurity in the study area

Coping Strategy	Percentage adoption in different agro-ecological zones				X^2	P-Value
	Arid (Yuku)	Semi-arid (Kauwi)	Transitional (Kasaini)	Semi-humid (Kaveta)		
Use off-income to buy food	85	66	53	58	11.29	<.001***
Taking loans to buy food	10	9	18	11	2.59	.46
Food Assistance for Asset programmes	49	34	32	20	11.96	<.001***
Relying on relief food	46	68	66	22	55.85	<.001***
Selling livestock to buy food	90	68	65	43	30.12	<.001***
Seek off-farm employment	41	29	21	26	4.39	.22
Sell forest products	28	6	8	4	16.39	<.001***
Sell sand	5	3	0	1	3.40	.34
Reduce number of meals	62	44	37	32	11.4	<.001***
Sell family assets	54	40	21	27	13.96	<.001***

Note *** significant at 99% confidence level.

4.4.2 Determinants of households' choice of specific coping strategies to food insecurity in the study area

The multivariate Probit regression model was run in Stata version 12. The model's coefficient estimates are shown in Table 4.22. The null hypothesis for the model's test of independence was rejected because the likelihood ratio test (Log-likelihood = -889.28; Prob > 2 = 0.00) of error term independence was significant, implying that the coping strategies are mutually interdependent. This justifies the use of a multivariate probit regression model in assessing the predictors of households' choice of different coping strategies because it captures wider effects than a univariate probit regression model.

The pairwise correlation coefficients (Rho) in Table 4.22 likewise show a positive correlation between the pairings, with the majority of them being highly significant, showing that the coping methods sets are complementary. Multicollinearity was not an issue because the variance inflation factor (VIF) values for all the predictor variables were between 1 and 3 (Appendix 3). According to Yoo *et al.* (2015) multicollinearity concerns arise when the VIF value is more than 10. As presented in Table 4.23, marginal effects were utilized to measure the influence of the predictors on the dependent variables.

Table 4.22: Coefficient estimates of multivariate probit regression results on determinants of households' adoption of specific coping strategies in the study area

Explanatory Variables	Dependent Variables				
	Reduced food consumption	**Sell livestock to buy food**	**Seek off-farm jobs**	**Sell family assets**	**Sell forest product**
Age	-0.01 (0.01)	-0.01 (0.01)	-0.02 (0.01)**	0.02 (0.01)**	-0.01 (0.01)
Gender	0.49 (0.16)***	0.10 (0.16)	-0.39 (0.17)**	0.35 (0.16)**	0.02 (0.02)
Household size	0.07 (0.03)**	0.10 (0.03)***	0.01 (0.03)	0.07 (0.03)***	0.11 (0.04)***
Education level	0.01 (0.02)	-0.03 (0.02)*	0.01 (0.02)	-0.03 (0.02)*	0.03 (0.02)
Access to credit	0.13 (0.15)	0.06 (0.14)*	0.08 (0.16)	0.01 (0.15)	0.01 (0.20)
Distance to the nearest market	-0.06 (0.03)*	-0.03 (0.03)	0.03 (0.03)	-0.01 (0.02)	0.01 (0.02)*
Land size	0.03 (0.01)***	0.03 (0.01)**	-0.00 (0.01)	0.01 (0.01)	0.01 (0.01)
Constant	-1.22 (0.40)***	-0.20 (0.40)	0.84 (0.43)**	-0.53 (0.40)***	-2.34 (0.56)***
	Rho 1	Rho 2	Rho 3	Rho 4	Rho 5
Rho 2	0.12				
Rho 3	0.44***	0.03			
Rho 4	0.33***	0.04	0.29***		
Rho 5	0.38***	0.26***	0.48***	0.19**	

Number of obs = 341; Wald chi2(35) = 108.19 Log likelihood = -883.83 Prob > chi2 = 0.00 Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2 (10) = 94.67 Prob > chi2 = 0.00; Figures in parentheses are standard errors; ***, **, * significant at 99%, 95% and 90% confidence levels, respectively.

Table 4.23: Marginal effects of explanatory variables on the dependent variables in the model

Explanatory Variables	Dependent Variables				
	Reduced food consumption	**Sell livestock to buy food**	**Seek off-farm jobs to buy food**	**Sell family assets**	**Sell forest products**
Age	-0.00	-0.00	-0.01	0.01	-0.00
	(0.00)	(0.00)	(0.01)***	(0.01)*	(0.00)
Gender	0.18	0.03	-0.12	0.12	-0.00
	(0.06)***	(0.06)	(0.05)	(0.05)**	(0.04)***
Household size	0.02	0.03	-0.00	0.02	-0.02
	(0.01)**	(0.01)***	(0.01)	(0.01)**	(0.01)***
Education level	0.00	-0.01	0.01	-0.01	0.01
	(0.17)	(0.01)*	(0.01)	(0.01)*	(0.01)
Access to credit	0.05	0.03	0.04	0.01	-0.01
	(0.05)	(0.16)*	(0.01)	(0.05)	(0.03)
Distance to the nearest market	-0.02	0.02	-0.01	-0.01	0.01
	(0.01)**	(0.01)**	(0.01)	(0.01)	(0.01)
Land size	0.01	0.02	-0.04	0.01	-0.01
	(0.00)***	(0.01)***	(0.00)	(0.01)	(0.01)**

Note: Figures in parentheses are standard errors; ***, **, * significant at 99%, 95% and 90% confidence levels, respectively.

The multivariate probit regression results showed that household head's age had a negative influence on the adoption of all coping strategies except selling family assets. The results revealed that the age of the household head had a significant positive and negative significant influence on the adoption of seeking off-farm jobs and selling family assets, respectively. The marginal effects showed that a unit increase in the age of the household head increased the probability of selling family assets while reducing that of seeking off-farm jobs by 1%.

Gender of the household head had a positive influence on reducing food consumption, selling livestock, selling family assets and selling forest products to buy food. The influence of gender of the household head was however negative on the adoption of seeking off-farm jobs. Further, the results indicated that the influence of the gender of the household head was significant on the adoption of selling family assets, reducing food consumption and seeking off-farm jobs with marginal effects of 0.12, 0.18, and 0.12, respectively. This implies that male-headed households were more likely to adopt selling of family assets and reduction of food consumption by 12% and 18%, respectively, compared to female-headed households which were 12% more likely to seek off-farm income to feed their households in times of food shortage.

As expected, household size had a significant positive influence on the adoption of reduction of food consumption and selling of livestock, family assets and forest products to buy food. From the results of the marginal effects, a unit increase in household size increased the probability of adopting reduction of food consumption, selling of family assets and forest products by 2% and that of adopting sale of livestock by 3%.

Regarding the education level of the household head, the results showed a significant negative influence on the adoption of selling of livestock and family assets to buy food with marginal effects of 0.01 on both coping strategies. The results imply that a unit increase in the number of schooling years of the household head reduced the probability of selling livestock and family assets to buy food by 1%. The results further indicated that access to credit facilities had a significant positive influence on the adoption of the sale of livestock to buy food with a marginal effect of 0.03. The results imply that households with access to credit were 0.03 times more likely to adopt selling of livestock as a coping strategy than households without access to credit facilities.

Additionally, distance to the market had a significant negative and positive influence on the adoption of reduction of food consumption and selling of forest products, respectively. It had a marginal effect of 0.02 on the adoption of reducing food consumption while that of forest products was 0.01 implying that a unit increase in distance to the nearest market reduced the adoption of reduction of food consumption as a food insecurity coping strategy by 2%. Similarly, it increased the adoption of selling forest products by 1%. Lastly, the results indicated that land size had a significant positive influence on the adoption of selling of livestock to buy food and reduction of food consumption with marginal effects of 0.02 and 0.01, respectively.

4.5 Farmers' adaptation strategies in response to climate variability and extreme climate events and determinants' of farmers' choice of specific adaptation strategies in the study area

4.5.1 Farmers' adaptation strategies in response to climate variability and extreme climate events

Results from the chi-square test of independence analysis indicated a statistically significant difference at 5% significance level in the farmers' adoption of mixed farming systems, use of improved crop varieties, use of manure, use of fertilizers, practicing irrigation, agroforestry, planting trees for shade and moving herds in search of pasture across the four agro-ecological zones.

Close analysis of the results indicated that a higher percentage of households in the arid (87%) and semi-arid (78%) zones practiced mixed crop and livestock farming systems compared to those in the transitional (71%) and semi-humid (62%) zones. It was evident that there was a low adoption of irrigation in all the zones with the lowest adoption reported in the arid (3%) and semi-arid (4%) zones. Similarly, farmers in the arid zone reported low adoption of planting trees for shade (26%) and agroforestry (18%) as opposed to the other three zones where most of the respondents had adopted the strategies.

With regard to livestock production, the most common adaptation strategies adopted by the farmers in the study area were reducing the number of livestock and seeking services from veterinary officers. Further scrutiny of the results however indicated that there was no significant difference, at 5% significance level in the adoption of reducing the number of livestock and seeking services from veterinary officers cross the four agro-ecological zones.

Table 4.24: Farmers' adaptation strategies in response to climate variability in the study area

Adaptation Strategies	Percentage adoption in different agro-ecological zones				X^2	P-Value
	Arid (Yuku Sub-location)	Semi-arid (Kauwi Sub-location)	Transitional (Kasaini Sub-location)	Semi-humid (Kaveta Sub-location)		
Switch from livestock to crop farming	10	9	11	17	4.63	.20
Mixed farming	87	78	71	62	13.20	<0.001***
Crop diversification	72	70	68	69	0.13	.99
Drought tolerant crop varieties	77	66	68	61	3.54	0.31
Improved crop varieties	31	68	55	65	16.34	.00***
Changing planting times	82	72	71	73	1.68	.64
Soil conservation techniques	69	68	79	79	5.10	.17
Use of manure	49	89	82	80	32.27	<0.001***
Use of fertilizers	3	9	50	56	92.70	<0.001***
Use pesticides	59	69	84	75	7.00	.07
Integrated Pest Management	28	44	40	56	9.87	.02
Water harvesting	31	34	24	47	8.59	.04
Water re-use	28	42	40	49	5.25	.16
Irrigation	3	4	11	18	17.01	<0.001***
Agroforestry	18	69	84	75	54.36	<0.001***
Plant shade trees	26	58	74	75	32.26	<0.001***
Reduce number of livestock	54	36	34	39	4.75	.19
Increase livestock diversity	5	8	11	4	2.62	.45
Animal feed supplements	8	15	11	17	2.65	.45
Seek veterinary services	54	34	42	43	5.75	.13

Note * Significant at 99% confidence level

4.5.2 Determinants of farmers' choice of specific adaptation strategies to climate variability and extreme climate events in the study area

The coefficient estimates of the multivariate probit model are presented in Table 4.25. The null hypothesis for the test of independence in the model was rejected since the likelihood ratio test (*Log-likelihood = -1394.05*; Prob > $\chi 2$ = 0.00) of independence of error terms was significant implying that there is mutual interdependence among the adaptation strategies and thereby justifying the use of multivariate probit regression model in assessing the determinants of farmers' choice of different adaptation strategies as it captures wider effects than a univariate probit model could obtain.

The pairwise correlation coefficients (Rho) shown in Table 4.26 also indicate a positive correlation between the pairs most of which are highly significant implying that the sets of adaptation strategies are complimentary. Variance inflation factor (VIF) values for all the explanatory variables were between 1 and 3 as shown in Appendix 3 implying that multicollinearity was not a concern since according to Yoo *et al.* (2015) multicollinearity concerns exist when the VIF value is greater than 10. The marginal effects presented in Table 4.27 were used to quantify the influence of explanatory variables on the dependent variables in the model.

Table 4.25: Coefficient estimates of multivariate probit regression results on determinants of farmers' choice of specific adaptation strategies in the study area

Explanatory variables	Dependent Variables							
	Crop diversification	**Drought resilient crops**	**Hybrid crop varieties**	**Soil conservation techniques**	**Use of fertilizer**	**Use of manure**	**Agroforestry**	**Use of Pesticides**
Age	-0.02 (0.01)**	-0.01 (0.01)	-0.00 (0.01)	-0.02 (0.01)**	-0.00 (0.00)	0.00 (0.01)	-0.01 (0.01)*	-0.01 (0.01)
Gender	0.32 (0.18)**	0.20 (0.17)	-0.11 (0.17)	0.25 (0.19)*	-0.46 (0.18)***	0.30 (0.19)*	0.25 (0.16)*	-0.37 (0.17)**
Household size	-0.05 (0.03)	0.04 (0.03)	-0.03 (0.03)	-0.06 (0.03)**	-0.01 (0.03)	0.00 (0.03)	-0.04 (0.03)	-0.03 (0.03)
Farmers' group membership	0.16 (0.23)	-0.31 (0.21)	-0.42 (0.21)**	0.57 (0.27)**	-0.09 (0.22)	-0.42 (0.24)*	0.21 (0.21)	0.27 (0.24)
Farming experience	0.01 (0.01)*	0.01 (0.01)	0.00 (0.01)	0.01 (0.01)*	0.00 (0.01)	-0.01 (0.01)	0.01 (0.01)	0.00 (0.01)
Education level	-0.00 (0.17)	0.02 (0.02)	0.07 (0.02)***	0.06 (0.02)***	0.01 (0.17)	0.06 (0.02)***	0.05 (0.02)***	0.05 (0.02)**
Access to credit	0.19 (0.17)	0.30 (0.16)*	0.08 (0.16)	-0.01 (0.17)	0.05 (0.16)	0.14 (0.19)	0.04 (0.15)	0.15 (0.17)
Access to extension services	0.17 (0.23)	0.51 (0.23)**	-0.30 (0.21)	0.43 (0.26)*	0.31 (0.21)*	0.34 (0.26)	0.41 (0.21)**	0.28 (0.23)
Distance to the nearest market	-0.03 (0.02)*	-0.02 (0.02)	-0.13 (0.03)***	-0.06 (0.02)***	-0.04 (0.03)*	0.01 (0.40)	-0.02 (0.02)	-0.09 (0.03)***
Access to weather information	-0.37 (0.18)	-0.11 (0.17)	-0.04 (0.17)	-0.38 (0.19)	0.27 (0.19)	-0.10 (0.19)	0.15 (0.16)	-0.07 (0.17)
Land size	0.01 (0.01)	0.03 (0.01)**	-0.00 (0.01)	0.01 (0.01)	-0.03 (0.01)**	-0.00 (0.01)	-0.01 (0.01)	-0.02 (0.02
Constant	1.18 (0.45)***	-0.10 (0.43)	0.47 (0.43)	0.91 (0.47)**	-0.45 (0.46)	-0.08 (0.48)	-0.52 (0.43)**	0.91 (0.46)**

Note: Figures in parentheses are standard errors; ***, **, * significant at 99%, 95% and 90% confidence levels, respectively.

Table 4.26: Pairwise correlation coefficients (Rho) of the dependent variables

	Rho 1	Rho 2	Rho 3	Rho 4	Rho 5	Rho 6	Rho 7	Rho 8
Rho 2	0.30***							
Rho 3	0.29***	0.19***						
Rho 4	0.01	0.10*	0.14*	0.01				
Rho 5	0.50***	0.31***	0.21***	0.08*				
Rho 6	0.01	0.13*	0.25***	0.16***	0.05			
Rho 7	0.26***	0.08*	0.13***	0.19***	0.24***	0.11**		
Rho 8	0.31	0.10*	0.28***	0.06	0.32***	0.10*	0.31***	

Number of observations = 341; Wald chi^2 (88) = 204.71; Log likelihood = -1394.05; Prob > chi2 = 0.00;

***, **, * significant at 99%, 95% and 90% confidence levels, respectively.

Table 4.27: Marginal effects of explanatory variables on dependent variables

Explanatory variables	Dependent Variables							
	Crop diversification	**Drought resilient crops**	**Hybrid crop varieties**	**Soil conservation techniques**	**Use of fertilizer**	**Use of manure**	**Agroforestry**	**Use of pesticides**
Age	-0.01 (0.05)**	-0.01 (0.01)	0.01 (0.01)	0.08 (0.05)	0.00 (0.00)	0.00 (0.00)	-0.01 (0.01)**	-0.01 (0.01)
Gender	0.12 (0.04)**	0.07 (0.06)	0.04 (0.06)	-0.01 (0.01)**	-0.15 (0.06)***	0.07 (0.05)*	0.09 (0.16)*	-0.11 (0.01)**
Household size	-0.02 (0.06)*	0.01 (0.01)	-0.01 (0.01)	-0.02 (0.01)**	-0.01 (0.01)	0.01 (0.01)	-0.02 (0.01)	-0.01 (0.01)
Farmers' group membership	0.06 (0.44)	-0.11 (0.07)	-0.13 (0.07)	0.17 (0.07)**	-0.01 (0.07)	-0.10 (0.06)*	0.08 (0.08)	0.08 (0.07)
Farming experience	0.01 (0.01)**	0.01 (0.01)*	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)	-0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Education level	-0.01 (0.01)	0.01 (0.01)	0.02 (0.01)***	0.01 (0.01)***	0.01 (0.01)*	0.02 (0.01)***	0.02 (0.01)***	0.01 (0.01)**
Access to credit	0.05 (0.05)	0.09 (0.05)*	0.03 (0.05)	0.01 (0.05)	0.01 (0.05)	0.03 (0.05)	0.00 (0.00)	0.04 (0.05)
Access to extension services	0.06 (0.07)	0.17 (0.08)**	-0.11 (0.07)	0.10 (0.07)	0.09 (0.07)	0.08 (0.07)	0.16 (0.07)**	0.09 (0.07)
Distance to the nearest market	-0.01 (0.06)*	-0.01 (0.01)	-0.05 (0.01)	-0.02 (0.01)***	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.04 (0.01)***
Access to weather information	-0.12 (0.01)	-0.03 (0.06)	-0.01 (0.06)	-0.10 (0.05)	0.01 (0.01)	-0.02 (0.05)	0.06 (0.06)	0.05 (0.05)
Land size	0.01 (0.01)	0.01 (0.01)**	-0.01 (0.01)	0.01 -(0.01)	-0.01 (0.01)	$7.84e^{-06}$ (0.00)	-0.01 (0.01)	0.01 (0.00)

Note: Figures in parentheses are standard errors; ***, **, * significant at 99%, 95% and 90% confidence levels, respectively.

Scrutiny of the multivariate probit regression results indicated that the age of the household head had a positive but insignificant influence on the adoption of the use of manure. There was however a negative influence of the household head's age on the adoption of crop diversification, planting drought-resilient crops, planting hybrid crop varieties, soil conservation techniques, agroforestry and use of pesticides. The influence of the household head's age was however only significant on the adoption of crop diversification, soil conservation measures and agroforestry. Further, analysis of the results of the marginal effect indicated that a unit increase in age of the household head decreased the likelihood of adopting crop diversification, soil conservation techniques and agroforestry by factors of 0.01, 0.08 and 0.01, respectively.

Further, the model results revealed that household head's gender significantly decreased the probability of fertilizers' and pesticides' adoption with female-headed households being 15% and 11% times more likely to adopt the use of fertilizers and pesticides, respectively, in comparison with their male counterparts. Additionally, the results indicated that the size of the household had a positive but insignificant association with a farmer's likelihood of adopting drought-resilient crop varieties. The results however showed that the influence of household size on the adoption of crop diversification, soil conservation technologies, hybrid crop varieties, agroforestry and use of pesticides and fertilizers was negative. Moreover, the results indicated that the influence of household size was statistically significant only on the adoption of soil conservation technologies with a marginal effect of 0.02 implying that a unit increase in household size decreased the odds of farmers' adoption of soil conservation measures by a factor of 0.02.

Additionally, the results pointed out a negative but nonsignificant influence of membership to a farmers' organization on the probability of farmers adopting planting of drought-resilient crop varieties, hybrid crop varieties as well as the application of both manure and fertilizers. A positive effect of membership to a farmers' organization was however reported on the probability of adopting soil conservation practices, pesticides, crop diversification and agroforestry. From the analysis of the marginal effects, membership in a farmers' organization significantly reduced the probability of planting improved crop varieties by a factor of by 0.13 while significantly increasing the odds of soil conservation technology adoption by 17%.

The results further revealed that farming experience significantly increased the likelihood of adopting all the adaptation techniques, except for manure use, where the influence was insignificantly negative. With marginal effects of 0.01 on each, farming experience significantly increased the probability of crop diversification and implementing different measures to conserve soil. The results implied that as farming experience increased, the likelihood of diversifying crop varieties and implementing different measures to conserve soil increased by 1%.

Additionally, the results revealed that except for crop diversification, the education level of the head of the household had a significant influence on the adoption of all the adaptation strategies. With marginal effects of 0.02, 0.01, 0.02, 0.02 and 0.01, respectively, the results revealed that the household head’s education level significantly increased the probability of planting hybrid crops, conserving soil, application of manure, agroforestry and pesticide use. The results implied that increasing the household head's education level increased the likelihood of using hybrid crop varieties, conserving soil, manure application, agroforestry and pesticide use by 2%, 1%, 2%, 2%, and 1%, respectively.

Moreover, the results indicated that access to credit facilities had a positive influence on the adoption of all the strategies except for soil conservation techniques. The influence of access to credit facilities was significant on the adoption of drought-resilient crops with a marginal effect of 0.09 implying that farmers with access to credit facilities were 0.09 times more likely to adopt drought-resilient crops than those without access to credit facilities.
Except for the use of hybrid crop varieties, access to extension services had a significant influence on the farmers’ probability of adopting all the adaptation strategies. Analysis of the results revealed that access to extension services significantly increased the likelihood of farmers’ adoption of drought-resistant crops, soil conservation techniques, use of fertilizers and agroforestry. Further, the marginal effects results showed that access to extension services increased the odds of adopting drought-resilient crops, soil conservation techniques, use of fertilizers and agroforestry adoption by 17%, 10%, 9 %, and 16%, respectively. Regarding access to weather information, a significant negative influence was reported on the adoption of all the adaptation strategies except for the usage of fertilizers and agroforestry.

Additionally, the results showed that, except for manure use, distance to the nearest market had a negative influence on the adoption of all adaptation techniques, meaning that ease of access to the market improved farmers' likelihood of adopting the various adaptation strategies. The marginal effects results indicated that a unit increase in distance from the market significantly decreased the chances of adopting crop diversification, use of hybrid crop varieties, soil conservation techniques, fertilizers, agroforestry and pesticides by 1%, 5%, 2%, 1%, 1% and 4%, respectively.

Finally, the results indicated a positive relationship between land size and the adoption of crop diversification, drought-resilient crops and soil conservation techniques. A negative effect was however reported on the adoption of hybrid crop varieties, use of fertilizers, manure, agroforestry and pesticides. Examination of the marginal effects revealed that unit increase in land size significantly increased the odds of adopting drought-resilient crops while decreasing that of adopting the use of fertilizers by 1%.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Rainfall and temperature trends and variability in the study area

5.1.1 Rainfall trends and variability in the study area

The results established that there was an insignificant declining trend in annual rainfall in all the four agro-ecological zones in the study area. This could be attributed to the current changes in the climate system resulting from global warming. Significant warming trends have been reported in Eastern Africa and could be linked to the decreasing rainfall trend in the region (Christensen *et al.,* 2007; Niang *et al.,* 2014; Williams and Funk, 2010). The decreasing trend in rainfall in the study area could result to frequent occurrence of drought incidences causing a significant reduction in crop yields as well as pasture and water shortage for livestock production which are key sources of livelihood in the region. The findings are in consonance with results from a similar study by Aduma *et al.* (2018) which indicated a non-significant declining trend in annual rainfall in the Amboseli Ecosystem of Kenya. A similar trend in annual rainfall was also recorded along the Coastal Tanzania by Mahongo and Francis (2012). Additionally, the results of this study are in agreement with IPCC projections which indicated '*very likely'* reductions in annual rainfall in most parts of Africa with a general decrease in the 20th century being experienced in many arid and semi-arid regions in Africa (Collins *et al.*, 2013; Niang *et al.,* 2014).

Seasonal rainfall trends analysis results revealed a decreasing trend in the March-April-May (MAM) seasonal rainfall, which is also known as the "long rains" (Camberlin and Okoola, 2003) in the arid and semi-arid agro-ecological zones and an increasing trend in the transitional and semi-humid zones. The findings point out the spatial variation in the "long rains" which implies that while there has been a decreasing trend in the drier zones (the arid and semi-arid zones), an increasing trend has been reported in the wetter zones (transitional and semi-humid zones). The differential trends in the "long rains" could be due to the fact that a warming atmosphere is likely to cause higher evapotranspiration rates in wetter regions owing to their higher moisture content and vegetation resulting in more cloud formation and thus more precipitation in wetter zones compared to the drier zones (Christensen *et al.,* 2007; Collins *et al.,* 2013; Trenberth *et al.*, 2007). Conversely, increasing temperatures in drier regions are likely to cause additional drying of vegetation and water bodies leading to reduced evapotranspiration rates thus resulting in reduced precipitation in the drier zones (Dai *et al.,* 2004; Trenberth *et al.,* 2007). The results corroborate findings from similar research by Gebrechorkos *et al.* (2019) which showed that whereas there was a non-significant declining trend in MAM seasonal precipitation in the eastern regions of Kenya and Ethiopia, an insignificant upward trend in MAM seasonal precipitation was recorded in the western regions of both countries. Vondou *et al.*(2021) also reported both increasing and decreasing trends in rainfall patterns in different agro-ecological zones in Cameroon.

In regard to the October-November-December (OND) seasonal rainfall, also known as the “short rains” (Camberlin and Okoola, 2003), the results revealed a non-significant decreasing trend in the four agro-ecological zones implying a reduction in the amount of “short rains” with time. The decreasing trend in “short rains” could be due to the reduction in moisture in all the zones following a long dry period between the long and “short rains” coupled with increasing temperature resulting from global warming, consequently reducing evapotranspiration rates which in turn lead to reduced precipitation. The decreasing trend in the OND rainfall poses a threat to food security in the study area since it is considered the most reliable season for rain-fed agriculture in the region. The results of this study are concurrent with findings from Mutua and Runguma (2012) which indicated a significant increase in the OND seasonal rainfall in Nairobi and Embu since the 1970s. Similar studies by Gebrechorkos *et al.* (2019) and Opiyo *et al.* (2014b) have also noted an increasing trend OND seasonal rainfall in western parts of Kenya (Bungoma and Kisumu) and Turkana, respectively.

Additionally, the results indicated that there was high inter-annual and seasonal precipitation variability in all the agro-ecological zones as indicated by the coefficient of variation values. A coefficient of variation (CV) larger than 30% indicates high variability (Araya and Stroosnijder, 2011). Inter-annual and seasonal precipitation variability in East Africa has been attributed to El-Nino Southern Oscillation (ENSO) climate variability

(Indeje *et al.,* 2000; Mutemi, 2003; Muthama *et al.,* 2014) as well as the increasing warming of the global climate (Schreck and Semazzi, 2004).

From the results, it was noted that the arid zone had the highest coefficient of variation for annual rainfall followed by the semi-humid and semi-arid zones while the transitional zone had the lowest. This finding implies that there is higher annual rainfall variability in the drier (arid) and wetter (semi-humid) zones compared to that in zones with intermediate climatic characteristics (semi-arid and transitional zones). The difference in rainfall variability in the zones could be because increasing temperatures are likely to result in large changes in the hydrological processes such as evapotranspiration and precipitation. Changes in these processes could extreme weather events with incidences of intense precipitation in the wetter zones and increased droughts incidences in the drier zones. On the other hand, rising temperatures are likely to have a moderate effect on the hydrological processes in the intermediate zones therefore resulting in less intense extreme weather events (Bates *et al.,* 2008; Dai *et al.,* 2004; Trenberth *et al.,* 2007). High rainfall variability is likely to cause incidences of weather anomalies such as droughts and floods which pose a significant threat to livelihoods in the study area due to their reliance on climate-sensitive natural resources. A similar finding of spatially different and high annual rainfall variability was reported by Tesfamariam *et al.* (2019) in different agro-ecologies in the rift valley lakes of Ethiopia. The results also corroborate findings from a similar study by Koskei *et al.* (2018) who reported high and varying annual rainfall variability in different agro-ecological zones in Baringo County, Kenya.

In regard to rainfall variability, the highest variability was reported in the arid zone followed by the semi-arid and semi-humid zones while the transitional zone had the lowest implying that MAM seasonal rainfall variability was higher in the arid, semi-arid and semi-humid zones compared to the transitional zone. The higher variability in arid and semi-arid zones could be probably due to the relatively higher temperatures in the arid and semi-arid lands compared to that in the wetter zones while the higher variability in semi-humid zone relative to the transitional zone could be attributed to higher moisture levels in the zone compared to those in the transitional zone.

Further, the results showed that the coefficient of variation for the OND seasonal rainfall was highest in the semi-humid zone followed by transitional and semi-arid zones while the arid zone had the lowest. The higher rainfall variability in the OND season in the semi-humid and transitional zones compared to the semi-arid and arid zones could be probably because of relatively higher moisture levels in the wetter zones compared to that in the drier zones resulting from the long dry period in between the long and "short rains". This causes more drying of water sources and vegetation in the arid and semi-arid zones compared to the wetter zones. The finding implies that location-specific analysis of rainfall variability should inform the design and execution of suitable adaptation measures for effective and successful climate variability response. The current study's results are consistent with findings by Ayanlade *et al.* (2018) which indicated a high and varying rainfall variability in growing seasons in the Rainforest and Guinea savanna agro-climatic zones in Nigeria. Similarly, Kisaka *et al.* (2015) reported high variability in both MAM and OND rainfall in different agro-ecological zones in Embu County, Eastern Kenya.

Further, the results indicated that the coefficient of variation for the OND seasonal precipitation was higher than that of MAM seasonal precipitation in all the agro-ecological zones except for the arid zone probably due to higher temperatures in the dry season between the long and short seasons since increasing temperatures are likely to cause high variability in rainfall patterns (Christensen *et al.*, 2007; Niang *et al.*, *2*014; Trenberth *et al.*, 2007). Additionally, around 50% of OND rainfall variability in Kenya could be attributed to the El Niño/Southern Oscillation (ENSO) which however has a very low influence on the MAM season (Muthama *et al.*, 2014). The higher rainfall variability in the OND seasonal rainfall compared to that in MAM seasonal rainfall in the research area could be a serious threat to food security since the OND seasonal rainfall is considered the main and most reliable season for crop production in the region. The results corroborate findings by Gummadi *et al.* (2020) which indicated an increasing variability in the OND seasonal rainfall in Embu County, Kenya.

5.1.2 Temperature trends and variability in the study area

Trend analysis results indicated a statistically significant upward trend in average annual maximum and minimum temperatures in all the four agro-ecological zones. A similar trend was recorded for OND seasonal average maximum and minimum temperatures in all the agro-ecological zones. An increasing but non-significant trend in average maximum and minimum temperatures for the MAM season was also recorded in all the agro-ecological zones. The rising temperature trend in the study area could be due to the current warming of the globe resulting from the rising GHGs concentration in the atmosphere where IPCC projections show that mean annual temperature rise is likely to surpass 2°C above the late 20th-century baseline in African regions in the middle of the 21st century and 4°C at the end of the 21st century (Niang *et al.*, 2014).

Coupled with decreasing rainfall trends, increasing temperatures are likely to cause increased and prolonged dry spells intensifying reduction in crop yields, scarcity of pasture and water shortage thereby threatening food security in the study area. The findings are in consonance with those from a study by Marigi *et al.* (2016) which showed a significant increasing temperature trend in South Eastern Kenya. Further, the current trend of results corroborates findings from similar studies (Asfaw *et al.*, 2017; Bobadoye *et al.*, 2014; Muhati *et al.*, 2018; Yvonne *et al.*, 2020).

In regard to temperature variability, the results established that there was low temperature variability in the study area (CV<30%) in all the agro-ecological zones compared to rainfall variability. This could be because according to Huntingford *et al.* (2013) changes in temperature means do not always imply a rise in temperature variability. Further, Pendergrass *et al.* (2017) noted that the magnitude of precipitation variability increases with change in mean precipitation as opposed to temperature variability which does not change systematically with warming. The current study's findings corroborate those from a similar study by Ngare *et al.* (2020) who reported low temperature variability as opposed to high rainfall variability in Kenya's Coastal region of Mombasa. Similarly, Kigomo *et al.* (2020) reported low inter-annual temperature variability in South West Mau Forest in Kenya.

5.2 Farmers' vulnerability to climate variability and extreme climate events in the study area

5.2.1 Exposure indicators

The results indicated that the variability in annual mean maximum and minimum temperatures, and annual mean precipitation, droughts, strong winds and livestock disease outbreaks had a positive relationship with exposure index implying that they increased the exposure of households in the study to climate variability and extreme climate events. The findings however indicated that floods had a negative influence on the exposure index implying that the occurrence of flood incidences in the study area reduced households' exposure to climate variability and extreme climate events. This could be probably because being an Arid and Semi-arid Land (ASAL), the occurrence of floods in the study area could increase soil moisture for rain-fed agriculture as well as availing water for livestock and irrigated agriculture thereby having a positive effect on agricultural productivity.

The results corroborate findings by Piya *et al.* (2012) which showed that the rates of change in minimum temperature and precipitation as well as the number of natural disasters such as droughts contributed positively to the exposure index. Similarly, a study carried out in the mid-hills of Himachal Pradesh, India by Ndungu *et al.* (2015) indicated that droughts had a positive relationship with the exposure index. The present study's findings however contradict results from similar studies by Ndungu *et al.* (2015) and Piya *et al.* (2012) that indicated a positive relationship of floods with exposure index in study regions with sub-tropical to temperate climatic conditions.

The findings further established that the coefficient of variation for annual mean maximum temperature had the highest influence on exposure index followed by the coefficient of variation in average annual minimum temperature, droughts, strong winds, floods, coefficient of variation for average annual rainfall and livestock disease outbreaks. The results imply that temperature variability has a higher influence on the exposure index compared to rainfall variability while droughts have a higher influence on the exposure index compared to the other natural disasters in the study area. The possible explanation for the higher influence of temperature variability on the exposure index could be higher temperature variability influences rainfall patterns and the occurrence of other natural disasters such as droughts, floods and livestock disease outbreaks. Further, the study area being an ASAL, droughts incidences are likely to cause adverse effects on people's livelihoods in comparison with the other natural disasters. The influence of temperature, rainfall variability and natural hazards on biophysical vulnerability was reported in similar studies (Ndungu *et al.*, 2015; Parker *et al.*, 2019; Piya *et al.*, 2012).

Further examination of the results revealed a statistically significant variation in the mean values for all exposure indicators across the agro-ecological zones implying that the different agro-ecological zones had varying exposure levels to climatic stressors probably due to the different geographical and agro-ecological characteristics of the zones. The arid and semi-arid zones had relatively higher mean values for all the natural disasters, the transitional zone had moderate mean values while the semi-humid zone had the least. The probable explanation for the higher mean values of the natural disasters in the arid and semi-arid zones in comparison with the wetter zones could be because increasing temperatures are likely to result in large changes in the hydrological processes causing more extreme weather events with incidences of increased droughts incidences in the drier zones. Additionally, higher temperatures and erratic rainfall patterns in the arid and semi-arid zones are likely to intensify the abundance, distribution and transmission of animal pathogens. This could amplify the occurrence of livestock diseases outbreaks putting the arid and semi-arid zones are at a higher risk of experiencing more climate-related disasters compared to the wetter zones.

The results corroborate findings by Owusu *et al.*(2021) which showed differences in natural hazards and climate variability experienced in different agro-ecological zones in Ghana. Similarly, Hoque *et al.* (2019) reported spatial variation in exposure index across the coastal region of Bangladesh.

5.2.2 Sensitivity indicators

5.2.2.1 Water sources sub-composite index

The weights for all the indicators of water sources sensitivity were positive implying a positive influence on the water sources sub-composite sensitivity index. The findings further showed that the number of times shallow wells dried due to droughts had the highest influence on the sub-composite sensitivity index followed by the number of times springs dried, the number of times earth dams dried, the number of times rivers dried and the number of times water pans dried while the number of times boreholes dried due to droughts had the least. The high influence of the number of times shallow wells, earth dams and rivers dried on the water sub-composite sensitivity index could be because they are the most commonly relied upon sources of water particularly in ASALs thus their drying results in significant water shortages for domestic, livestock and agricultural use in the study area.

Additionally, the findings showed a significant difference in the number of times different sources of water dried due to drought across the agro-ecological zones where the highest mean values for all the water sources except boreholes was recorded in decreasing order in arid, semi-arid, transitional and semi-humid zones. The high number of times different sources of water dried in the arid and semi-arid zones in comparison with that in the transitional and semi-humid zones may be attributable to different climatic conditions in the zones. The arid and semi-arid zones receive erratic rainfall patterns which, coupled with climate variability, are likely to result in higher recurrence of droughts incidences and high temperatures which accelerate drying of water sources in the drier zones compared to the wetter zones.

The findings are in agreement with results from a study by Faramarzi *et al.* (2013) which indicated that increasing temperature and high precipitation variability are projected to cause significant water shortages in arid and semi-arid regions in Africa. Similarly, a report by FAO (2011a) showed that the hydrological cycle is anticipated to intensify as warming increases the evaporation rates from land and sea, causing a decline in rainfall in the already dry arid and semi-arid areas thereby worsening scarcity of water in the drier zones.

Additionally, according to IPCC (2001) an average global temperature rise of more than 1.5°C is anticipated to result in a decline in water supply in many of the world's water-stressed regions.

5.2.2.2 Overall sensitivity

All the weights for overall sensitivity indicators were positive except the proportion of off-farm income thereby implying a positive influence on the sensitivity index. The negative weight of the proportion of off-farm income indicated a negative influence on the sensitivity index. Unlike on-farm income, off-farm income decreases households' sensitivity to climate variability since it is reliable, stable and less dependent on climate-sensitive activities. Similar studies have reported that a higher proportion of non-farm income decreases households' vulnerability to environmental change (Collier *et al.,* 2008; Ndungu *et al.,* 2015; Piya *et al.,* 2012).

The numbers of cows and goats killed by droughts had the highest influence on the sensitivity index implying that frequent droughts are likely to cause a significant reduction in livestock production which is a key livelihood option in the study area thereby increasing households' vulnerability to climate variability and extreme climate events. The findings corroborate results from studies conducted by Ndungu *et al.* (2015) and Piya *et al.* (2012) which indicated that the number of livestock killed by climate-related extremes had a high influence on the sensitivity index.

Additionally, the findings showed that the proportion of on-farm and off-farm incomes had the second highest influence on the sensitivity index where while the proportion of on-farm income increased the households' sensitivity, the proportion of off-farm income reduced sensitivity since it is reliable and less dependent on climate-sensitive activities compared to the climate-sensitive on-farm income. This finding implies that income diversification with the adoption of more off-farm income-generating activities would be an important adaptation strategy in reducing households' susceptibility to climatic shocks. The current trend of results is concurrent with findings from similar studies (Collier *et al.,* 2008; Ndungu *et al.*, 2015; Opiyo *et al.*, 2014a; Piya *et al.*, 2012).

Additionally, the results revealed that the water sources sub-composite sensitivity index ranked third in its influence on the overall sensitivity index implying that the effect of climatic variations on water sources increases households' sensitivity and therefore adoption of water harvesting technologies that are less sensitive to climatic variations would play a critical role in reducing households' sensitivity to climate variability in the research area. A similar study by Ndungu *et al.* (2015) found that a decreasing trend in water sources increased households' sensitivity to environmental change in the mid-hills of Himachal Pradesh, India.

The results further established that the mean values for all the indicators of sensitivity were significantly different across the four agro-ecological zones. As expected, the arid agro-ecological zone had the highest mean values of all the sensitivity indicators, followed by the semi-arid and transitional zones while the semi-humid zone had the least. The current trend of results implies that households in the agro-ecological zones are affected differently by exposure to climate variability and extreme climate events and the degree of sensitivity increases with aridity with households in the arid zone being highly affected compared to those in the semi-humid zones. Similar findings on differentiated sensitivity levels in different zones were noted by Owusu *et al.* (2021) and Hoque *et al.* (2019).

5.2.3 Adaptive capacity indicators

5.2.3.1 Indicators for physical livelihood assets

The results indicated that the number of gadgets used to assess information and the number of sources for timely weather forecasts had positive weights and thus a positive relationship with the adaptive capacity index. The results imply that the number of gadgets used to assess information and the number of sources of timely weather forecasts increased the households' adaptive capacity probably because they increased farmers' awareness of climate variability and occurrence of extreme climate events which is essential in making informed decisions on adoption of different adaptation strategies.

Conversely, the weights for proximity to the nearest markets, permanent sources of water, motorable roads and health facilities were negative indicating a negative relationship with the adaptive capacity index implying that the adaptive capacity of households reduced with increasing distances from motorable roads, markets, permanent water sources and health facilities. This could be because increasing distances reduce access to important products and services like agricultural inputs, water, health services and information which are critical in improving households' adaptive capacity.

Additionally, close examination of the results established a statistically significant variation, at 95% confidence level, in the mean scores for the indicators of physical livelihood assets except for distance to the nearest mortorable road across the four agro-ecological zones implying that the physical livelihood assets' sub-composite indices varied across the agro-ecological zones. The number of gadgets used to assess information was highest in the semi-humid zone followed by semi-arid and transitional zones and the lowest in the arid zone. The high number of gadgets in the semi-humid and semi-arid zones may be attributable to the relatively higher financial capacity owing to the high estimated gross monthly income and savings reported in the two zones enabling households to afford the gadgets in comparison with lower financial capacity reported in the transitional and arid zones. Moreover, the results revealed that distance to the nearest motorable road followed a decreasing order of arid, semi-humid, semi-arid and transitional zones. The longest distance to the motorable road in the arid zone could be attributed to its location in a marginalized area, far from the County headquarters therefore receiving less attention regarding infrastructural development.

Similarly, the arid zone had the longest distance to the nearest permanent water source which could be due to the higher sensitivity of water sources such as rivers, dams and water pans to climate variability as well as the absence of alternative water sources such as piped water due to marginalization in the zone. The semi-humid zone had the second largest distance to the permanent water source probably due to over-extraction of water in boreholes resulting from the high population in the zone and rationing of piped water. The short distances to a permanent water source in the semi-arid and transitional zones may be due to the presence of a variety of sources of water like rivers, boreholes and piped water which enables the households to have alternative water sources in case one dries up.

Further, the longest distance to the nearest market and health center was registered by the arid zone followed by the transitional and the semi-arid zones while the semi- humid zone had the shortest. The long distances from the market could be due to the location of the arid, semi-arid and transitional zones from the County headquarters compared to the semi-humid zone which is within the County headquarters.

Other researchers have reported that accessing weather-related information increases households' adaptation to climatic change (Asrat and Simane, 2018; Belay *et al.*, 2017; Fagariba *et al.*, 2018). Further, the findings are concurrent with findings from other studies that indicated that good roads and proximity to markets increase the accessibility of important products and services such as agricultural inputs, water, health services and information which are important in enhancing households' ability to adapt (Belay *et al.*, 2017; Marie *et al.*, 2020). Additionally, the current trend of results is consistent with findings by Ndungu *et al.* (2015) and Piya *et al.* (2012)which showed that shorter distances to the nearest market and motorable road positively influence households' adaptive capacity.

5.2.3.2 Indicators for human livelihood assets

Examination of the results revealed that weights for all the indicators of human livelihood assets were positive implying a positive relationship with the adaptive capacity index. The number of persons with formal employment had the highest weight followed by the highest educational level and lastly, the number of vocational courses attended. The results imply that households with formal employment have higher adaptive capacity probably because they have a stable off-farm income which increases their ability to adopt different adaptation strategies thereby increasing their resilience to climate variability.

Similarly, high formal education levels and vocational training sharpen creative thinking and skills for involvement in different off-farm income-generating strategies that are less sensitive to climate risks thus diversifying livelihood options to enhance households' off-farm income which is an important buffer in averting climate-related risks (Asrat and Simane, 2018; Fagariba *et al.*, 2018). Additionally, high education levels and training increase the probability of adopting different adaptation strategies since farmers with high education levels have a higher probability of perceiving variations in climate and the associated risks and have awareness and skills to implement new technologies (Belay et *al.,* 2017; Deressa *et al.,* 2008).

The current trend of results corroborates findings reported by Ndungu *et al.* (2015) which showed that the number of persons with formal employment, highest educational level attained and the number of vocational courses attended positively influenced households' adaptive capacity. Similarly, Piya *et al.* (2012) reported that the highest education qualification and the number of vocational training attained had a positive relationship with adaptive capacity among households in Chepang area in the Mid-hills of Nepal.

The results further established that the semi-humid zone registered the highest mean scores for all the human livelihood assets' indicators, the transitional zone had the second highest mean values and the semi-arid zone registered the third highest mean values while the arid zone registered the lowest. This finding implies that human assets' sub-composite index of households reduces with aridity probably because of higher poverty levels and marginalization in arid and semi-arid zones which reduce access to basic education and consequently employment opportunities in those zones compared to wetter zones (Barrow and Mogaka, 2007; Dobie, 2001; Njoka *et al.,* 2016). Intervention measures aimed at enhancing households' resilience to climate variability should therefore prioritize enhancing human assets in arid and semi-arid areas through creation of opportunities to increase formal employment and access to not only basic education but also tertiary education in colleges, universities and technical institutions.

5.2.3.3 Indicators for natural livelihood assets

The study established that all the indicators of natural livelihood assets except the size of unproductive land positively influenced the households' adaptive capacity index. The results indicated that total land size had the highest weight followed by productive land size under crops and productive land size under pasture, the number of large bullock stock and lastly, the unproductive land size. Large productive land size under crop and pasture encourage intensified mixed farming which would result in increased agricultural productivity for both subsistence and economic purposes thereby increasing households' adaptive capacity (Fisher *et al.,* 2015; Simotwo *et al.,* 2018).

Additionally, large productive land sizes increase households' capacity to adopt various adaptation options such as crop diversification, mixed crop and livestock farming and agro-forestry which would have otherwise been limited by small land sizes (Fadina and Barjolle, 2018). Further, the number of large bullock stock is an important factor of production since the majority of farmers in the study area utilize ox and donkeys for ploughing thus high number of large bullock stock enhances a household's agricultural productivity hence increasing its adaptive capacity. On the other hand, large unproductive land size would reduce households' adaptive capacity since it reduces their capacity for agricultural productivity as well as the capacity to adopt land-intensive adaptation strategies (Asrat and Simane, 2018).

Further examination of the results revealed that the mean values for all the indicators of natural livelihood assets were highest in the drier (arid and semi-arid) zones and the least in the wetter (semi-humid and transitional) zones except for the productive land size under crops and pasture. The mean values for productive land size under crops followed a decreasing order of semi-arid, arid, transitional and semi-humid zones. For the productive land size under pasture, the mean values had a decreasing order of arid, transitional, semi-arid and semi-humid zones.

The difference in the mean values for total land sizes could be because the arid and semi-arid lands have bigger land sizes since they are less densely populated compared to the semi-humid and transitional zones which are densely populated probably due to their proximity to the County headquarters. The relatively lower mean values for crop land in the arid zone in contrast to the semi-arid zone could be because even though the arid zone has bigger total land sizes, only small portions of the total land are cultivated due increasing temperatures, unreliable rainfall patterns and droughts resulting in recurrent crop failures in the dry zone while farmers in the semi-arid zone cultivate relatively bigger land since they have relatively better climatic conditions and higher adaptive capacity to invest in different adaptation strategies as opposed to the arid zone. According to Ludena and Yoon (2015), Nelson *et al.* (2010) and Piya *et al.* (2012), high adaptive capacity increases the probability of adopting different adaptation strategies in response to climate variability.

Despite having better climatic conditions for agriculture contrasted with the arid and semi-arid zones, crop farming is done on very small pieces of land in the transitional and semi-humid zones probably because most households own small pieces of land due to the intense subdivision of land to cater for the high populations in the zones. The results are in agreement with findings from other studies which reported that intensive land subdivision resulting from high population rates had reduced agricultural production in Kenya (Birch, 2018; Museleku *et al.*, 2018; Muyanga and Jayne, 2014).

Additionally, the highest mean values for land size under pasture in the arid zone compared to the other zones could be attributed to the fact that the zone receives relatively low rainfall suitable for crop production and thus a bigger proportion of their expansive pieces of land is dedicated to livestock rearing which is an important livelihood option in the arid zone. The relatively lower mean values in the semi-arid zone in comparison with the transitional zone could be probably because a higher proportion of the total land size is used for crop production owing to the farmers' ability to invest in different adaptation strategies thanks to their higher financial capacity reported in the zone as opposed to those in the transitional zone (Brooks *et al.,* 2005; Nelson *et al.,* 2010; Piya *et al.,* 2012).

Further, the high number of large bullock stock in the arid and semi-arid zones compared to the transitional and semi-humid zones could be probably due to the availability of expansive sizes of land for livestock rearing in the arid and semi-arid zones compared to the relatively smaller land sizes in the transitional and semi-humid zones which reduces households capacity to keep a high number of large bullocks. Additionally, households in the arid and semi-arid zones rely on cheap and available ox and donkeys to fetch water from distant water sources and for ploughing as opposed to tractors which would be expensive to plough the big land sizes in the zones. Conversely, households in the wetter zones have access to piped water and boreholes and have smaller crop lands and relatively higher financial capacity to afford mechanized farming in comparison with those in arid and semi-arid lands.

The present study's findings are in consonance with those by Mesfin *et al.* (2020) who while working on the assessment of households' adaptive capacity to climatic variations in the Central Rift Valley of Ethiopia established that productive land had a larger influence on farmland's contribution to the natural capital sub-composite index while a larger proportion of less productive land reduced the influence of farmland to the natural capital sub-composite index thereby decreasing households' adaptive capacity. Additionally, Ndungu *et al.* (2015) noted a positive relationship of productive land size and the number of large bullocks with the adaptive capacity but a negative relationship of unproductive land size with the adaptive capacity index. Similar results were reported by Piya e*t al.* (2012) while working on the vulnerability of rural households to climate change and extremes among households in Chepang area in the Mid-hills of Nepal.

5.2.3.4 Indicators for social assets

The results indicated that all the social assets' indicators positively influenced the households' adaptive capacity index. The highest amount of credit accessed in the past ten years contributed the highest to the adaptive capacity index followed by the number of loan facilities accessed and the number of extension services accessed over the past one year. Credit facilities are important in giving financial assistance to households which enables them to cope with seasonal food shortages as well as invest in off-farm income generation activities thus diversifying their livelihood options which enhance their adaptive capacity. Further, access to credit facilities enhances households' capacity to adopt adaptation measures like planting hybrid crops, water harvesting and soil conservation technologies which require substantial financial investments (Arun and Yeo, 2020; Awotide *et al.*, 2015; Tesfaye and Seifu, 2016). Similarly, access to extension services increases households' understanding of climatic variations and related risks and provides knowledge and skills to farmers for implementation of relevant adaptation strategies to avert the risks thus enhancing households' adaptive capacity (Belay et *al.,* 2017; Fagariba *et al.,* 2018; Teklewold *et al.,* 2019).

Further, the results indicated that there was a significant difference in the average scores for the number of extension services accessed in the past one year across the four agro-ecological zones where the mean values were highest in the semi-humid zone, second highest in the semi-arid zone followed by the arid zone and the least in the transitional zone. The possible reason for the high access to extension services in the semi-humid and semi-arid zones compared to the arid zone could be attributed to their proximity to the County headquarters while the relatively lower access in the transitional zone could be because priority intervention is usually given to drier zones which are mostly affected by climate variability and extreme climate events compared to the relatively wetter zones thus the transitional zone receiving lesser attention due to its intermediate climatic conditions. The highest amount of credit accessed over a period of ten years was high in the transitional and semi-humid zones and lower in the arid and semi-arid zones probably because of their closer proximity to the County headquarters and therefore have ease of access to financial institutions compared to that in the arid and semi-arid zones which are located far from the County headquarters.

The current trend of results corroborates findings from Mesfin *et al.*(2020) which showed that knowledge, information provision and innovation had a positive influence on households' adaptive capacity. Further, the results are in consonance with findings by Ndungu *et al.* (2015) and Piya *et al.* (2012) which indicated a positive relationship of access to credit with adaptive capacity. Similar results were reported in other studies (Arun and Yeo, 2020; Belay *et al.,* 2017; Fagariba *et al.,* 2018; Teklewold *et al.,* 2019).

5.2.3.5 Indicators for financial assets

All weights for the financial assets' indicators were positive, implying that they positively influenced the adaptive capacity index. In terms of magnitude, estimated gross monthly income contributed the highest to the adaptive capacity, estimated monthly savings ranked second while the livelihood diversification index had the lowest influence. Higher household income and savings mean a greater financial capacity to meet immediate food needs in periods of food shortages as well as the capacity to invest in education and other livelihood options thereby providing a buffer against climate variability-related risks (Chepkoech *et al.*, 2019; Mesfin *et al.*, 2020; Piya *et al.*, 2012). Additionally, higher gross income and savings increase households' capacity for timely adoption of capital-intense adaptation options such as hybrid crops, water harvesting, fertilizers and irrigation. Similarly, a higher diversification index distributes climate-related risks among a variety of livelihood options enabling households to switch to less climate-sensitive livelihood options when the need arises thus increasing the households' adaptive capacity (Piya *et al.*, 2012).

The results further indicated that the mean values for the livelihood diversification index were significantly different while those for estimated gross monthly income and estimate monthly savings were not significantly different across the four agro-ecological zones. The results indicated that estimated gross monthly income and savings were highest in the semi-humid and semi-arid zones followed by the transitional zone and the lowest in the arid zone probably because households in the semi-humid zone have more access to off-farm income generating sources due to their proximity to the County headquarters while those in the semi-arid zone, having experienced high exposure to climate variability and extreme climate events, have adopted different off-farm livelihoods options as indicated by their higher livelihood diversification index. On the other hand, low monthly income and savings in the transitional zone could be probably because of the lower diversification of livelihood options in the zone while in the arid zone, the low income and savings could be attributable to low opportunities for education, employment and access to credit facilities due to their location far from the County headquarters.

Further, the results indicated that the livelihood diversification index was higher in arid and semi-arid zones and lower in transitional and semi-humid zones which could be ascribed to higher exposure to climate variability and extreme climate events in the arid and semi-arid zones forcing households to invest in several off-farm activities to diversify their income since on-farm income is not reliable contrary to those in the semi-humid and transitional zones who have relatively lower exposure levels.

Similar findings where household income and savings increased households adaptive capacity were reported in other studies (Chepkoech *et al.*, 2019; Egyir *et al.,* 2015; Fagariba *et al.*, 2018; Hoque *et al.*, 2019; Mesfin *et al.*, 2020). Further, Ndungu *et al.* (2015) reported a positive influence of monthly income and savings on households' adaptive capacity in the mid-hills of Himachal Pradesh, India. Moreover Piya *et al.* (2012) while working on the vulnerability of rural households to climate change and extremes among households in Chepang area in the Mid-hills of Nepal reported a positive influence of monthly income, savings and the livelihood diversification index on households' adaptive capacity.

5.2.3.6 Weights for indicators of adaptive capacity

The results revealed that physical assets had the highest weight and thus the greatest influence on adaptive capacity followed by financial assets, social assets, human assets and finally the natural assets. Physical assets play a crucial role in enhancing the utilization of natural assets and access to services that enhance social, financial and human assets. For example, good roads increase access to markets that provide accessibility of farming inputs like fertilizers and improved seeds and services such as agricultural extension, credit facilities and weather forecasts which are critical in climate variability adaptation. Additionally, markets provide opportunities for employment and off-farm income activities which enhance the financial assets.

Financial assets had the second highest weight indicating their importance in enhancing households' adaptive capacity since they influence the ability to access all the other forms of assets. Social and human assets had a moderate influence on adaptive capacity probably because they are influenced by the physical and financial assets. The natural assets on the other hand had the least influence on the adaptive capacity index owing to its sensitivity to climatic shocks compared to the other assets.

The findings are in agreement with those reported by Ndungu *et al.* (2015) indicating that physical assets had the highest influence on total adaptive capacity while natural assets had the least. Conversely, Piya *et al.* (2012) reported that financial assets had the highest influence on adaptive capacity among households in Chepang area in the Mid-hills of Nepal. Regarding natural assets, Piya *et al.* (2012) reported a similar finding as the current study indicating that natural assets had the least influence on the adaptive capacity index since, in comparison to other asset kinds, natural assets are more influenced by climatic variations and related calamities.

5.2.3.7 Adaptive capacity sub-composite indices

Scrutiny of results from one-way analysis of variance indicated that mean values for physical, natural and human assets' sub-composite indices were significantly different across the four agro-ecological zones. However, further examination of the results indicated that there was no statistically significant difference in the mean values for social and financial assets' sub-composite indices. The physical assets sub-composite index score was the highest in the semi-humid zone, the semi-arid and transitional zones had the second and third highest index scores respectively, while the arid zone had the least. The high index scores in the semi-humid and semi-arid zones could be attributable to the higher number of gargets, sources of timely weather forecasts and reduced distance to market, health facility and permanent water sources reported in the two zones in comparison with the transitional and arid zones.

Similarly, human assets sub-composite index score was highest in the semi-humid zone due to the highest mean of all the indicators of human assets recorded in the zone while the lowest human assets sub-composite index score in the arid zone could be attributed to the lowest means recorded for the indicators of human assets in the arid zone contrasted with the other zones. The natural assets sub-composite index on the other hand was highest in the arid zone followed by the semi-arid zone and lowest in the semi-humid followed by transitional agro-ecological zones due to the higher mean values of total land size, productive land size under crop and pasture and the number of large bullocks recorded in the arid and semi-arid zones compared to that in transitional and semi-humid zones.

Further, the social assets sub-composite index had the highest score in the semi-humid zone followed by the transitional zone while the arid and semi-arid agro-ecological zones had the lowest which could be attributed to the relatively higher amount of credit facility accessed and the number of times extension services were accessed in the semi-humid and transitional zones compared to that in the arid and semi-arid zones. The financial assets sub-composite index score followed a descending order of semi-humid, arid, semi-arid and transitional zones. The high financial assets' sub-composite index score in the semi-humid zone could be ascribed to the high gross monthly income and savings recorded in the zone relative to the other zones while the low financial assets' sub-composite index in the transitional zone could be attributed to the lower livelihood diversification index reported in the zone compared to the other zones.

The results are concurrent with findings from a similar study by Tessema and Simane (2019) which indicated varying livelihood assets' indices in different agro-ecological zones in Ethiopia's Fincha'a sub-basin of the upper Blue Nile. Similarly, Piya *et al.*(2012) reported differential adaptive capacity indices in varying Village Development Committee (VDCs) in Chepang area of Nepal's Mid-hills.

5.2.4 Overall vulnerability index

Examination of the study results indicated a statistically significant difference in the overall vulnerability index and its components' indices across the four agro-ecological zones. In terms of exposure, the results indicated that the transitional zone had the highest exposure index followed by arid and semi-arid zones while the semi-humid zone had the least exposure. The highest exposure index in the transitional zone could be attributed to the highest coefficient of variation in mean annual maximum and minimum temperature in the zone compared to the other zones. On the other hand, the second highest exposure index in the arid zone could be ascribed to the relatively higher numbers of drought incidences, livestock diseases and strong winds reported in the zone in comparison with that in the semi-arid and semi-humid zones.

In regard to sensitivity, the arid zone had the highest sensitivity index score followed by the semi-arid zone which could be attributed to the higher number of acres of cropland destroyed by droughts, livestock killed by droughts, higher share of on-farm income as well as higher water sources sensitivity index in the arid and semi-arid zones as opposed to the transitional and semi-humid zones.

Further, the results showed that the highest adaptive capacity index was registered in the semi-humid zone followed by semi-arid and transitional zones while the arid zone registered the lowest adaptive capacity index. The highest adaptive capacity index in the semi-humid zone could be probably due to the highest physical, human, social and financial assets' sub-composite indices recorded in the zone in comparison with the other zones. Additionally, the semi-arid zone's second rank in adaptive capacity index could be attributable to the relatively higher physical, natural and financial assets sub-composite indices compared to the transitional zone. Conversely, the lowest adaptive capacity index in the arid zone could be explained by the lowest physical, human, social and financial indices reported in the zone.

Regarding the overall vulnerability index, the study's findings established that the arid zone had the highest vulnerability index followed by the transitional and semi-arid zones while the semi-humid zone had the least. The highest vulnerability index in the arid zone could be explained by the second high exposure and highest sensitivity levels coupled with the lowest adaptive capacity reported in the zones. For the transitional zone, even though it had a moderate sensitivity index, the highest exposure and the second lowest adaptive capacity indices increased its vulnerability index score making it the second most vulnerable zone. This finding implies that regions exhibiting moderate exposure and sensitivity to climatic shocks are at the risk of having high vulnerability levels if their adaptive capacity is not enhanced.

The moderate vulnerability index in the semi-arid zone could be explained by the high adaptive capacity index reported in the zone. This finding implies that households' vulnerability to climatic variations in arid and semi-arid lands can be reduced by investing in initiatives that increase the households' adaptive capacity. Further, the semi-humid zone had the lowest vulnerability index which could be ascribed to the lowest exposure and sensitivity levels coupled with the highest adaptive capacity index recorded in the zone.

The results of the study corroborate findings by Hoque *et al.* (2019) which revealed that districts (Bhola and Patuakhali) with higher exposure and sensitivity levels with low adaptive capacity were the top most vulnerable districts to climate change while low sensitivity and high adaptive capacity in Khulna district, conversely, reduced the effects of high exposure to climate disasters in Bangladesh's coastal region. In a similar study, Bobadoye *et al.* (2019) also reported a high degree of variation in household's vulnerability levels in the same community indicating that different adaptive capacity levels significantly influence a household's overall vulnerability even when exposure levels to climatic shocks are the same.

Further, the results corroborate findings by Ndungu *et al.* (2015) who while assessing households' vulnerability to climatic variations in of Himachal Pradesh's Mid-Hills in India reported that the Kandaghat area was the most vulnerable study site owing to the highest exposure levels along with the lowest adaptive capacity index. Additionally, the authors noted that despite having a lower exposure index score, the Naggar block ranked the second highly vulnerable area due to the highest sensitivity and lower adaptive capacity indices reported in the block. Moreover, the study reported that Kullu block had the lowest vulnerability index score owing to its lowest sensitivity and highest adaptive capacity indices while the Solan area ranked second in low vulnerability index due to its second position in sensitivity and adaptive capacity indices.

Further, Ndungu *et al.* (2015) reported that study sites located near the district headquarters had low vulnerability levels in comparison with those situated far from the district headquarters since households located far from the district headquarters experience more social economic and biophysical vulnerability. Similarly, Piya *et al.* (2012) pointed out that even in areas with relatively lower exposure levels, a sudden occurrence of extreme weather events would significantly impact livelihoods if the communities do not have adequate adaptive capacity thus emphasizing the importance of enhancing households' adaptive capacity to increase their resilience to climatic variations.

5.2.5 Vulnerability quartiles

The results of the study established a statistically significant variation in the vulnerability quartiles across the four agro-ecological zones. From the results, it was noted that the arid zone had the highest percentage of households in the high vulnerability quartile followed by the transitional and semi-arid zones while the semi-humid zone had the lowest percentage. The highest percentage of households belonging to the high vulnerability category in the arid zone could be ascribed to the highest vulnerability index reported in the zone implying that most of the households are highly vulnerable and very few belong to the moderate and low vulnerability categories.

Similarly, the second high percentage of households belonging to the high vulnerability category in the transitional zone could be attributed to the high vulnerability index reported in the zone where most of the households are highly vulnerable with few households belonging to the low vulnerability category. The moderate vulnerability quartile had the highest percentage of households in the semi-humid zone since having ranked the least in overall vulnerability, majority of the households fall in the moderate and low vulnerability categories. Additionally, the semi-arid zone having ranked third in overall vulnerability had the third highest percentage of households' in the moderate vulnerability and second highest percentage in the low vulnerability category.

The results concur with findings from similar research by Owusu *et al.* (2021) which indicated that vulnerability levels of households were not uniformly distributed in three different agro-ecological zones in Ghana. In a similar study, Hoque *et al.* (2019) also reported a heterogeneous distribution of vulnerability levels in three distinct districts in the coastal region of Bangladesh. Further, the results of the present study corroborate findings by Bobadoye *et al. (*2019) which showed a high disparity in the vulnerability of households in five wards of Kajiado East Sub-county with varying percentages of households belonging to three different vulnerable categories.

5.2.6 Spatial vulnerability of households to climate variability and extreme climate events in the study area

Spatial vulnerability assessment is crucial in identifying vulnerability hotspots and patterns in a community which are important for informed planning, resource allocation and implementation of adaptation measures with the aim of increasing households' resilience to climate variability and extreme climate events. Vulnerability maps allow location-specific targeting of interventions with the recognition of the spatial variability of vulnerability levels of households within the same locality.

Maps depicting the spatial distribution of exposure, sensitivity and adaptive capacity revealed variation of exposure, sensitivity, adaptive capacity and overall vulnerability levels of households to climatic variations and extreme weather events in the four agro-ecological zones. The variation in the spatial distribution of exposure, sensitivity, adaptive capacity and overall vulnerability levels of households in the agro-ecological zones could be attributed to the differences in the occurrence of climatic variability and natural disasters and the associated effects of the disasters on livelihoods as well as the varying adaptive capacity levels in different zones as discussed in section 5.2.

The results concur with findings from a similar study by Hoque *et al.* (*2*019) who assessed agricultural livelihood vulnerability to climatic changes in Coastal Bangladesh and presented varying spatial distribution of exposure, sensitivity, adaptive capacity and overall vulnerability across the coastal districts. Similarly, Bobadoye *et al.* (2019) noted differences in the spatial distribution of vulnerability of pastoral households to changes in climate in different wards of Kajiado East Sub-county. Additionally, while working on climate vulnerability and impacts analysis in Kenya, Marigi (2017) presented varying spatial distribution of vulnerability in different parts of Kenya. Further, the results corroborate findings by Heltberg and Bonch-osmolovskiy (2011) who reported substantial spatial variation of vulnerability and its components in ten agro-ecological zones in Tajikistan, Central Asia.

5.3 Predictive modeling of farmers' vulnerability to climate change and extreme climate events in the study area

The results of the current study established that various households' socio-economic features had a varying influence on the households' vulnerability categories. The results showed that the household head's age had a significant negative influence on a household belonging to the low vulnerability category compared to those with younger household heads probably because households with elderly heads are highly vulnerable in comparison with younger household heads since the elderly do not have the energy to engage in diversified livelihood options and thus have lower adaptive capacity compared to younger households.

Additionally, younger households have a higher probability of adopting different adaptation measures since they are innovative and have the energy to implement new techniques aimed at improving agricultural production compared to older households. The findings are in consonance with those by Ncube *et al.* (2016) which indicated that a unit increase in household head's age increased the chances of the household being classified as moderately or highly vulnerable in Lambani and Alice Provinces in South Africa. Similarly, Opiyo *et al.* (2014a) while assessing households' vulnerability to climatic shocks in Kenya's pastoral rangelands, found out that the household heads' age significantly increased households' vulnerability in Turkana County.

Regarding proximity to the market, increasing market distance increased households' vulnerability to climate variability thereby reducing the probability of belonging in the low and moderate vulnerability categories. The probable reason could be that increasing market distances reduce access to social and financial assets which are crucial in enhancing households' adaptive capacity. The current trend of findings is concurrent with findings from a similar study by Ghosh and Ghosal (2020) which indicated that decreasing distance to the market reduced households' vulnerability to climatic stressors in the Himalayan foothills of West Bengal, India. Similarly, Marie *et al.* (2020) found that accessibility to market increased farmers' probability of adopting various adaptation techniques thereby reducing their sensitivity to climate change.

The results further indicated that the highest education level attained in the household positively influenced a household's likelihood of belonging to the low and moderate vulnerability categories. This implies that households with members who had attained higher education levels were less vulnerable in comparison with their counterparts with low academic qualifications. The positive influence of education on low and moderate vulnerability categories could be because high education levels increase opportunities for formal employment and engagement in diversified income-generating activities which intensify a household's human capital thereby enhancing its adaptive capacity (Asrat and Simane, 2018; Fagariba *et al.,* 2018). Further, farmers with high education levels have higher chances of perceiving climatic variations and the associated risks and have awareness and skills to implement new technologies thus higher probability of implementing various adaptation measures compared to those with low to no academic qualifications (Belay et *al.,* 2017; Deressa *et al.,* 2008).

In a similar study, Azumah *et al.* (2020) noted that higher academic qualifications increased the likelihood of a household becoming less vulnerable to climate change in Ghanaian's South Tongu and Zabzugu districts. Similarly, Ghosh and Ghosal (2020) found that access to higher secondary education reduced households' vulnerability to climatic variations in the Himalayan foothills of West Bengal, India. Further, the results corroborate findings by Matsalabi *et al.* (2018) which showed that a unit increase in the number of educated members decreased the probability of a household being vulnerable by 11.5% in Aguie district of Niger.

Additionally, the results revealed that the arid agro-ecological zone reduced the odds of a household belonging to the low and moderate vulnerability categories relative to the high vulnerability category while the semi-humid agro-ecological zone increased the probability of household belonging to the low and moderate vulnerability categories implying that households in the arid agro-ecological zone were more susceptible to climate variability and extreme weather events in comparison with those in the semi-humid zone. The negative influence of arid agro-ecological zone on households belonging to the low and moderate vulnerability categories could be explained by the harsh climatic conditions coupled with high exposures to climatic variability and natural disasters which increase the vulnerability of households in the arid zone. Similarly, low adaptive capacity owing to the marginalization of the zone also increases the vulnerability index of households in the arid zone. The positive influence of the semi-humid zone on households belonging to the low and moderate vulnerability categories on the other hand could be attributable to the low exposure and sensitivity levels in the zone owing to its relatively wetter climatic conditions and higher adaptive capacity due to its proximity to the County headquarters.

The current trend of results is in consonance with findings by Owusu *et al.* (2021) which indicated that agro-ecological zones strongly influenced households' vulnerability in Ghana where while 58.8% of the households in the highly vulnerable category were from the Guinea Savannah agro-ecological zone, only 11.8% of the households in that category were from the Moist Semi-Deciduous Forest agro-ecological zone. Similarly, Chauhan *et al.* (2020) reported a varying influence of biogeographical zones on social and ecological vulnerability indices of agricultural communities in Himachal Pradesh, India.

Further, the results showed a positive relationship between household heads' gender and the probability of a household belonging to the low vulnerability category implying that households headed by men had a higher likelihood of being less vulnerable in comparison with those headed by women. The possible reason could be that men have better access to services that enhance their adaptive capacities such as education and employment opportunities as well as the ability to be involved in labor-intensive off-farm livelihood strategies compared to women. In addition, households headed by men have a higher probability of adopting diverse adaptation strategies since they have better access and ability to adopt new techniques to boost agricultural productivity in comparison with their female counterparts.

The positive influence of gender of the household head on the probability of households being less vulnerable was also highlighted by Opiyo *et al.* (2014a) while working on households' vulnerability to climate-induced stresses in Kenya's pastoral rangelands in

Turkana County. Concurrent findings have also been reported by other researchers (Asrat and Simane, 2018; Belay *et al.,* 2017; Mihiretu *et al.,* 2019).

Regarding access to extension services, the findings showed that households with access to extension services had higher probability of falling in the low vulnerability category compared to those without probably because extension services increase awareness on climatic changes and related risks as well as providing households with knowledge and skills to implement relevant adaptation strategies to avert the risks thus enhancing households' adaptive capacity. The current trend of results concurs with findings from similar studies (Belay *et al.,* 2017; Fagariba *et al.,* 2018; Nhemachena *et al.,* 2014; Teklewold *et al.,* 2019).

Additionally, the results indicated that access to credit facilities positively influenced the probability of a household belonging to the low and moderate vulnerability category implying that access to credit facilities reduced the vulnerability of households to climate variability. The positive influence of access to credit facilities on reducing households' vulnerability could be attributed to its contribution to adaptive capacity by providing the financial ability to households to aid in the adoption of capital-intense adaptation strategies and technologies as well as investing in off-farm income generation activities which help farmers diversify their livelihood options.

The results concur with findings by Azumah *et al.* (2020) who while assessing farm households' perceived climate change impacts, vulnerability and resilience in Ghana reported that access to credit facilities increased the likelihood of households being in the low vulnerability category. Further, Arun and Yeo (2020) found a positive association between access to credit facilities and the adoption of changing cropping date, crop type, crop variety and investment in irrigation among households in Nepal. Similarly, Tesso *et al.* (2012) noted that accessibility of financial services increased the resilience of households by 16.6% due to its importance in influencing the adoption of adaptation options like planting hybrid seeds which would otherwise be limited by financial constraints.

Household size on the other hand reduced the odds of a household belonging to the low vulnerability category implying that households with more family members had higher chances of being in the high vulnerability category as opposed to the low category. The possible explanation could be due to the fact that bigger household size has a higher demand for resources where household income is directed to meeting the household's basic needs with little left for investment in education and diversified off-farm generation activities which enhance a household's adaptive capacity. The results corroborate a similar study by Matsalabi *et al.* (2018) which indicated a highly significant and positive influence of family size on households' vulnerability where a unit increase in household size increased the vulnerability by 48.1% in farming households in Aguie district of Niger. Additionally, Opiyo *et al.* (2014a) also reported a positive influence of household size with vulnerability among pastoral households in Turkana County.

In regard to the moderate vulnerability category, the findings however showed a positive effect of the size of the household on the probability of households being in the moderate vulnerability category compared to the high vulnerability category which could be because a larger household size provides an opportunity to improve productivity where productive members could be utilized as a human resource for both farm and off-farm income-generating activities thereby enhancing the households' financial capital. In addition, a larger household size provides family labor for the adoption of labor-intensive adaptation strategies. A positive association between household size and low vulnerability was also reported by Nkondze *et al.*(2013). Similar studies also reported a positive relationship between the adoption of labor-intensive adaptation techniques and the number of members in a household (Asrat and Simane, 2018; Belay *et al.*, 2017; Jiri *et al.*, 2015).

Contrary to the expectation, land size was negatively associated with the probability of a household belonging to the low and moderate vulnerability categories implying that bigger land sizes increased the vulnerability of households which could be because larger land sizes were recorded in the arid zone which has high exposure to climate-related natural disasters and thus higher agricultural sensitivity. Additionally, households in the arid zone recorded low financial capital thus limiting their ability to invest in technologies that increase their land productivity. Similar findings by Boori and Voženílek (2014) indicated that areas with undeveloped or less developed land in Olomouc, Czech Republic were vulnerable to environmental changes but improvement of agricultural force to turn it into a developed area would increase its adaptive capacity and resilience. The results however contradict findings by Ghosh and Ghosal (2020) who while examining the determinants of households' vulnerability to climatic changes in the Himalayan foothills of West Bengal in India, noted that agricultural land size positively influenced the low vulnerability of households in the study area.

5.4 Coping strategies to food insecurity and determinants of households' choice of specific coping strategies in the study area

5.4.1 Households' coping strategies to climate variability induced food insecurity

Examination of the present study's results revealed that there was a significant variation in the adoption of several coping strategies to food insecurity in the four agro-ecological zones. This could be because the different agro-ecological zones have varying exposure levels to climatic extremes as well as different adaptive capacities due to the heterogeneous climatic and socio-economic settings. Households in the semi-humid zone, for example, are less likely to experience extreme food shortages which might force them to reduce their daily meal consumption since they have relatively favorable climatic conditions for crop farming compared to those in the arid zone. Further, households in the arid zones are often exposed to subsequent droughts and food shortages and have therefore invested most of their efforts in off-farm income-generating activities in order to meet their food needs as opposed to those in the semi-humid areas.

The results are in agreement with findings from a similar study by Tsegaye *et al.* (2018) which established that there was a significant variation in coping strategies used by households such as borrowing food and money as well as reducing meal frequency and amount across different climatic zones in Dabat District, Northwest Ethiopia. Similarly, Berlie (2015) noted that households in three different agro-ecological zones in Lay Gayint District, Ethiopia had adopted different coping strategies to food insecurity with reduction of the numbers and types of meals and selling land to purchase food being more adopted in the most vulnerable agro-ecological zone, Kolla, lowland.

The results indicated that most farmers from the arid and semi-arid zones used off-farm income to buy food compared to those in the transitional and semi-humid zones. This could be explained by the fact that the arid and semi-arid zones receive erratic and little rainfall causing subsequent crop failures and food shortage, and thus farmers have to rely more on off-farm income to buy food compared to those in the transitional and semi-humid zones which receive relatively adequate rainfall for crop production in most seasons. The results are in consonance with findings from similar studies which noted that households used off-farm income to buy food in times of food shortage (Makoti and Waswa, 2015; NDMA, 2017; Wabwoba *et al., 2*016).

As indicated by the results, most farmers in the arid and semi-arid zones sold livestock to buy food in comparison with those in the transitional and semi-humid zones. This could be attributed to the fact that the arid and semi-arid zones are mostly suitable for livestock production than crop production compared to the transitional and semi-humid zones which receive relatively adequate rainfall for crop production and have smaller pieces of land that can hardly support large herds of livestock. The results concur with findings from Opiyo *et al.* (2015) which indicated that selling livestock to buy food was an important coping strategy to food shortage in Turkana County, a dryland in Kenya. Additionally, Khatri-chhetri and Maharjan (2006) also noted that selling livestock to buy food was a common coping strategy to food deficit in Dailekh District, in Nepal.

Similarly, the results showed that a larger percentage of farmers in the arid and semi-arid zones reduced the number of meals per day to cope with food shortages from drought compared to their counterparts in the semi-humid and transitional zones. This implies that farmers in the drier agro-ecological zones are at a higher risk of experiencing food shortages due to climate variability and extreme climate events compared to their counterparts in the relatively wetter agro-ecological zones. The results are in agreement with findings from similar studies by Sani and Kemaw (2019), Tsegaye *et al.* (2018) and

Berlie (2015) which indicated that reduction in the number of meals per day was a common coping strategy to food shortage. Further, the current trend of results corroborates findings of similar work by (Makoti and Waswa, 2015).

A larger proportion of households in the arid and semi-arid zones benefited from the food assistance for assets programmes as opposed to their counterparts in the transitional and semi-humid zones. This could be because most of the intervention programmes by the World Food Programme in partnership with other development partners such as Caritas-Kitui and NDMA target the dryland regions of Kitui County due to their higher vulnerability to droughts. The food assistance for assets programmes provide immediate food needs for the most vulnerable farmers. This increasing their long-term food security and resilience to climate variability and extreme climate events by enhancing the farmers' capacity to adopt different adaptation measures such as soil conservation and farm water harvesting structures for supplementary irrigation (Caritas Kitui, 2016; WFP, 2017). Key informant interviews with stakeholders however revealed that the programmes had been suspended for more than 5 years thereby leaving the households to fend for themselves in times of food shortages.

Regarding selling forest products, the results further indicated that a greater percentage of households in the arid zone were selling forest products such as charcoal, timber and firewood to cope with drought compared to the other zones. This is probably because the arid zones experience more frequent and severe droughts compared to the other agro-ecological zones in the study area thus households have incorporated exploitation of forestry products such as charcoal and wood fuel as a means of income diversification in times of droughts. Further, households in the arid zones have relatively larger pieces of land with indigenous tree species which provide an opportunity for charcoal production compared to the other zones. Unsustainable exploitation of forestry products however could contribute to deforestation and further desertification thereby increasing the households' vulnerability to climate-related disasters. The results are in consonance with findings from a similar study by Opiyo *et al.* (2015) which pointed out that production and selling of charcoal was a major source of income for coping with food shortages during drought among households in Turkana County in North Eastern Kenya. Additionally, Makoti and Waswa (2015) also noted that 54.2% of the respondents in Kwale County used income from charcoal production to cope with food insecurity.

5.4.2 Determinants of households' choice of adoption of specific coping strategies to food insecurity in the study area

As noted by Maddison (2007), the ability and decision to adopt a particular coping strategy are determined by several socio-economic factors. Results from the multivariate probit regression model indicated that different socio-economic characteristics of farmers had a varying influence on the farmers' choice of specific coping strategies to food insecurity in the study area. The results implied that households with older household heads were more likely to sell family assets to buy food in times of food shortage compared to those with younger household heads while households with younger household heads were more likely to seek off-farm jobs compared to older household heads. The reason for this could be as age increases household heads become less productive and may therefore not be able to engage in off-farm income generating activities thereby resorting to selling their family assets to buy food in the face of food insecurity. Similar studies indicated that households with older household heads were more vulnerable to food insecurity since as the household head grows old, opportunities to engage in meaningful income-generating activities are diminished (Bukenya, 2017; Sani and Kemaw, 2019).

Regarding gender of the household head, the results indicated that male-headed households were more likely to adopt selling of family assets and reduction of food consumption compared to female-headed households which were on the other hand more likely to seek off-farm income to feed their households in times of food shortage. The reason could be that women are in charge of their families' welfare and are therefore more likely to use available resources and skills towards improving the household's food needs compared to men. Similar work by Lutomia *et al.* (2019) indicated that female household heads provide a critical buffer against food consumption shortfalls since they give more priority to improving their household's food security. In addition, Ibnouf (2009)reported that women tend to use almost all of their non-agricultural income to cater for the welfare of the household as opposed to their male counterparts who often use cash income for other purposes.

The significant positive influence of the household size on the adoption of reduction of food consumption and selling of livestock, family assets and forest products to buy food in the present study could be because a larger household size has a higher demand for food resources compared to smaller households and therefore larger households might not meet the higher household food demands in times of food shortage and therefore resort to the reduction of food consumption and selling of livestock, family assets and forest products such as charcoal to buy food. The results are in agreement with findings from a similar study by Ajao *et al.* (2010) that revealed that food availability to larger families per head was frequently lower than that of smaller families and that per capita food intake decreases with an increase in family size. Similar work by Sani and Kemaw (2019) also indicated that households with larger family sizes tend to be more food deficient than those with smaller family sizes.

As expected, the results indicated that the education level of the household head reduced the probability of selling livestock and family assets to buy food in the study area by 1% which could be explained by the fact that being an important human capital, education increases a household's opportunities for food access as well as production capacity. Increased access to agricultural inputs and technology in climate-smart agricultural practices could enhance household's food productivity in the face of climatic uncertainties thereby improving its food security. Other studies also reported that education has a positive influence on a household's food security (Benjamin and Umeh, 2012; Kirimi *et al.*, 2013; Maziya *et al.*, 2017).

Further, the results indicated that households with access to credit were more likely to adopt selling of livestock as a coping strategy than households without access to credit facilities which could be due to the fact that access to credit provides capital to households for investment in livestock production whose sales, in turn, provide income for food purchase in times of food shortage. The current trend of the results is in agreement with findings from other studies which indicated that access to credit increases the chances of farming households acquiring productive resources which boost production thus improving the household's food security (Awotide *et al.*, 2015; Maziya *et al.*, 2017).

Distance to the market had a significant negative and positive influence on the adoption of reduction of food consumption and selling of forest products, respectively, implying that households near the market were less likely to reduce food consumption compared to those far away from the market who were more likely to sell forest products to buy food. This could be because access to the market increases access to food products as well as agricultural inputs, information and technologies for enhanced agricultural production thus improving the households' food security. The results are in agreement with findings by Glenna *et al.* (2017) which established that households that have access to major market centers had a significantly higher likelihood of being food secure compared to those without. Further, Hebebrand and Wedding (2010) also noted that proximity to the market increases households' access to food products since trade in markets allows food to flow from areas of surplus to areas of deficit.

Lastly, the results indicated that households with larger land sizes were more likely to use income from livestock sales to buy food compared to those with smaller sizes of land. This could be explained by the fact that large sizes of land increase a household's capacity to keep larger herds of livestock and hence households with larger land sizes can sell more livestock to buy food in times of food shortages compared to those with smaller pieces of land. A similar study by Asmelash (2014) indicated that households with large herd sizes had better chances of earning more income from livestock production, thus enabling them to purchase food on cash when they are faced with food deficit as well as investing in farm inputs thereby increasing their food security.

Contrary to the expectation, the results implied that an increase in land size increased a household's probability of adopting reduction of food consumption as a coping strategy to food shortage. This could be because most households in the study area use smaller proportions of their total land sizes for crop production since large land sizes may require more investments in terms of farm inputs and labor. Further, recurrent crop failures due to droughts may also discourage farmers from cultivating large sizes of land. The results however contradict findings by Muraoka *et al.* (2014) which indicated that land size had a positive influence on the value of crop production, net crop income and net household income per adult equivalent in Kenya. Similarly, contradictory findings were reported by Apanovich and Mazur (2018) who noted that each additional acre of household's land size in Masaka District, Uganda was associated with a 70% higher probability of having more than two meals among the households.

5.5 Farmers' adaptation strategies to climate variability and extreme climate events and the determinants of the choice of specific adaptation strategies in the study area

5.5.1 Farmers' adaptation strategies to climate variability and extreme climate events in the study area

Close examination of the present study's findings established a significant variation in the farmers' adoption of mixed farming systems, use of hybrid seeds, manure use, application of fertilizers, practicing irrigation, agroforestry, planting trees for shade and moving herds in search of pasture across the four agro-ecological zones. The possible explanation for the variation in the adoption of the above-mentioned strategies could be the difference in livelihood assets in the agro-ecological zones which are critical determinants of households' ability to adopt different adaptation strategies. Households in the arid and semi-arid zone, for example, are more likely to adopt mixed crop and livestock farming since they possess larger sizes of land compared to those in the transitional and semi-humid zones. According to Fadina and Barjolle (2018), large land sizes increases the likelihood of adopting a variety of adaptation strategies.

On the other hand, households in semi-humid zones are more likely to adopt the use of improved crop varieties and fertilizers owing to their higher financial capacity compared to those in the arid zones. According to Acquah and Onumah (2011), Fagariba *et al.* (2018) and Osei (2017), financial constraint is a major limitation to farmers adaptation to climate variability. Additionally, households in regions that experience higher exposure and sensitivity levels are more likely to adopt various adaptation strategies to cushion themselves against severe agricultural losses compared to those with less exposure and sensitivity (Maddison, 2007; Mutunga *et al.*, 2017; van Valkengoed *et al.*, 2022).

The results corroborate findings by Dasmani *et al.* (2020) which indicated variation in the adoption of different climate change adaptation strategies in three agro-ecological zones in Ghana. In addition, the results are in agreement with findings from a similar study by Seo *et al.* (2008) who reported differential adaptation strategies by agro-ecological zones in livestock management systems in Africa. Similarly, while working on smallholder farmers' perception and adaptation to climate change and variability in Kitui County, Kenya, Mutunga *et al.* (2017) reported differential adoption of adaptation strategies by smallholder farmers' in Kaveta and Mikuyuni Villages.

The results indicated that a higher percentage of households in the arid and semi-arid zones practiced mixed crop and livestock farming systems compared to those in the transitional and semi-humid zones. The reason for the higher adoption of mixed farming in the arid and semi-arid zones could be due to the fact that farmers in the arid and semi-arid zones are more likely to experience low crop yields owing to the higher temperatures and erratic rainfall patterns in the zones as opposed to their counterparts in the transitional and semi-humid zones. Adoption of both crop and livestock production systems therefore helps farmers in the arid and semi-arid zones gain benefits from the resulting crop-livestock interactions thereby achieving greater farm efficiency, productivity and sustainability. Additionally, income from livestock provides a significant buffer for low crop yields in the arid and semi-arid zones which is crucial in shielding the farmers from food insecurity. Further, households in the arid and semi-arid zones possess bigger land sizes proving adequate crop and pasture lands for mixed farming. The results are in agreement with findings from other studies (Herrero *et al.*, 2010; Sumberg, 2003; Thornton and Herrero, 2015).

In regard to the use of improved crop varieties, the results indicated low adoption in the arid zone compared to the other three zones, which could be attributed to low financial capacity in the zone thus limiting the ability of farmers to afford the improved crop varieties. Key informant interviews with the local leaders revealed that most farmers did not have the financial capacity to buy improved crop variety seeds since at the time of the planting season most of the farmers in the zone are already faced with food shortages and relying on off-farm income to buy food. Similar results where farmers adopted the use of improved seed varieties to reduce agricultural losses resulting from climate variability and extreme climate events have been reported in other studies (Atlin *et al.*, 2017; van Ettena *et al.,* 2019). Further, Fagariba *et al.* (2018) also noted that high cost of farm inputs such as improved seeds was a hindrance to farmers' adaptation to climate variability and extreme climate events.

Additionally, the results indicated low adoption of irrigation in all the zones with the lowest adoption reported in the arid and semi-arid zones compared to transitional and semi-humid zones. The lower adoption of irrigation in arid and semi-arid zones could be attributed to lack of access to water for irrigation owing to the higher sensitivity of water sources to climate variability reported in the zones compared to the transitional and semi-humid zones as well as financial constraints and inadequate technical capacity to invest in irrigation. The results concur with findings by Mutunga *et al.* (2017) which showed low adoption of irrigation among smallholder farmers in Kitui County. Similarly, Osei (2017) while working on climate change adaptation constraints among smallholder farmers in rural households of the central region of Ghana reported irrigation as the least adopted adaptation strategy due to unreliable sources of water and lack of financial resources.

Pertaining to agroforestry and planting trees for shade, the results established that most farmers in the semi-humid, transitional and semi-arid zones had adopted the strategies. On the contrary, very low adoption was reported in the arid zone compared to the other three zones. The high adoption of the strategies in the semi-humid, transitional and semi-arid zones could be probably because the climatic conditions in the zones are favorable to agroforestry trees owing to the moderate temperatures and availability of soil moisture compared to the higher temperatures, low rainfall and frequent water shortages in the arid zone making it difficult for agroforestry and shade trees to thrive in the arid zone. Additionally, farmers in the semi-humid, transitional and semi-arid zones have higher access to extension services which provide opportunities to learn about agroforestry technologies and the best tree species for their zones due to their proximity to the County headquarters compared to those in the arid zone. Fagariba *et al.* (2018) also reported high adoption of agroforestry by farmers in Sissala West District since farmers perceived it as the best adaptation method to improve microclimate, boost soil fertility and reduce the high intensity of direct sunlight on the crops and soil nutrients. Additionally, Thorlakson and Neufeldt (2012) noted that agroforestry was an important adaptation strategy since farmers who practiced it had improved standards of living than those who had not adopted the practice due to improved farm productivity, increased off-farm incomes and better environmental conditions of their farms thereby reducing their vulnerability to climate change.

With regard to the use of fertilizers, the results established low adoption in arid and semi-arid lands compared to the transitional and semi-humid zones which could be attributed to lower financial capital in the zones thus farmers resort to the utilization of cheap and readily available organic manure as opposed to the costly fertilizers. Additionally, farmers in the semi-humid and transitional zones have relatively smaller pieces of croplands compared to the arid and semi-arid zones thus are forced to rely on inorganic fertilizers to boost productivity. The current trend of results concurs with findings by Fagariba *et al. (*2018) which showed that most farmers in Sissala West District perceived the high cost of most agricultural inputs such as fertilizers as a setback to adaptation. Similarly, research findings from a study by Acquah and Onumah (2011) revealed that high input cost prevents poor smallholder farmers from accessing the needed farm inputs for climate change adaptation. Further, the results indicated that the adoption of manure was lowest in the arid zone compared to the other three zones. The low adoption could be attributed to the large farm sizes reported in the arid zone relative to the other zones which enable farmers to practice shifting cultivation by farming on smaller proportions of the farmlands from season to season thus relying on natural nutrient recycling. In addition, most farmlands in the arid zones are naturally fertile since farmers in the arid zone do not practice intense agriculture due to the low and erratic rain patterns, which often result in subsequent crop failure especially in the long rain reason leaving farmers with only one main season (“short rains”) for crop production, consequently giving farmlands sufficient time for natural nutrient regeneration. On the other hand, farmlands in the other zones are nutrient deficient since nutrients have been overexploited for decades thus farmers have to rely on manure and fertilizers to boost their productivity. Similar results where the use of organic fertilizers as an adaptation strategy to climate change and variability was adopted by farmers have been reported in other studies (Fagariba *et al.,* 2018; Mutunga *et al.,* 2017; Ndamani and Watanabe, 2015; Tiwari *et al.,* 2014).

Regarding livestock production, the most common adaptation strategies adopted by the farmers in the study area were reducing the number of livestock and seeking services from veterinary officers. The results established that a greater percentage of farmers in the arid zone had adopted reducing number of livestock compared to their counterparts in the other three zones. This could be because since livestock production is a major livelihood option in the arid zone compared to the other zones owing to the harsh climatic conditions for crop farming as well as the availability of large pasture lands for large scale livestock production, farmers resort to reducing their livestock herds to manageable numbers in the event of pasture and water shortage since recurring droughts and increasing temperatures in the arid zone are likely to strain the supply of pasture and water for livestock production. Similar results have been reported in other studies by Tiruneh and Tegene, (2018) and Ripple *et al*. (2014).

Concerning seeking veterinary services, more farmers in the arid zone had adopted the strategy compared to their counterparts in the other zones which could be attributed to the higher sensitivity of livestock to pests and diseases in arid zone relative to the other zones owing to the higher temperatures and erratic rainfall patterns which intensify the abundance, distribution and transmission of animal pathogens. The results concur with findings by Baylis and Githeko (2006) who noted that climate change is likely to alter the abundance, distribution and transmission of animal pathogens thereby amplifying livestock diseases outbreaks. The importance of veterinary services in climate change adaptation has also been highlighted by Stephen and Soos (2021).

5.5.2 Determinants of farmers' choice of specific adaptation strategies to climate variability and extreme climate events in the study area

The ability and decision to adopt a particular adaptation strategy are determined by several socio-economic factors (Maddison, 2007). Results from the present study indicated that different socio-economic characteristics of farmers had a varying influence on the farmers' choice of specific adaptation strategies to climate variability and extremes. The results showed that there was a significant negative influence of age on the adoption of crop diversification, soil conservation techniques and agroforestry which implies that younger farmers in the study area were more likely to adopt the adaptation strategies compared to older farmers. This could be because younger farmers are innovative and likely to try new technologies and methods to improve agricultural productivity. Conversely, in most cases, older farmers are often not aware of recent innovations in agriculture and/or are reluctant to try new methods. Similar findings where there was a significant negative influence of age on the adoption of mixed cropping and improved crop varieties were reported in other studies (Ali *et al.*, 2014; Ojo and Baiyegunhi, 2018).

With regard to the gender of the household head, female-headed households were more likely to use fertilizers and pesticides compared to their male counterparts which could be attributed to the fact that female-headed households have less access to resources such as land and therefore resort to investing in the use of fertilizers and pesticides to boost agricultural productivity in their small pieces of land. On the other hand, the results indicated that male-headed households were more likely to adopt crop diversification, use of manure and agroforestry as opposed to female households. The probable reason could be that female-headed households are usually constrained by family labor since they are culturally assigned responsibility in domestic activities and also have less access to resources and information compared to male-headed households which limit their ability to carry out labor-intensive activities (Asrat and Simane, 2018; Belay *et al.*, 2017; Deressa *et al.*, 2008).

The easiness with which male-headed households adapt to climate change compared to female-headed ones was also highlighted by Tenge *et al.* (2004) and while working on the social and economic factors that influence the adoption of soil and water conservation (SWC) measures in the West Usambara highlands, Tanzania. Further, Deressa *et al*. (2008) noted that male-headed households are more likely to have access to technologies and climate change information than female-headed households and therefore better placed in adopting diverse adaptation strategies than female-headed households. In addition, Mihiretu *et al.* (2019), Asrat and Simane (2018) and Belay *et al.*(2017) also reported that male-headed households had a higher probability of adopting new agricultural technologies compared to their female counterparts.

The results of the current study are however contrary to findings by Nhemachena *et al.* (2014) which showed that female-headed households in Southern Africa were more likely to take up climate change adaptation practices since they are responsible for much of the agricultural work in the region and therefore have greater experience and access to information on various management and farming practices.

The negative influence of household size noted on the adoption of soil conservation techniques could be explained by the fact that since not all members in the family are actively engaged in agricultural activities, a bigger household size would increase demand for resources thereby diverting family labor to off-farm jobs to supplement households' food and economic needs. The results are in agreement with findings by Dumenu and Tiamgne (2020) which indicated that a household with more dependents was more likely to direct a larger proportion of its resources towards the household's welfare leaving it with little resources for adapting to climate change and variability thereby increasing its vulnerability to climate variability and extremes. In addition, Arun and Yeo (2020) reported a negative influence of household size on farmers' adoption of adaptation strategies such as crop irrigation, changing of crop date, crop type, and crop varieties. Similarly, Tizale (2007) found that there was a possibility that households with large families diverted part of their labor to off-farm income-generating activities which help to ease the consumption pressure imposed by a large family. The results, however, contradict findings from similar studies by Asrat and Simane (2018), Belay *et al.* (2017) and Jiri *et* *al.* (2015) which indicated a positive influence of household size on the adoption of labor-intensive adaptation strategies.

From the study, membership in a farmers' organization reduced farmers' probability of adopting hybrid crop varieties. Discussions with farmers and key informants from relevant institutions revealed that the high cost of hybrid crop varieties discouraged households from adopting the strategy thus gaining knowledge about the hybrid crop varieties without financial facilitation from the organizations was not adequate in enabling farmers to adopt the strategy. It was however noted that membership in a farmers' organization significantly increased the probability of adopting soil conservation techniques probably because farmers' organizations in form of cooperatives, self-help groups or market groups function as sources of information, learning platforms and social support systems that are critical in creating linkages with other actors, providing space for knowledge generation and sharing, discussion of innovation and information necessary in adapting to changes in climatic conditions.

The current trend of results is concurrent with findings of similar studies (Borda-rodriguez and Vicari, 2015; Kearney and Berkes, 2007). In addition, studies by Kangogo *et al.* (2020), Žurovec and Vedeld (2019) and Bryan *et al.* (2011) indicated that farmers belonging to farmers' organizations were more likely to adopt different adaptation strategies since social networks facilitate information flows through discussion of problems, sharing innovations and technologies as well as making collaborative decisions which enhance their capacity to adapt to climate variability and extreme climate events.

Further examination of the present study's results revealed that the farming experience of the household head positively influenced the adoption of crop diversification and soil conservation techniques which could be ascribed to the fact that experienced farmers have high skills in farming techniques and management and are able to spread risk in the face of climate variability and extreme climate events by exploiting strategic complementarities in different adaptation strategies. The results are in agreement with findings from similar studies by Asrat and Simane (2018) and Belay *et al.* (2017) which revealed a positive influence of farming experience on the adoption of several adaptation strategies. Further, the current trend of results corroborates findings of a similar work by Hassan and Nhemachena (2008).

The education level of the household head increased the probability of adopting hybrid crop varieties, soil conservation techniques, use of manure, agroforestry and use of pesticides which is attributable to the fact that educated farmers are more likely to perceive changes in climatic conditions, better recognize the risks associated with climatic changes and have better reasoning capability and awareness about new technologies. The results are in consonance with findings from similar studies (Asrat and Simane, 2018; Belay *et al.*, 2017; Deressa *et al.*, 2008; Fagariba *et al.*, 2018; Hassan and Nhemachena, 2008).

Access to credit facilities had a positive influence on the adoption of all the strategies except for soil conservation techniques. The results imply that access to credit facilities increased the probability of farmers adopting different adaptation strategies which could be attributed to the fact that access to credit facilities increases farmers' financial capacity to meet transaction costs associated with several adaptation strategies. The results are in agreement with similar studies by Arun and Yeo (2020), Fagariba *et al.* (2018) and Tesfaye and Seifu (2016) which indicated a positive relationship between access to credit facilities and adoption of different adaptation strategies.

Regarding access to extension services, the results indicated a significant positive influence on the adoption of drought-resilient crops, soil conservation techniques, use of fertilizers and agroforestry probably because agricultural extension services provide farmers an opportunity to acquire information and training on climatic variations, new technologies and innovations as well as new skills and technical capacity for sustainable implementation of adaptation strategies. The results are in agreement with findings from similar studies which reported a positive influence of access to extension services on farmers' adoption of different adaptation strategies (Belay et *al.*, 2017; Fagariba *et al.*, 2018; Nhemachena *et al.*, 2014; Teklewold *et al.*, 2019).

Contrary to the expectation, access to weather information had an insignificant negative influence on the adoption of all the adaptation strategies except for the use of fertilizers and agroforestry. Similar studies noted that access to weather information increases farmers awareness of climatic changes which is essential in making informed decisions on preparedness to reduce agricultural losses that might occur from climate variability and extreme climate events thereby increasing the probability of farmers adopting different adaptation strategies (Asrat and Simane, 2018; Belay *et al.,* 2017; Fagariba *et al.,* 2018; Nhemachena *et al.*, 2014). The negative influence of access to weather information on the adoption of the different adaptation strategies in this study could suggest that farmers are more likely to invest in off-farm livelihood options as opposed to agriculture upon noting the possibility of occurrence of extreme weather events.

The results further indicated that distance to the nearest market had a negative influence on the adoption of all the adaptation strategies except for use of manure implying that ease of access to the market increased farmers' probability of adopting the different adaptation strategies. Proximity to market facilitates farmers’ access to information and agricultural inputs such as hybrid crop varieties, fertilizers and pesticides as well as a market for selling agricultural outputs thereby increasing the likelihood of adopting different adaptation strategies. The results are in consonance with findings by Marie *et al.* (2020) which pointed that farmers with market access were 0.34 times more likely to adopt climate change adaptation strategies than those without. Further, Belay *et al.* (2017) found a positive and significant effect of distance to the nearest market on farmer input intensity and crop diversification among farmers in Arsi Negelle district of West Arsi Zone, Oromia Regional State of Ethiopia.

Lastly, land size increased the probability of adopting drought-resilient crops while reducing the probability of adopting the use of fertilizers. The mixed effect of land size on the adoption of the different strategies could be because a large farm size allows farmers space to practice crop diversification and also discourage the adoption of high-cost strategies. The results of the study are in consonance with findings from Žurovec and Vedeld (2019). Similarly, Fadina and Barjolle (2018) found that lac like diversification of crops and livestock, agroforestry, perennial plantation and use of hybrid crops in South Benin.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study established that there was a non-significant decreasing trend in annual rainfall in all the four agro-ecological zones in the study area. The decreasing annual rainfall which could be attributed to the current changes of the climate system resulting from global warming is likely to result in frequent occurrence of drought incidences causing a significant reduction in crop yields as well as pasture and water shortage for livestock production which are the main sources of livelihood in the study area.

In regard to seasonal rainfall trend analysis, the study established that there was a decreasing trend in March-April-May (MAM) seasonal rainfall in the arid and semi-arid agro-ecological zones and an increasing trend in the transitional and semi-humid zones. Further, the study deduced that there was a non-significant decreasing trend in the October-November-December (OND) seasonal rainfall in the four agro-ecological zones. The decreasing trend in OND seasonal rainfall has a negative implication on food security since the OND seasonal rainfall is considered the most reliable season for rain-fed agriculture in the study area.

Additionally, there was a higher annual rainfall variability in the drier (arid) and wetter (semi-humid) zones compared to that in zones with intermediate climatic characteristics (semi-arid and transitional zones). This implies that the drier and wetter zones are likely to experience a higher occurrence of extreme weather events such as droughts, high-intensity rainfall and floods compared to the intermediate zones.

With reference to temperature, the study established that there was a statistically significant increasing trend in annual and OND seasonal average maximum and minimum temperatures was reported in all the four agro-ecological zones. The trend in average maximum and minimum temperatures for the MAM season in all the agro-ecological zones was however not significant. In regard to variability, the study established that there was low temperature variability in all the agro-ecological zones.

Further, the study deduced that there was low-temperature variability compared to rainfall variability in all the four agro-ecological zones.

Regarding households' vulnerability, the study deduced that there was a statistically significant difference in the overall vulnerability and its components' indices across the four agro-ecological zones.

In terms of exposure, the study found that the transitional and arid zones had the highest and second highest exposure indices due to the high rate of change in minimum and maximum temperatures and the number of droughts reported in the zones, respectively. Additionally, temperature variability and occurrence of droughts highly influenced the exposure levels of households.

Further, the study established that sensitivity increased with aridity where the arid zone recorded the highest sensitivity index score followed by the semi-arid and transitional zones while the semi-humid zone had the least sensitivity index score.

Regarding adaptive capacity, the semi-humid zone had the highest adaptive capacity followed by the semi-arid and transitional zones while the arid zone had the lowest adaptive capacity index score. Further, the study established that adaptive capacity was the most important component in reducing households' vulnerability to climate variability and extreme climate events and can thus be influenced by policy to enhance households' resilience to climatic shocks.

Regarding the overall vulnerability index, the study found that the arid zone had the highest vulnerability index which could be explained by the second highest exposure and highest sensitivity levels as well as the lowest adaptive capacity reported in the zone. Further, even though the transitional zone had a moderate sensitivity index, the highest exposure and moderate adaptive capacity indices increased its vulnerability index score making it the second most vulnerable zone. The study therefore concludes that regions exhibiting moderate exposure and sensitivity to climate variability and extreme climate events are at the risk of having high vulnerability levels if their adaptive capacity is not enhanced.

Additionally, the present study established that different socio-economic characteristics of households had varying influence on the households' vulnerability levels. Variables such as the highest level of education, access to credit facilities, access to extension services and decreasing distance to markets increased the probability of a household belonging to the low and moderate vulnerability categories. The study therefore concludes that increasing opportunities for access to education, markets, weather information, extension services and credit facilities would be critical in enhancing households' adaptive capacity thereby reducing their vulnerability to climate variability and extreme climate events.

In regard to food shortage coping strategies, the study established that there was a statistically significant difference in the adoption of the use of off-income to buy food, food for work programmes, receiving relief food, selling livestock to buy food, selling forest products and reducing the number of meals per day as food shortage coping strategies in the four agro-ecological zones.

With reference to adaptation strategies, there was a statistically significant difference in the adoption of mixed farming systems, use of improved crop varieties, use of manure, use of fertilizers, practicing irrigation, agroforestry and planting trees for shade as of adaptation strategies to climate variability across the four agro-ecological zones.

Further, the study established that different socio-economic characteristics that different socio-economic characteristics had varying influence on the farmers' choice of specific coping and adaptation strategies in the study area.

6.2 Study's contribution to knowledge

The present study was motivated by the need to understand the vulnerability patterns of households in different agro-ecological zones in Kitui County, Kenya, which is crucial in guiding effective planning and implementation of adaptation strategies, in order to increase households' resilience to the effects of climate variability and extreme climate events. Previous vulnerability assessment studies in Kitui County have been done on regional scales (Marigi, 2017; Mwangi *et al.*, 2020) with little focus on household-level assessments. The present study therefore contributes to knowledge by providing a household-level vulnerability profile of the study area by measuring indicators of exposure, sensitivity and adaptive capacity at the household level as opposed to the county and ward levels as measured by Marigi (2017) and Mwangi *et al.* (2020), respectively, since the decision and ability to adopt different coping and adaptation strategies are determined at the household level. Additionally, being the first household-level vulnerability assessment in the study area, the findings of the present study provide a baseline for evaluating the effectiveness of climate variability interventions in reducing households' vulnerability in the study area.

Moreover, the study provides evidence-based information on comparative adoption of different coping and adaptation strategies to climate variability and extreme climate events by farmers in different agro-ecological zones in the study area resulting from different exposure levels and adaptive capacities of households in the different agro-ecological zones. This information is important to policymakers and other stakeholders in designing and implementation of policies, programmes and projects aimed at enhancing households' adaptive capacity and resilience to climate variability and extreme climate events with respect to different agro-ecological zones in the study area.

6.3 Recommendations

From the findings, the present study makes the following recommendations aimed at increasing households' resilience to climate variability and extreme climate events by enhancing their adaptive capacity to minimize their sensitivity and consequently vulnerability to climate variability and extreme climate events.

i. Farmers should embrace planned adaptation that increases their agricultural productivity in the advent of climate variability by adopting strategies such as mixed farming, crop diversification, planting drought resilient and improved crop varieties, irrigation, and water harvesting and soil moisture conservation techniques among others with respect to their agro-ecological zone.

ii. Farmers should diversify their livelihood options with more emphasis on off-farm income-generating activities which provide a buffer against climate risks on climate-sensitive livelihood options.

iii. Farmers should be proactive in seeking climate-related information and extension services from the relevant institutions to enhance their ability to adapt to climate variability and extreme climate events.

iv. Climate variability and extreme climate events intervention policies, programmes and projects by the County Government of Kitui and relevant stakeholders should be guided by location-specific rainfall trend analysis and household vulnerability levels in different agro-ecological zones in the County for effective response to climate variability.

v. The County Government of Kitui and other key stakeholders in climate risk and disaster management such as the National Drought Management Authority and Kenya Meteorological Department should provide farmers with timely and accurate weather forecasts to enable them to prepare adequately for climate variability and extreme climate events.

vi. The County Government of Kitui should improve farmers’ access to markets, credit facilities and extension services to enhance their adaptive capacity.

vii. The County Government of Kitui and other non-governmental organizations should prioritize enhancing access to basic and tertiary education in policies and programmes aimed at enhancing households resilience to climate variability especially in the arid and marginalized zones since education is an important human asset that increases access to employment opportunities, household off-farm income and ability to adopt different adaptation strategies thereby enhancing households’ adaptive capacity.

viii. The County Government of Kitui should provide more employment opportunities to households in the study area with priority in the arid and semi-arid zones to increase their human and financial capital thereby enhancing their adaptive capacity to climate variability and extreme climate events.

ix. Policies, programmes and projects by the County Government of Kitui and other stakeholders aimed at enhancing households' ability to cope with food insecurity should be informed by different socio-economic characteristics that influence households' ability to cope with insecurity in specific agro-ecological zones.

x. Climate variability adaptation policies, programmes and projects by government and non-governmental agencies aimed at helping farmers adapt to climate variability and extreme climate events should be guided by local farmers' needs in specific agro-ecological zones.

xi. Since various socio-economic characteristics have varying influence on farmers' choice of different adaptation strategies, climate variability adaptation interventions by County Government of Kitui and other stakeholders should target specific socio-economic characteristics that are relevant to the adaptation strategies in question.

6.4 Suggestions for further studies

The study recommends further studies in the following areas;

i. Analysis of seasonal variability trend of rainfall onset for informed timely planting as an adaptation strategy to climate variability in the study area.

ii. Analysis of seasonal rainfall intensity and distribution and its effects on the productivity of different crop varieties in the study area.

iii. Assessment of the effectiveness of different adaptation strategies in reducing households' sensitivity to climate variability and extreme climate events in the study area.

iv. Assessment of institutional response to climate variability and extreme climate events in the study area.

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APPENDICES

Appendix 1: Household Survey Interview Schedule

Vulnerability of farmers to Climate Variability and Extreme climate events in different agro-ecological zones Kitui County - Kenya

Please answer all of the questions honestly as they pertain to your household. This survey is solely for academic purposes and we commit to keeping all the responses confidential. It would be very appreciated if you could answer all of the questions.

Enumerator's Name: _________________ Date of interview: _______/____/____

Time when the interview started: ___________End: ___________________________

Sub-County:__________________Ward:______________Location:_________________

Sub-Location_____________ Village: ____________________

Coordinates:

N_______________________________S____________________________

	Respondent's name.		
	Phone No.		
	ID No.		
	Respondent's sex/gender	1=male, 2=female	
	Respondent's age		In years
	Relationship with Household head (HH)	1=Household head, 2=Spouse of the household head, 3=Grown up child, 4=Relative, 5=Others (Specify)	
1.	HH's gender	1=male, 2=female	

2.	HH age		In years
3.	HH marital status	1= Single 2=Monogamously married 3=Polygamously married, 4= Divorced/ separated 5= Widowed	
4.	Household type	1=Male headed 2=Female headed 3=De jure female headed (widow, never married, divorced), 4=De facto female headed (husband absent) 5= Not yet married, 6=Polygamous	
5.	HH's level of education	1=none, 2=primary, 3=secondary, 4=College 5=University 6=Others (specify)	
6.	HH's occupation	1=full-time farmer, 2=Business	

		3=Casual labourer 4= Formal employment 5=Others (specify)	
7.	What is the main occupation of the Spouse?	1=full-time farmer, 2=Business 3=Casual labourer 4= Formal employment 5=Others (specify)	
8.	Number of family members in the household (Including respondent)?		
9.	Indicate number of family members actively engaged in daily agricultural activities______		
10.	What is the **Main** labour source in the farm? ______	1=Family labour, 2=Hired labour, 3=Others (specify)	
11.	Do you belong any farmers' organization?	0=No, 1=Yes	
12.	If yes is the group registered?	0=No, 1=Yes	

13.	How often do you make your contributions?	1=Always pays on time; 2=Never pays on time; 3=Rarely pays; 4= Never pays	
14.	Indicate the number of years you have been a member in the organization_____		Indicate the years
15.	How often are the organization's meeting held?_______	1= Weekly; 2= Fortnightly; 3= Monthly; 4= Quarter yearly	
16.	Do you play any leadership role in the organization?	0= None; 1= Chairperson; 2= secretary or treasurer	
17.	What is your total land size?________		(In acres)
18.	For how long have you been cultivating your current farm?		Give the number of year e.g. 10
19.	How much of your land is/was:		

	a) Allocated family land? .... b) Inherited? .... c) Purchased? ...... d) Rented in?		
20.	Describe the state of the land when you obtained this land?	1=Virgin land/pasture, 2=Land under fallow, 3=Already under cultivation, 4=Others (Please specify)	
21.	Do you hold the title Deed to this piece of land?	1=Yes, 2=No	If yes go to 22
22.	If not what is the relationship with the title deed holder ……	1=Landlord, 2=Parent, 3=Community 4=Others (specify)	
23.	How much land is under **crops** (in the current season)?______		(In acres)
24.	How much land is under **pasture** (in the current season)?______		(In acres)

25.	How much land is under fallow (in the current season)?______		(In acres)
26.	What is the land acreage under irrigation throughout the year?_______		(In acres)
27.	What is the land acreage under irrigation during dry spells?________		(In acres)
28.	Have you rented out part of your land?.	Yes=1, 2=No	If No go to 32
29.	If yes what size ______		(In acres)
30.	What is your approximate annual on-farm		Indicate the amount
31.	What is your approximate off-farm annual income? ________		Indicate the amount
32.	Do you have access to loans?	Yes=1, 2=No	If No go to 37
33.	What is the total amount of loan you can access if free of debt? ______		Amount (Ksh)
34.	How much loan did you borrow in the past one year? _________		Amount (Ksh)

35.	Have you noticed any significant changes in weather patterns over the years in relation to agricultural water availability?_	0=no, 1=yes	
36.	If YES, what changes have you observed? a) Increased number of seasons without enough rainfall _______ b) Rainfall increase _______ c) Rainfall decreased _______ d) Flooding _______ e) Rain starts later than expected f) Starts later and ends early___- g) Shorter periods of rainfall_____ h) Higher temperature _______ i) Lower temperatures _______ j) Long inter-seasonal dry spells __ k) Rain starts earlier than expected ____ l) Low overall amounts of rainfall_____ Others (specify) _______	0=No such Change; 1=Increased in frequency 2=Decrease in frequency	
37.	What is your type of farming activity?	1) Livestock (2) Crop (3) Mixed (4) Others (Specify)	

	VULNERABILITY TO CLIMATE VARIABILITY AND EXTREME CLIMATE EVENTS

Exposure

38. What is your opinion of the number and frequency of disasters listed below in the last ten years?

Disaster	**Frequency**			**Estimated number of incidents in the last 10 years**
	Increased	**No change**	**Decreased**	
Floods				
Droughts				
Storms/strong winds				
Wild /forest fires				
Livestock diseases				
Community inter-border conflicts				
Human-wildlife conflict				
Total				

Sensitivity

39. Has any of the following been impacted by disasters (droughts, floods, wild/forest fires, livestock diseases, and conflicts (community inter-border conflicts or human-wildlife conflict) in the past 10 years?

Extreme event	**Human**		**Cows**		**Goats**		**Sheep**		**Others**		**Total**
Floods	Dead	Injured	Dead	Injured	Dead	Injured	Dead	Injured	Dead	Injured	
Droughts											
Storms/strong winds											
Wild /forest fires											
Livestock diseases											
community inter-border conflict											
Human - wildlife Conflict											
Total											

40. Has any of the following been damaged by disasters (droughts, floods, wild/forest fires, livestock diseases, and conflicts (community inter-border conflicts or human-wildlife conflict) in the recent ten years?

Extreme event	Trees (acre/number	Crops (acres)	Productive land (acres)	Road (Km)	House (Number)	Others
Droughts						
Storms/strong winds						
Wild /forest fires						
Livestock diseases						
Conflicts						
Total						

41. What is your opinion of the trends in water quantity in following water sources during the past 10 years?

Water Source	Trend in water quantity			Estimated number of times it has dried up in the last ten years
	Increased	No change	Decreased	
River/stream				
Bore hole				
Shallow well				
Spring				
Earth/sand dam				
Water pan				
Other (specify)				

42. Estimate your household income in the following:

Income structure	Tick	Estimate per year/12 months (Kshs.)

Natural resource-based Income		
Farm wages/ Earnings from Crops		
Livestock production		
Honey Sales		
Forestry products		
Sand harvesting		
Others (specify)		
Total		
Non-natural based income		
Salaried jobs		
Remittances		
Skilled non-farm jobs		
Small business returns		
Others(specify)		
Total		

43. Adaptive Capacity

Component Indicators	**Guiding questions**	**Number**
Physical Assets	Indicate the number of gadgets owned and used in accessing the information	
	Indicate the number of time you accessed extension services in last 1 year	
	Indicate the number of sources of timely early warning weather information	
	Distance in Km to the nearest motorable road	
	Distance in Km to the nearest market	
	Distance in Km to the nearest Water source	
	Distance in Km to the nearest health facility	

Human Assets	Highest level of education of qualification in the family	Level	Number of schooling years

		None Primary High School College Graduate Post Graduate	
	Number of persons in the HH having salaried employment?	Indicate the number	
	Trainings or vocational course attended by family members	Indicate the number	
Natural Assets	What is the size of your land?	Size in acres	
	Size of productive land in acres		
	Size of unproductive land in acres		
	Do you have bullock Small stock (includes goats and sheep Large stock (includes cows, camels, donkeys	Indicate number	
	What is the estimated Gross household income per month?	________________Kshs	
	What is the estimated household savings per month?	_______________________Kshs	
Social Assets	Are you a member of any community based organization? Yes[ ] No[ ] Are you a member of any cooperative society? Yes[ ] No[ ]	Indicate number	
	Indicate the number of credit facilities accessed in the last five years		

	LIVELIHOOD STRATEGIES

44. What are your livelihoods strategies/options?

Livelihood strategy/option	Tick	Estimate amount earned per year/12 months (Kshs.)
Crop farming		
Livestock farming		
Mixed-crop and livestock farming		
Sale of forest products (specify)		
Formal employment		
Informal employment		
Self-employment		
Others (specify)		
Total		

	ADAPTATION TO CLIMATE VARIABILITY AND EXTREME CLIMATE EVENTS

45. Which of the following adaptation strategies have you adopted in your HH in response to the changing climate?

Adaptation Options	Adopted? Yes or No
Shift from livestock keeping to crops farming	
Mixed crop-livestock system	
Crop diversification	
Plant Drought resilient crops	
Build a water-harvesting scheme	
Practice reuse of water	
Crop diversification	
Planting drought tolerant varieties	
Changing planting time	
Implement soil conservation techniques	

Buy insurance	
Put trees for shading	
Irrigation	
Change from crop to livestock	
Reduce number of livestock	
Increase livestock diversity	
Use animal feeds supplements	
Migrate to urban area	
Find off-farm job	
Lease your land	
Use of chemical fertilizer	
Use of organic fertilizer (manure)	
Use minimum tillage	
Use improved crop varieties	
Use of inorganic fertilizer	
Use of pesticides	
Agro-forestry	
Integrated pest management	
Seeking support from veterinary officers	
Move herd from one place to another	
No adaptation	
Others (specify)	

46. Which of the following coping strategies have you adopted in your HH in response to the climate variability induced food shortage?

Coping Strategies	**Adopted? Yes or No**
Selling livestock to buy food	
Reducing the number of meals per day	
Selling household assets	
Relying on relief food	
Working on food for work projects	
Borrowing food from relatives	
Take loans to buy food	
Migrate to urban area	

Find off-farm job	
Sell land	
Others (specify)	

Appendix 2: Key Informants Interview Schedule

Farmers' Vulnerability to Climate Variability and Extreme climate events in Kitui County - Kenya

The questions are designed purely for research purpose and therefore your responses will be treated with strict **confidentiality**. Answering all the questions will be greatly appreciated.

Name of the respondent: ______________________ Age:_________

Occupation______________ Leadership Position:________________________

Sub-County:__________________Ward:______________Location:_________________

Sub-Location_____________ Village: ____________________

Date of interview: _______/____/____

1. What is your perception on changes in the following weather elements in the last 10 years?
   i. Total annual rainfall
   ii. Onset of short rain season
   iii. Onset of long rain season
   iv. Duration of short rain season
   v. Duration of long rain season
   vi. Inter-seasonal dry spells
   vii. Number of seasons with inadequate rainfall
   viii. Temperature

2. What is your perception on frequency and number of incidents of the following disasters in the last 10 years?

i. Floods
ii. Droughts
iii. Strong winds/storms
iv. Wild/forest fires
v. Livestock diseases
vi. Community-interborder conflicts over resources, e.g. water/pasture
vii. Community intra-conflicts over resources, e.g. water/pasture
viii. Human-wildlife conflicts

3. What are the main sources of income in this community?
4. Which are the main sources of water in the area?
5. How many times have the water sources dried in the last 10 years?
6. What is the distance to the nearest permanent water source?

7. How have the changes affected the community livelihoods with regard to the following;

i. Crop yields
ii. Livestock production
iii. Household income
iv. Water resources
v. Forests
vi. Human health (incidences of humans dead/injured/emancipated by climate extremes, food poisoning, water borne diseases etc)
vii. Education (school drop-out incidents)
viii. Social (family conflicts, separation/divorce, crimes etc)

8. Which adaptation measures have you adopted to reduce the effects of climate variability and extremes?
9. Which challenges do you face in your efforts to adapt to climate variability and extremes?
10. How do you /your community cope with extreme climate events?

11. How often do you receive extension services in a year?
12. Do you receive early warning weather information and from which sources?
13. Do you receive relief food and from which organizations?
14. Do you belong to any community based organization? How many CBOs are there in the area?
15. Do you have membership in a SACCO? How many SACCOs are there in the area?
16. Have you received any other assistance from Governmental or Non-governmental organizations to cope with extreme climate events in the past 10 Years?
17. If Yes, what kind of assistance and from which organizations?
18. What kind of assistance would you prioritize in order to effectively adapt to climate variability and extreme climate events?

Appendix 3: Multicollinearity test for explanatory variables used in the study

Variables	VIF
Agro-ecological zone	1.169
Gender of the household head	1.128
Age of the household head	2.085
House hold size	1.146
Membership to farmers group	1.425
Years involved in farming in this piece of land	1.989
Access to credit when free of debt	1.082
Acess to extension services	1.372
Access to Early warning information	1.064
Distance in Km to the nearest market	1.109
Highest education level in the HH (Number of schooling years)	1.095
Size of your land	1.271

a. Dependent Variable: Overall Vulnerability Index 1

Appendix 4: Field Photos

Data collection at Yuku

Source: Field Photo by Author (2019)

Micro-catchment water harvesting using *Zai* pits in Kasaini

Source: Field Photos by Author (2019)

Soil conservation by terracing in Kauwi

Source: Field Photos by Author (2019)

Small scale irrigation in Kasaini

Source: Field Photos by Author (2019)