DROUGHT DRIVERS, PROJECTION AND EFFECTS ON CEREAL YIELDS AND SMALLHOLDER FARMERS' ADAPTATION STRATEGIES IN MAKUENI COUNTY, KENYA

JACKOB HAYWOOD JACK ONDIKO

A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Geography of Egerton University

EGERTON UNIVERSITY

OCTOBER, 2024

DECLARATION AND RECOMMENDATION

Declaration

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

Signature……………………………………..Date …………………………………………

Jackob Haywood Jack Ondiko

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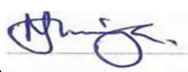
Recommendation

This thesis has been submitted with our approval as University Supervisors

Signature…………  ……………… Date………18/10/2024…………………

Dr. Amon M. Karanja, Ph.D

Department of Geography

Masinde Muliro University of Science and Technology

Signature…………………………………………... Date…..………………………….……

Dr. Obulinji W. Humphreys, Ph.D

Department of Geography

Egerton University

Signature…………………………….………………..Date…………………………………

Prof. Kennedy Nyabuti Ondimu, Ph.D

Department of Geography

Egerton University

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DEDICATION

This work is dedicated to my late parents, John R. Haywood and Deborah Adhiambo Ondiko Haywood who believed in me and supported my education.

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ABSTRACT

Increasing frequency and severity of drought is a major challenge to rain-fed cereal production in Arid and Semi-Arid Lands globally. Frequent and severe droughts affect cereal production and food security resulting in increased vulnerability, malnutrition and even human deaths in the affected regions in Kenya. The specific objectives of the study were to: project drought trends in Makueni County between 2024 to 2054; determine the influence of Indian Ocean Dipole on occurrence and nature of droughts; examine the effect of drought on cereal yields; find out the drought adaptations practiced in Makueni County and evaluate outcomes of drought adaptation strategies among smallholder cereal farmers in Makueni County. The study adopted Explanatory Sequential Mixed Methods Research Design. Five data sets were used in the study: Rainfall data (1990 to 2020), Indian Ocean Sea Surface Temperatures data (1990 to 2020), cereal data (1990 to 2020), household data (N=225) and key informants (N=16). Extraction from secondary sources, content analysis, triangulation, survey and key informant interviews were used in data collection. Standardized Precipitation Index, Autoregressive Integrated Moving-Average Models, Coefficient of determination Pearson's *r* and descriptive techniques were used in data analysis. There were erratic, unpredictable and fluctuating rainfall patterns accompanied by 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts between 1990 and 2020. An increasing trend of seasonal droughts was projected due to declining March-April-May seasonal rainfall. An upward trend in October-November-December seasonal rainfall was projected from 2024 to 2054. Sea Surface Temperatures in Equatorial Western Indian Ocean and Equatorial Eastern Indian Ocean influence occurrence of drought in Makueni County whereby R^2 values of 0.580 (58%) and 0.674 (67.4%) were established, respectively. There was a significant, positive correlation between rainfall and sorghum, finger millet and maize yields. More females than men adapted to droughts through use of Indigenous Knowledge: drought prediction and monitoring (61%), bio-control of weeds (57%), use of farm manure (54%), supplementary irrigation (51%) and early planting of seeds (51%). Most of the smallholder farmers who adopted small farm sizes for sorghum (43%), finger millet (42%) and maize (60%) recorded low yields between 1 and 10 bags. Information and data generated by the study are expected to result in improvement in drought adaptation policy formulation and adaptive capacity of the smallholder cereal farmers hence improvement in food production and security.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZs	-Agro-Ecological Zones
AGNES	**-** Africa Group of Negotiators Experts Support
AMO	-Atlantic Multi-decadal Oscillation
ANN	- Artificial Neural Networks
ARIMA	**-** Autoregressive Integrated Moving-Average
ASALs	-Arid and Semi-Arid Lands
ATLAS	- Adaptation Thought Leadership and Assessments
CBAs	-Community Based Adaptations
CBO	- Community Based Organizations
CCAFS	-Climate Change and Food Security
CGoM	-County Government of Makueni
DJF	- December-January-February
DT	- Drought-Tolerant
EEIO	- Equatorial Eastern Indian Ocean
ENACTS	- Enhancing National Climate Services
ENSO	-El Niño Southern Oscillation
EWIO	-Equatorial Western Indian Ocean
FAO	-Food and Agricultural Organization of the United Nations
FEWS-NET	- Famine Early Warning Systems Network
GCA	- Global Center on Adaptation

GoK -Government of Kenya

GWPEA -Global Water Partnership Eastern Africa

HoA - Horn of Africa

ICPAC - Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre

IGAD - Intergovernmental Authority on Development

IK - Indigenous Knowledge

IFAD - International Fund for Agricultural Development

IOD -Indian Ocean Dipole

IPCC -Intergovernmental Panel on Climate Change

ITCZ -Inter-Tropical Convergence Zone

JJA - June-July-August

JRC - Joint Research Centre

KCEP-CRAL-Kenya Cereal Enhancement Programme – Climate Resilient Agricultural Livelihood

KEFRI Kenya Forestry Research Institute

KMD - Kenya Meteorological Department

KNBS **-** Kenya National Bureau of Statistics

LCL - Lower Control Limit

MAM - March-April-May

MMT - Million Metric Tonne

MoA - Ministry of Agriculture

NACOSTI -National Commission for Science, Technology and Innovation

NAO -North Atlantic Oscillation

NCCAP -National Climate Change Action Plan

NCCRS -National Climate Change Response Strategy

NDMA - National Drought Management Authority

NDVI - Normalized Difference Vegetation Index

NEMA -National Environment Management Authority of Kenya

NGEC **-** National Gender and Equality Commission

NGO **-** Non-Governmental Organization

NOAA - National Oceanic and Atmospheric Administration

OECD **-** Organization for Economic Cooperation and Development

OND - October-November-December

PCC - Pearson's Coefficient of Correlation

SCAO **-** Sub-County Agriculture Office

SDGs -Sustainable Development Goals

SHGs - Self Help Groups

SO -Southern Oscillation

SON - September-October-November

SPI -Standardized Precipitation Index

SSTs - Sea Surface Temperatures

UN - United Nations

UNFCCC - United Nations Framework Convention on Climate Change

UNICEF - United Nations Children's Fund

UNITAR - United Nations Institute for Training and Research

UPC **-** Upper Control Limit

USA - United States of America

USDA - United States Department of Agriculture

WFP - World Food Programme

WHO - World Health Organization

WMO **-** World Meteorological Organization

WPO - Western Pacific Oscillation

WRF-EMS - Weather Research and Projection-Environmental Modelling System

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Drought is a prolonged period of limited precipitation that is statistically below the seasonal or annual means recorded in a given region (Tsige *et al.*, 2019). Droughts include hydrological, agricultural, economic, meteorological and ecological droughts. Meteorological drought can be shown by indicators which include variation in climatic conditions which may result in a deficit in rainfall and high temperatures (Ruwanza *et al*., 2022). World Meteorological Organization (WMO) (2024a) pointed out that the last two decades experienced high temperatures which influenced climatic conditions and droughts in different regions globally. Drought results in low moisture in soils, degradation, loss of biodiversity, and reduced productivity of varied terrestrial ecosystems.

Global drought trends are uncertain with regional drought fluctuations where 52 global mega-droughts were detected from 1951 to 2016 (Spinoni *et al*., 2019). Increased frequency, magnitude, duration and drought onset are major global challenges affecting cereal yields despite the rapid increase in global population. Drought affected 1.5 billion people globally between 1998 and 2017 (United Nations Office for Disaster Risk Reduction [UNDRR], 2021). Food demand-supply gap scenario is experienced which results in food insecurity in many regions globally.

Increased frequency and severity of droughts have been recorded in various parts of the world (Han *et al*., 2022; Kew *et al*., 2021; Leeper *et al*., 2022; Wahl *et al*., 2022; Xue & Ullrich, 2022). The droughts result in aridity and desertification. The Mid-West United States, a large part of South America, the Eurasian belt extending from Eastern Europe to Eastern Asia and equatorial Africa are drought hotspots (Reho *et al.*, 2024). Arid and Semi-Arid Lands (ASALs) in Africa are affected by recurrent droughts.

Droughts in Africa are associated with El Niño Southern Oscillation (ENSO) (Li *et al*., 2022), Pacific Decadal Oscillation (PDO) (Ayugi *et al*., 2022), Indian Ocean Monsoon (IOM) (Toreti *et al*., 2022) and Indian Ocean Dipole (IOD) (Ratna *et al*., 2021) among other drivers. Droughts in East Africa are associated with IOD (Ratna *et al.*, 2021). In addition, Funk *et al*. (2014) linked IOD to 2000, 2009, and 2011 droughts in the region. Funk *et al*. (2018) also linked IOD to droughts in Western Indian Ocean along the Coast of East Africa. Further, Sagero *et al*. (2018) linked IOD to climate variability in Kenya.

Africa experiences high frequency of droughts WMO (2024b). Africa has experienced increasing drought frequency in the last one century: 1910s, 1940s, 1960s, 1970s, 1980s, 1990s, 2000s and 2010s (Funk *et al*., 2023; Gbegbelegbe *et al*., 2024; Han *et al*., 2022; Kew *et al*., 2019; Ruwanza *et al*., 2022). Funk *et al*. (2023) also established that droughts have been recorded in the early 2020s. Approximately 45% of land in Africa is degraded and comprise ASALs (Africa Group of Negotiators Experts Support [AGNES], 2020); whose further degradation is associated with climate variability which limits rain-fed cereal production. Central Africa experienced severe droughts in the 1980s and 2000s (McCabe & Wolock, 2015). An upward drought trend, frequency, and severity was projected in Africa where East Africa (Patil *et al*., 2023) and Southern Africa (Ruwanza *et al.,* 2022) recorded increasing drought recurrence. The Horn of Africa (HoA) including Eritrea, North-west Ethiopia, and Eastern Somalia experienced extreme droughts in 1940s, 1950s, 1960s, 1980s, and 1990s signifying a decade return period (Han *et al*., 2022; Kew *et al*., 2019; Musei *et al*., 2020). Several drought episodes were also experienced in North-eastern Africa in 1980s, 2000s, and 2010s while central parts of East Africa experienced severe drought in 2003 (Haile *et al*., 2019). These droughts have significantly affected cereal yields despite the rapid annual increase in demand thereby making the continent food insecure.

According to Haile *et al*. (2019) over 10 severe droughts have been recorded in East Africa since 1970s whereas Kenya recorded droughts in 2010, 2011 and 2012. These frequent droughts significantly influence yields of sorghum (*Sorghum bicolor* (L.) Moench), finger millet (*Eleusine coracana* (L.) Gaertn) and maize (*Zea mays* (L.), hence food security. However, these cereals are used as both drought adaptation options as well as potential food grains for managing food insecurity during drought in ASALs in Kenya. In spite of the adoption of these drought-resilient cereals in ASALs in Kenya, increased drought severity and frequency which was experienced from 1990 to 2020, affected yields significantly (Nyangena, 2020).

Ondiko and Karanja (2021) reported that Kenya experienced a reduced drought return period from five to three years whereby 1999-2000 recorded the worst drought events in the last 50 years. Furthermore, Han *et al*. (2022), Kew *et al*. (2019), Lam *et al*. (2023), Ondiko and Karanja (2021) and Venton (2018) established that droughts have occurred in Kenya in all the decades since 1900 with severe droughts experienced in 1930s, 1940s, 1950s 1980s, 1990s and 2000s. The studies also indicated that periodic droughts ranged from mild to severe; mostly affecting North-eastern, Coast, Nyanza and parts of North Rift Valley. Numerous severe drought events were also identified in ASALs regionally such as Makueni County. Even though recurrent droughts are a major challenge to food security in Makueni County, barely any projection of these events were done in the region.

According to Mutua *et al*. (2016), Makueni County has experienced twelve meteorological droughts from 1997 to 2009. The meteorological droughts were mild but with high frequency. This is a major concern because of fluctuating cereal yields and an increase in food insecurity in the county. Nyangena (2020) also established an increase in the frequency of droughts whose effect on agro-production in the county was significant. Sorghum, finger millet and maize are drought-resilient cereals (Mbinda *et al*., 2021; Nhamo, 2019). Frequent droughts have significantly affected their yields hence causing food insecurity in ASALs in areas such as Makueni County in Kenya. Drought significantly influences soil temperature, soil salinity (Hadebe *et al*., 2017), and rainfall patterns (Mundia *et al*., 2019) beyond the optimum cereal production conditions. It also influences sorghum (Yahaya *et al.,* 2023), finger millet (Mbinda *et al*., 2021) and maize (Poudel, 2023) production conditions hence resulting in a reduction in yields and consequently resulting in food insecurity in ASALs in Kenya.

Even though frequent droughts significantly affect cereal yields, Community Based Adaptations (CBAs) influence adoption of agricultural technology which influences improvement in cereal yields (Mundia *et al*., 2019). In addition, Xu *et al*. (2017) attributed 56% of crop yields to improved science and agricultural technology in China. Adoption of early maturing sorghum varieties resulted in improvement in yields in Nigeria (Yakubu *et al*., 2021). Irrigation farming was undertaken in Sudan where water from the Blue Nile and White Nile rivers was used thereby improving cereal yields (Kool *et al.*, 2014). This was established as a useful drought adaptation strategy. Further, increased use of Indigenous Knowledge (IK) in drought adaptation in Tanzania resulted in improved cereal yields (Madege *et al*., 2017).

Beinah *et al.* (2020), Nkurunziza *et al*. (2022) and Ondiko and Recha (2022) established that both biotic and abiotic stresses such as persistent and cyclical droughts influence cereal production in semi-arid tropics and marginal lands such as Makueni County. In addition, Aoko (2023), Muui *et al.* (2023), Mwadalu *et al*. (2022) and World Food Programme [WFP] (2018) found that adoption of drought-resilient cereals such as sorghum, finger millet and some maize varieties resulted in improved yields for smallholder farmers in Makueni County in Kenya. Kagwiria *et al*. (2019) focused on crop-specific drought adaptations, however, the effect of droughts on multiple types of cereals was yet to be addressed. Adoption of CBAs and IK drought adaptations were undertaken to improve cereal production in ASALs in Kenya such as Makueni County (Aoko, 2023; Kagwiria *et al.*, 2019; Radeny *et al.*, 2019). Therefore, this study statistically analysed the effects of drought on cereal yields through correlation analysis.

1.2 Statement of the Problem

Location of Kenya along the equator and a long coastline of the Indian Ocean, that are vast low altitude areas and widespread ASALs covering 80% of the surface area, make the country significantly vulnerable to frequent droughts. Increasing frequency and severity of droughts in Makueni County is a key concern to stakeholders in the cereal production sector. Projected increase in droughts is also a major concern to the Government of Kenya (GoK) and County Government of Makueni (CGoM). Frequent and severe droughts affect cereal production and food security resulting in increased vulnerability, malnutrition and even human deaths in the affected ASALs in Kenya. Therefore, it was necessary to conduct a trend analysis and project drought in Makueni County from 2024 to 2054.

Even though increase in drought recurrence and severity has been recorded in Makueni County, there was limited information on the drivers of the frequent droughts. Therefore, this study determined the magnitude of association of IOD with frequent drought events in Makueni County. Establishment of drought drivers provide information upon which drought risk adaptation policy can be developed to improve resilience and to reduce level of vulnerability of smallholder cereal farmers in Makueni County.

Even though numerous drought responses, policies, and institutional frameworks have been put in place by GoK, increased frequency and severity of droughts have been experienced from 1990 to 2020 with significant effects on rain-fed cereal production and yields in ASALs. There was also limited information on drought-cereal correlational studies on multiple drought-tolerant (DT) cereals such as sorghum, finger millet and maize in Makueni County. These DT cereal varieties are suitable for varied Agro-Ecological Zones (AEZs) such as ASALs that cover a large surface area in Kenya hence playing a major role in managing food insecurity in ASALs. Despite the suitable agro-production conditions in Makueni County, there was a food supply gap due to low and fluctuating cereal yields in the region.

The GoK, through the Kenya Ministry of Agriculture (MoA) and CGoM implemented the Kenya Cereal Enhancement Programme – Climate Resilient Agricultural Livelihood (KCEP-

CRAL) which was effective from 2014 to 2022, in Makueni County. The main objectives of KCEP-CRAL were to contribute towards increasing productivity and profitability of key cereal commodities: maize, sorghum and millet, and associated pulses. These efforts were geared towards improving national food security and smallholder income generation by supporting farmers in both medium- and high-potential cereal production areas in Kenya. Even though these DT cereals were adopted among other drought adaptations, the extent to which these strategies have been adopted and their outcomes in ASALs such as Makueni County was still unclear. Therefore, the information on outcomes of the drought adaptation strategies is necessary in order to upscale the most useful ones in other ASALs in similar AEZs.

It is for these shortcomings that this study addressed the food supply gap in the face of increasing frequency and severity of drought through evaluation of the outcomes of drought adaptation strategies among smallholder cereal farmers in Makueni County. These efforts will improve drought adaptation capacity, cereal production and yields; hence improvement in food security and livelihoods of smallholder cereal farmers in Makueni County. Furthermore, the study of smallholder cereal production in Makueni County would enable up-scaling of the CBAs and IKs to droughts in other ASALs with similar pedo-climatic conditions thereby improving cereal yields and hence food security in Kenya.

1.3 Objectives of the Study

1.3.1 Broad Objective

The broad objective of the study is to contribute to drought projection, drought-related disaster management, promotion of food security and overall wellbeing among smallholder households in Makueni County.

1.3.2 Specific Objectives

The study was guided by the following specific objectives:

i. To establish the trend and project drought in Makueni County between 2024 and 2054.
ii. To determine the influence of Indian Ocean Dipole on the occurrence and nature of droughts in Makueni County between 1990 and 2020.
iii. To examine the effect of drought on cereal yields in Makueni County from 1990 to 2020.
iv. To find out the community-based drought adaptations practiced in Makueni County.

v. To evaluate the outcomes of drought adaptation strategies among smallholder cereal farmers in Makueni County.

1.4 Research Questions

(i) What is the trend of drought in Makueni County for the period 2024 to 2054?

(ii) What is the influence of Indian Ocean Dipole on occurrence and nature of drought in Makueni County between 1990 and 2020?

(iii) What are the effects of drought on cereal yields in Makueni County between 1990 and 2020?

(iv) What are the drought adaptation strategies practiced by smallholder cereal farmers in Makueni County?

(v) What are the outcomes of drought adaptation strategies practiced by smallholder cereal farmers in Makueni County?

1.5 Justification of the Study

The United Nations (UN) established Sustainable Development Goal (SDG) 13 which is aimed at combating climate change and its impacts by 2030 (UN, 2019). The United Nations Framework Convention on Climate Change (UNFCCC) (Kuh, 2018) was also enacted in 1994 as a basis for institutional structure for climate change protocols and policies to enable improvement on global climate change response to foster economic development and to increase cereal production and yields hence food security. The GoK also established the National Drought Management Authority (NDMA) (GoK, 2020a), the National Climate Change Response Strategy (NCCRS), 2010 (GoK, 2010), the Climate Change Act, 2016 (GoK, 2017a), and the National Climate Change Action Plan (NCCAP) (Kenya) 2018-2022 (GoK, 2018a). In these policy documents, the government seeks to: manage drought risks (GoK, 2020a); enhance understanding of climate variability and change and their impacts nationally and regionally, and formulate programs that enhance drought resilience and adaptive capacity in ASALs (United Nations Office for Disaster Risk Reduction, 2021). Therefore, projection of drought in Makueni County enables the achievement of the objectives of GoK on improving drought resilience and adaptive capacity to improve cereal yields hence food security. These efforts result in improvement of livelihoods of smallholder cereal farmers in the county. In addition, information on drought projection can be used in drought adaptation policy formulation, data-driven decision making, drought adaptive capacity building, drought risk management, and effective adaptation to drought to improve cereal yields hence food security in Kenya.

Makueni County was chosen for the study due to its location in AEZ 5 which is an ASAL in Eastern Kenya (Kitinya *et al*., 2012). The county experiences similar agro-ecological conditions and Tropical Semi-Desert climate of the Central and Northern areas with bimodal rainfall regimes in March-April-May (MAM) and October-November-December (OND) which are suitable agro-climatic conditions for production of DT cereals such as sorghum, finger millet and maize. The county was also chosen due to the inadequacy in cereal production despite existence of suitable agro-production conditions, hence a production gap (Amukono, 2016; Gichure, 2017). Even though Makueni County experienced fluctuating cereal yields, the county was chosen for this study because it is one of the leading producers of sorghum in the country.

The period from 1990 to 2020 was chosen due to the increase in frequency and severity of droughts in ASALs in Kenya over the past three decades (Mutua *et al*., 2016; Ondiko & Karanja, 2021; Uhe *et al*., 2018). Mutua *et al*. (2016) and Nyangena (2020) established an increase in frequency and severity of droughts in Makueni County. High frequency and severity of droughts in Makueni County significantly affect cereal production and food security. This study established occurrence and nature of drought, which are key aspects of the phenomenon. This effort resulted in historical drought trend analysis and establishment of the nature of drought between 1990 and 2020. In addition, this study resulted in drought trend projection for three decades covering between 2024 and 2054. Drought projection provides insights in drought risk hence creating an opportunity for effective drought response, drought adaptation and building resilience against the events.

The projection period which covered 2024 to 2054, a duration of three decades, was chosen for this study on the basis that projection of time series data covers a similar period of available historical data for a study. The time gap covering 2021 to 2023 was uncovered on the basis that it was part of the study period. The historical rainfall data covered a period of three decades; that is from 1990 to 2020. Climatic forcing events have resulted in key concerns whereby Msongaleli *et al*. (2013) projected a reduction in tropical cereal yields by 11% to 46% by 2050 due to climate variability despite increasing population and consequent demand for food. Ayugi *et al*. (2022) projected increase in drought conditions in Africa due to the variability in atmospheric and oceanic circulations in the Indian Ocean. Mutua *et al*. (2016) also projected the recurrence of droughts driven by a deficit in OND rainfall in the country every three to four years while a general deficit in annual rainfall is projected to result in droughts every five years. The projected food demand-supply gap is a major concern to GoK, CGoM and smallholder cereal farmers in Makueni County. This study used total annual amount of rainfall for 1990 to 2020 for drought trend analysis and projection for 2024 to 2054.

This study focused on drought due to its slow onset and creeping nature (Mohammed *et al*., 2017), complex nature and variation in duration besides its negative effects on cereal production thus, impacting food security globally (Gbegbelegbe *et al*., 2024; Leeper *et al*., 2022; Ma *et al*., 2022; Toreti *et al*., 2022). The phenomenon was also chosen for this study due to its unpredictable nature that may last a long duration leading to widespread ecosystem destruction and crop loss as indicated by Song *et al*. (2020).

The effect of drought is also compounded by its slow onset and creeping nature which creates a major climatic challenge to prediction and adaptation (Mohammed *et al*., 2017). According to Gbegbelegbe *et al*. (2024), Leeper *et al*. (2022), Ma *et al*. (2022) and Toreti *et al*. (2022), the complex nature of drought may last two to three months or even longer periods whereby multiple-year droughts are also recorded. Song *et al*. (2020) indicated that droughts may last a long duration with a high unpredictability thereby leading to widespread ecosystem destruction and crop loss.

This study enables better understanding of drought drivers and trends which enable improvement in drought response and adaptation hence improvement in cereal yields and food security in Makueni County. Further, the consequent improvement in cereal yields and food security results in improvement in livelihoods among smallholder cereal producers in Makueni County. In addition, information on drought drivers and trends enables smallholder cereal farmers and other stakeholders in Makueni County to better understand and adapt to the projected drought risks in the region. The study also resulted in empirical evidence on drought drivers, trends and drought projection which can inform appropriate drought interventions and to limit vulnerability among smallholder cereal farmers while improving livelihoods of smallholder cereal farmers and cereal yields.

Even though a number of methods including a deep learning approach, Weather Research and Projection-Environmental Modelling System (WRF-EMS) (Sagero *et al*., 2016), Random Forest (RF) algorithm based on Normalized Difference Vegetation Index (NDVI) (Wambua, 2016), Linear Autoregression and Gaussian process modeling methods (Barreta *et al.*, 2020), Using Indices and Artificial Neural Networks (ANN) (Wambua *et al.*, 2014), machine learning techniques (Ali, 2020) and use of band-pass filtered daily rainfall data techniques (Kazora *et al.* (2023) have been identified as useful in drought modeling in ASALs, there is limited modeling of actual drought events in Kenya. Therefore, this study projected droughts in Makueni County between 2024 and 2054 using Autoregressive Integrated Moving-Average (ARIMA) Model.

Goal 2 of the SDGs advocates for "Ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture by 2030" (UN, 2019). The GoK also prioritized agriculture as a key economic pillar and developed Kenya Vision 2030 Plan (GoK, 2007), the "Big Four Agenda" (GoK, 2017b), and Food Security Act, 2014 (GoK, 2014a). This study contributed to the attainment of the objectives in these policy documents through the evaluation of outcomes of drought adaptation strategies practiced by smallholder cereal farmers in Makueni County that can be up-scaled to other ASALs in Kenya. Up-scaling of IK and CBAs also enables the attainment of food nutrition and security in ASALs in Kenya. This study enables effective response to the effects of climate variability and change by evaluation of IK and CBAs to drought which result in improvement in yields of diversified DT cereals. In addition, the diversification of cereals manages yield perturbations under drought events (Dardonville *et al.*, 2020). Evaluation of drought adaptation strategies bridges the gap in use of IK and CBAs to droughts in ASALs enabling smallholder cereal farmers in Makueni County to reduce the cost of cereal production through choice of more significant adaptation techniques while improving yields and livelihoods.

Sorghum, finger millet, and maize were chosen for this study since they are the most popular staple foods and also provide necessary nutritional requirements and can be used to manage malnutrition and food insecurity in Makueni County. The DT cereals were also chosen for the study due to their significance as drought adaptation mechanisms due to their resilience to the frequent droughts in Makueni County. Further, this study complements the efforts by both CGoM and GoK through MoA which implemented the KCEP-CRAL in Makueni County from 2014 to 2022 (Food and Agriculture Organization of the United Nations [FAO], 2015; GoK, 2016). This study provides information which builds onto the efforts of the KCEP-CRAL whose aim was to contribute to food security and to improve income generation for smallholder farmers by supporting agricultural productivity and profitability of key cereals including sorghum, finger millet, maize, and some pulses. In addition, this study contributes to the improvement in cereal production, hence food security in Makueni County by evaluating CBA and IK drought adaptation techniques to establish the most popular and the most significant in cereal production in the region.

This study was guided by the First County Integrated Development Plan 2013-2017 in Makueni County (GoK, 2013), National Disaster Risk Management Policy 2017 (GoK, 2017c) and Makueni County Spatial Plan (2019-2029) (CGoM) (2019). Findings on drought adaptation strategies provide insights on their appropriateness, especially for cereal production in fragile ASAL environments such as Makueni County.

1.6 Scope and Limitations of the Study

This section addresses the scope of the study. The scope of this study covers the area of study, period under study, datasets used in the study and study approaches.

1.6.1 Scope of the Study

This study was conducted in Makueni County whereby it covered 1990 to 2020 since climate-based studies cover a long duration usually thirty years. The study established the nature and drought trends from 1990 to 2020 and projected droughts in Makueni County for the period 2024 to 2054. Limitation created by spatial-temporal variation in the occurrence of drought events were addressed by focusing on ASALs with similar AEZ conditions, climatic, pedological conditions, and drought-prone areas where frequent droughts were experienced between 1990 and 2020.

This study used Standardized Precipitation Index (SPI) for drought trend analysis. Multiple Linear Regression was used for analysis of the influence of Indian Ocean Dipole on occurrence of drought in Makueni County. The study used Correlation analysis for determination of the effect of drought on cereal yields in Makueni County. Descriptive statistics was used for analysis of drought adaptation strategies adopted by smallholder cereal farmers in Makueni County. Triangulation was adopted for the acquisition of cereal data due to gaps in the data from a single secondary source as recommended by Bengtsson (2016).

Even though other factors also influence droughts in East Africa, this study focused on the influence of IOD on occurrence and nature of drought in Makueni County. IOD was chosen for the study because it is the primary driver of drought in the study area. Indian Ocean Sea Surface Temperatures (SSTs) data was collected from the Western Indian Ocean (WIO) (10^0S-10^0N, 50^0-70^0E) (Block A) and Equatorial Eastern Indian Ocean (EEIO) (0^0-10^0S, 90^0-110^0E) (Block B) for the period 1990 to 2020. The study examined the effects of drought on sorghum, finger millet, and maize yields; which are the major staple cereals in the county.

Makueni County is considered a climate change hotspot by Climate Change and Food Security (CCAFS) (Ouya *et al.*, 2020). The county is one of the leading cereal producers in Kenya (Beinah *et al*., 2020; Mwadalau *et al.*, 2022; Njagi *et al.*, 2019). Makueni County which is one of the ASALs in Kenya, experienced significant drought events between 1990 and 2020 (Mutua *et al*., 2016; Uhe *et al*., 2018). Frequent droughts and location of the county in an ASAL region led to the choice of the county for the study.

This study focused on DT cereals which include sorghum, finger millet and maize due to their adaptability to various AEZs including ASALs such as Makueni County. The cereals are staple foods that are very nutritious and support multiple uses including livestock feed and source of energy (Mundia *et al*., 2019; Queiroz *et al.* (2019). Sorghum and finger millet were also chosen for the study due to their autonomous adaptability to drought conditions, multipurpose use, C_4 photosynthetic nature and high genetic variability (Belete, 2020; Crutchfield, 2017; Tigchelaar *et al*., 2017; WFP, 2018). The cereals are also popular among farmers in ASALs such as Makueni County. Furthermore, finger millet is used in the study due to its disease-preventive health-benefits (Beinah *et al*., 2020).

The smallholder cereal farmers who form the majority (75%) of the farmers in Makueni County were the focus of this study. Gichure (2017) and National Environment Management Authority of Kenya (NEMA) (2019) established that smallholder cereal farmers primarily rely on rain-fed cereal production.

1.6.2 Limitations of the Study

This study encountered inadequacy of long-term rainfall data for some meteorological stations in the study area. The rainfall data was collected from Dwa Sisal Estates and Makindu meteorological stations in Kibwezi East and Kibwezi West sub-Counties, respectively. Gridded rainfall data which is merged rainfall data from Enhancing National Climate Services (ENACTS) for Kilome and Makueni sub-Counties which lacked meteorological rainfall data was provided by Kenya Meteorological Department (KMD). The ENACTS rainfall data is reconstructed data which includes combining station and satellite estimates of rainfall.

This study encountered harsh hydrological conditions in the study area. This challenge was caused by the flooding of a number of seasonal rivers during the data collection period which happened in April, May and June 2023 whereby April is the peak rainfall month for MAM rainfall season in Makueni County. Therefore, longer routes were used to enable collection of data.

This study encountered inadequate and incomplete long-term cereal data. The inadequacy and incomplete gaps in cereal data was linked to inadequate and incomplete agricultural records. Therefore, the study used extraction from secondary sources and triangulation method in order to collect the required data from various agricultural records in Makueni County and from MoA. Triangulation entailed collection of annual cereal yields data from annual cereal production reports, crop performance reports and agricultural review reports from MoA. The cereals data from these reports were used to create cereals data for 1990 to 2020.

This study encountered inadequate micro-level household data on cereal production and yields. Therefore, this study used macro-level cereal production data from secondary sources in Makueni County where existing gaps were addressed by multiple imputations (MI) method.

1.7 Assumptions of the Study

The study was based on the following assumptions:

i. Cereal production statistics at the MoA offices in Makueni County reflect household level production trends.

ii. All the smallholder cereal farmers in Makueni County have adapted to droughts by practicing IK and CBAs.

1.8 Definition of Terms

Agronomic Practices – Agronomic practices are agricultural technique and strategies used to improve crop production with the aim of increasing yields while limiting impact on the environment and ensuring sustainability (Kuyah *et al*., 2021). Agronomic practices include the methods of planting crops, irrigation systems, pest control measures, fertilization and harvesting. In this study, agronomic practices include methods of planting crops, adopting irrigation and pest control measures practiced by smallholder cereal farmers in Makueni County.

Cereal – A cereal is any crop originating from the grass (Gramineae) family that produces consumable grains and comprises nine species: wheat (*Triticum*), maize (corn) (*Zea*), rice (*Oryza*), barley (*Hordeum*), sorghum (*Sorghum*), rye (*Secale*), oat (*Avena*), millet (*Pennisetum*), and triticale (*Triticale hexaploide* Lart.); a hybrid of rye and wheat (Papageorgiou & Skendi, 2018). In this study, the term cereal refers to sorghum, finger millet and drought-resilient maize varieties cultivated in Makueni County. The cereal produce was measured in 90 kilogrammes (kg) bags while yields were measured in kilogrammes per hectare ($kgha^{-1}$).

Cereal Production – Cereal production is the process of preparation and cultivation of land, growing crops, addition of manure and/or fertilizer, pest and weed control, harvesting, preservation, storage and processing of cereals in a season or a year (Mamai *et al*., 2020; Organization for Economic Cooperation and Development [OECD], 2024) or the total output or quantity of cereal per farmer in a region or country in a season or a year (Fan *et al*., 2012; Ray *et al*., 2013). In this study, cereal production refers to the total annual output or quantity of sorghum, finger millet and maize per farmer in Makueni County from 1990 to 2020.

Cereal Yield – Cereal yield or productivity is the cereal output or quantity per unit of land (Gollin, 2018). In this study, cereal yield is the output or quantity of sorghum, finger millet and maize per hectare in Makueni County. Cereal yields were measured in $kgha^{-1}$.

Climate Change – According to United Nations Institute for Training and Research (UNITAR) (2015) climate change is a long-term spatiotemporal statistically defined change in average regional or global weather conditions and patterns especially in temperatures that may last months to years and caused by either natural or anthropogenic forcing. In this study, climate change is a long-term spatiotemporal statistically defined change in average regional weather patterns in Makueni County, especially rainfall and temperature changes caused by natural forcing related to IOD between 1990 and 2020.

Climate Variability – According to National Oceanic and Atmospheric Administration (NOAA) (2018) climate variability is the natural variation in a climatic parameter such as rainfall, from its mean and is exhibited in eventful extremes caused by natural forcing on the climate on spatial and temporal scales. In this study, climate variability is the variation in Indian Ocean SSTs which is indicated in degrees Celsius (^{O}C) and rainfall amounts in millimetres (mm); from the temporal-based means resulting in droughts in Makueni County, Kenya.

Community-Based Adaptation (CBA) – According to Kithuku (2019) CBA is a collection of traditional or communal approaches to disaster adaptation that are integrated to empower the local communities' capacity to adapt and to improve resilience to droughts to reduce disaster risk and to improve food production and yields. In this study, CBAs are the traditional and local community approaches such as the adoption of IK, traditional grain production practices, traditional seed preservation methods and traditional biological pest and disease control strategies that are practiced by smallholder cereal farmers in Makueni County.

Drought- Drought is a period of limited precipitation that is statistically below the seasonal or annual means recorded in a given region (Tsige *et al*., 2019). In this study, drought refers to limited rainfall that is statistically below the annual rainfall means of 500 mm in Makueni County, Kenya.

Drought Adaptation – According to Bahta and Myeki (2021) drought adaptation is a process where actual and projected impacts of climate variability/change are responded to through adjustments to limit negative environmental, socioeconomic and agricultural threats. In this study, drought adaptation is the adoption of CBA and IK adaptations, quality cereal seeds and short-season cereals, increasing or decreasing farm size, IK-based drought projection, and adoption of irrigation farming among other strategies that target an increase in cereal yields in Makueni County, Kenya.

Food Security – Food security is the availability and accessibility to regular, safe, adequate, and nutritious food for dietary needs for a healthy and active life of all the people in a given region (FAO, International Fund for Agricultural Development [IFAD], United Nations Children's Fund [UNICEF], WFP & World Health Organization [WHO], 2022). In this study, food security is the availability and accessibility to regular, safe, adequate, and nutritious sorghum, finger millet, and maize for dietary needs for a healthy and active life of all the people in Makueni County, Kenya.

Drought Projection – Drought projection is a process or technique which models past and present conditions, state or data in order to determine the future direction (Christian *et al.*, 2023; Harisson *et al*., 2022; Lam *et al.,* 2023). In this study, drought projection is the modelling of the drought conditions in Makueni County between 2024 and 2054.

Household - According to Mather *et al*. (2019) and United States (U.S) Census Bureau (2021) a household is made up of people who reside in a single homestead and share cooking arrangements. In this study, a household refers to a group of people who reside in a single homestead and share cooking arrangements in Makueni County.

Indian Ocean Dipole (IOD) – IOD is a mode of climate developed as a result of Ocean-atmosphere interaction in the tropical Indian Ocean resulting in inter-annual climate variability (Ratna *et al*., 2021). In this study, IOD is a drought driver in Makueni County where mean annual SSTs were measured in ^{O}C.

Indigenous Knowledge (IK) – IK refers to knowledge acquired over a long period through interaction with the environment and transmitted from one generation to another using traditional oratory and cultural practices and it is specific to a location (Mugambiwa, 2018). In this study, IK refers to traditional skills in cereal production, preservation, and bio-control of pests, soil conservation, and drought adaptation strategies practiced by the local communities in Makueni County, Kenya.

Mild Drought – According McKee *et al*. (1993) mild drought is a category of drought that is indicated as ranging between -1.00 to -1.49 on the SPI. In this study, mild drought is used to categorize drought whose characteristics range between -1.00 to -1.99 on SPI and recorded in Makueni County between 1990 and 2020.

Near-Normal Drought – According McKee *et al*. (1993) mild drought is a category of drought that is indicated as ranging between -0.99 to 0.99 on the SPI. In this study, mild drought is used to categorize drought whose characteristics range between -0.99 to 0.99 on the SPI and recorded in Makueni County between 1990 and 2020.

Sea Surface Temperature (SST) – SST is the thermal condition of the water at the surface of the Ocean and varies with latitude where warmer and colder conditions are experienced near the equator and the polar Oceans, respectively (Pastor, 2021). In this study, SST is the thermal condition of water at the surface of the Indian Ocean which is recorded in the Equatorial Western Indian Ocean (EWIO) and EEIO and they are measured in ^{O}C.

Smallholder Farmer – A smallholder farmer is a person undertaking agricultural production on a family owned and run farm of less than two hectares (ha) of land where labour is provided by the family members and the produce is primarily for family use (FAO, 2017). In this study, a smallholder farmer is a person undertaking sorghum, finger millet and maize production on a family owned and run farm of less than 2 ha of land where labour is provided by the family members and the produce is primarily for household use in Makueni County.

Trend – Trend is the general direction in which something or a statistical mean is developing, changing or moving towards (Ibebuchi & Abu, 2023; Rousi *et al.*, 2022; Shenoy *et al.*, 2022). Trend can be linear, rectilinear, upward, downward, increasing, reducing, consistent or fluctuating. In this study, trend is the general direction of drought events in Makueni County which is detected using ARIMA Model for the period between 2024 and 2054.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter presents review of relevant literature on drought drivers, nature and trends of drought, effects of drought on cereal yields and drought adaptation practices. This chapter also presents the theoretical framework and conceptual framework.

2.2 Nature and Trend of Drought

Increase in frequency and severity of droughts in different regions of the world is a major challenge to rain-fed cereal production and yields leading to food insecurity. Droughts are classified as meteorological, hydrological, agricultural or socio-economic droughts (Fan *et al*., 2022; Ruwanza *et al.*, 2022; Tsige *et al*., 2019). This study focused on meteorological drought which is a prolonged period of limited precipitation that is statistically below the seasonal or annual mean recorded in a given region (Tsige *et al.*, 2019). A deficit in rainfall during drought results in a deficit in soil moisture which negatively affects cereal yields for rain-fed agro-systems. The effect of drought is also compounded by its slow onset and creeping nature which creates a major climatic challenge to prediction and adaptation (Mohammed *et al*., 2017).

According to Gbegbelegbe *et al*. (2024), Leeper *et al*. (2022), Ma *et al*. (2022) and Toreti *et al*. (2022) the complex nature of drought may last two to three months or even longer periods whereby multiple-year droughts are also recorded. Song *et al*. (2020) indicated that droughts may last a long duration with a high unpredictability thereby leading to widespread ecosystem destruction and crop loss. Further, Zhang *et al*. (2016) reported an increase in area under desertification by 1.74% every decade due to increased drought recurrence from 1950 to 2008 globally. The spatiotemporal variability in occurrence of drought creates the need to establish the nature and frequency of droughts in different regions of the world. Drought trend analysis enables adaptive capacity building which consequently bolsters rain-fed cereal production and yields in ASALs.

Shiru *et al*. (2018), Song *et al*. (2020) and Spinoni *et al*. (2019) established an increase in frequency and severity of droughts globally from 1950. In addition, Spinoni *et al*. (2019) reported a high uncertainty in regional drought trends from 1951 to 2016. Wahl *et al*. (2022) and Xue and Ullrich (2022) indicated an increase in drought frequency in North America and other parts of the world. The droughts had a significant effect on cereal yields in the affected regions. Moreover, Wahl *et al*. (2022) identified an increasing trend in droughts in the South-eastern and Western United States of America (USA) over the past one century while a decreasing trend was observed in North-eastern USA. While in agreement with these studies, Leeper *et al*. (2022) revealed that Western USA experienced fewer frequencies of flash droughts which comprise 9.8% of all the recorded droughts in the country. The study also indicated that a large area of the region extending to 50% of the land experienced severe drought in 2002. A study covering 2001 to 2013 projected an increase in frequency and severity of droughts in USA (Kuwayama *et al*., 2019). The drought conditions are associated with climatic variations and solar variability. An increasing frequency of droughts in the USA is a major concern considering the rising demand for cereals for human food, animal feed, and bio-energy in the country. Further, Reho *et al.* (2024) found that Mid-West United States, a large part of South America, the Eurasian belt extending from Eastern Europe to Eastern Asia and equatorial Africa are drought hotspots.

An increase in the frequency and severity of droughts was recorded in Africa since the 1970s (Haile *et al.*, 2019; Shiru *et al.,* 2018). In addition, extreme continental droughts were experienced in 1910s, 1940s, 1960s, 1970s, 1980s and 1990s signalling a decade return period (Funk *et al*., 2023; Gbegbelegbe *et al*., 2024; Han *et al*., 2022; Kew *et al*., 2019; Ruwanza *et al.*, 2022). Further, a large part of Africa was a drought hot spot in 1990s where North Africa and the Sahel region experienced mega-droughts (Spinoni *et al*., 2019). Shiru *et al*. (2018) indicated that moderate droughts were experienced from 1971 to 2012 with barely any severe droughts in Nigeria. However, the study projected an increase in the frequency and severity of droughts in Nigeria where the phenomenon was associated with climatic variations in both the Atlantic Ocean and over the Sahelian belt.

A study conducted in North-eastern highlands of Ethiopia by Toreti *et al*. (2022) established a positive trend and increasing frequency of drought in the region. Han *et al.* (2022) identified the region as drought-prone and very sensitive to the impacts of drought whereby increasing trend was recorded. In addition, Tefera *et al*. (2019) revealed an increase in upward drought trend and frequency where a two-year return period was realized in the Tigray region in Northern Ethiopia. Furthermore, the study found that drought in the region is spatially variable and more severe. Sudan experiences major droughts after every ten years (Global Water Partnership Eastern Africa [GWPEA], 2015). Further, Yagoub *et al*. (2017) established an association between increasing drought frequency in Sudan with declining rainfall from 1961 to

2013. The study also found that Sudan is among the most drought-vulnerable countries in Africa and experiences frequent extreme droughts. Further, Han *et al.* (2022) found that the 2010/2011 drought was the worst event experienced in the country in the past 60 years. Eltohami (2016) also indicated a high dependency on rain-fed crop production by about 80% of the farmers despite a high frequency of droughts in Sudan. Haile *et al.* (2019) established that East Africa has experienced an increase in frequency and severity of droughts since 1970s, hence a key concern due to the rising population and demand for food.

Spinoni *et al*. (2019) revealed that Kenya experienced mega-droughts from 2014 to 2019. Further, single to multi-year droughts occurred in Kenya in all the decades since 1900 while severe droughts were experienced in 1930s, 1940s, 1950s 1980s, 1990s and 2000s (Han *et al.* (2022); Kew *et al*., 2019; Ondiko & Karanja, 2021; Venton, 2018). In addition, Nyangena (2020) established an increase in the frequency, severity, and magnitude of droughts in Kenya from 1990 to 2020. Meanwhile, Ondiko and Karanja (2021) reported a reduction in the drought-return period from five to three years in the country. Karanja (2018) established that the 1999/2000 drought was the most severe in Kenya since early 1960s to early 2010s, a period spanning five decades. Even though 80% of the surface area in Kenya is ASAL (Venton, 2018) and experiences frequent droughts, these regions still support the production of drought-resilient cereals such as sorghum, finger millet, and some maize varieties.

Kenya experienced La Niña droughts in 2016 and 2017 due to a deficit in OND seasonal rainfall which was more severe in ASALs (Uhe *et al.*, 2018). Besides, Mutua *et al*. (2016) projected the recurrence of droughts driven by a deficit in OND rainfall in the country every three to four years while a general deficit in annual rainfall is projected to result in droughts every five years. However, the natuture, trend and effects of droughts on cereal yields in the region were yet to be addressed.

A study by GWPEA (2015) reported a return period of ten years for major droughts while minor droughts recurred after every three to four years in Kenya. In addition, NEMA (2019) noted that droughts were expected to last some months to a year whereby multi-year droughts lasting two to three years occurred in Eastern Kenya in the last two decades. The high frequency and short drought return periods in Kenya are an indication of an upward drought trend.

The increase in frequency, severity and magnitude of droughts in Eastern Kenya poses a significant challenge to rain-fed cereal production and yields despite the rapid annual increase in demand. Gichure (2017) also revealed persistent and cyclical droughts that significantly influence cereal yields in Eastern Kenya which resulted in food insecurity in Makueni County. Mutua *et al*. (2016) noted that Makueni County is located in an ASAL region that has experienced frequent droughts since 1990s.

The complex nature, slow development, increase in frequency, coverage of large spatial extent and severe physical and socioeconomic effects of droughts, make drought projection necessary to limit the vulnerability of smallholder cereal farmers while increasing productivity (Nyangena, 2020). Further, the increased frequency of drought from 1990 to 2020 points towards a continued trend of the phenomenon in the future (Nyangena, 2020; Ondiko & Karanja, 2021; Uhe *et al*., 2018) hence the necessity to project drought in the county. Projection avails useful information on drought which may be used for improvement in resilience thereby limiting the vulnerability of smallholder cereal farmers, drought adaptation and mitigation policy development, planning and response. These actions increase cereal yields thereby improving food security in the county.

Mutua *et al*. (2016) indicated that Makueni County experienced twelve moderate meteorological droughts from 1997 to 2009. Though, the cause and magnitude of the effects of frequent droughts on multiple cereal yields in the county was still unclear. Even though the droughts were moderate, the high frequency is a major concern to cereal production and therefore food security in the region. Therefore, this study projected the trends of drought in Makueni County. Drought trend projection enables the smallholder cereal farmers to develop capacity and improve adaption to the events to improve cereal yields.

Nyangena (2020) assessed the macro-level frequency of droughts in various regions in Kenya where the study advised a lower-scale determination of drought effects on various sectors of the economy. However, a gap in drought projection was established in the region. In this regard, to fill these knowledge gaps, this study assessed the occurrence, nature and trend of drought and projected droughts in the study area. In addition, drought projection enables improvement in drought adaptation and data-driven decision making thereby improving cereal yields hence food security in Makueni County.

2.3 Influence of Indian Ocean Dipole on Occurrence and Nature of Drought

Increasing frequency and severity of droughts in ASALs globally (Shiru *et al*., 2018; Song *et al*., 2020; Spinoni *et al*., 2019); poses a major challenge to cereal production whereby fluctuations in yields are recorded despite an increase in annual demand, hence food insecurity. Moreover, studies have been conducted to establish the causes of regional droughts whose frequency, trends, magnitude and severity vary from one region to another. To enable improvement in resilience and adaptation to droughts, there is a need to understand its drivers.

Several climatic drivers influence the occurrence and nature of drought. These drivers include ENSO (McKenna *et al*., 2020); Atlantic Multi-decadal Oscillation (AMO) (Pastor *et al*., 2020); Pacific Southern Oscillation (PSO) and PDO (Ayugi *et al.*, 2022), Inter-decadal Pacific Oscillation (IPO) (Howes *et al*., 2018) and Inter-tropical Convergence Zone (ITCZ) (Liu *et al*., 2020a). Further, North Atlantic Oscillation (NAO) (Pastor *et al*., 2020), Madden-Julian Oscillation (MJO) (Thandlam *et al*., 2023), North Pacific Oscillation (NPO) and West Pacific Oscillation (WPO) (Aru *et al*., 2023) are also natural climatic events associated with droughts.

Kenya experienced La Niña droughts in 2016 and 2017 due to a deficit in OND seasonal rainfall which was more severe in ASALs (Uhe *et al*., 2018). Lim and Hendon (2017) established that weak La Niña droughts were experienced in East Africa in 2016 and that the droughts were driven by a strong negative phase of IOD. The study also revealed that coupling La Niña and IOD conditions resulted in extremely wet conditions in Indonesia and Australia in 2016.

According to Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC), Famine Early Warning Systems Network [FEWS-NET], WMO, FAO, WFP and Joint Research Centre (JRC) (2022) La Niña was linked to droughts in East Africa where 12 OND La Niña phenomena were succeeded by 9 dry MAM seasons from 1998 to 2022. The IOD events in the Indian Ocean and surrounding regions has been noted to be co-occurring with El Niño and La Niña (ENSO) events which are recorded in the tropical Pacific Ocean. Positive IOD events are often associated with El Niño while negative IOD events are associated with La Niña (Zhang *et al.*, 2024). Therefore, ENSO events which occur in the tropical Pacific Ocean are modulated by IOD. On the other hand, ENSO is a primary driver of seasonal and interannual variability of IOD events (Zhang *et al.*, 2024).

Even though global climatic conditions experience upward warming trend, the coupling relationship between La Niña and negative IOD phase has changed (Zu *et al*., 2024). The study established a significant reduction in the impact of La Niña on IOD up-to one-third of the pre-1999 levels. Song and Ren (2022) indicated a coupling relationship between La Niña and IOD which has been resulting in variation in climatic conditions in different regions globally.

Even though El Niño (Dong & McPhaden, 2018) and La Niña (Koesuma *et al.*, 2021) were linked to droughts in East Africa where 12 OND La Niña phenomena were succeeded by 9 dry MAM seasons from 1998 to 2022 (ICPAC *et al.*, 2022) IOD is the principal driver of droughts around the Indian Ocean and the East African region (Ratna *et al.*, 2021).

Pfeiffer *et al*. (2017) established that the EWIO (Figure 1) heated up more rapidly than the rest of the tropical oceans in the 20th Century, hence a major factor in the rise of global SST means. In addition, Zinke *et al*. (2016) reported rapid warming in the past six decades thereby increasing SSTs up-to 1.2^{0}C in the EWIO leading to several extreme phenomena including droughts and floods. The increase in SSTs was evident in the 1997/1998 El Niño event. The study also attributed increase in SSTs in the EWIO to anthropogenic forcing in the 21st century. Further, SST variability in the Indian Ocean influences warming conditions in the Sahelian belt through teleconnections. Moreover, IOD influences the climatic conditions in the EWIO and East African region (Funk *et al*., 2018).

According to Tierney *et al*. (2015) warming in the Indian Ocean began in the 1840s and coincided with an increase in total radiance in solar activity. McKenna *et al*. (2020) also indicated a significant warming trend in the Indian Ocean due to a complex thermodynamic Bjerknes feedback. The warming in the Indian Ocean resulted in a significant increase in SSTs where IOD is the principal/ inherent climate mode. An *et al*. (2022) also reported that IOD which is also referred to as Indian Ocean Zonal Mode (IOZM) is a dipole pattern of Indian Ocean SST variability within the tropics. In addition, McKenna *et al.* (2021) indicated that IOD is an atmosphere-ocean self-generating event within the Indian Ocean that is generally seasonal and phase-bound where it begins in June-July-August (JJA) (boreal/summer), peaks in September-October-November (SON) (fall/ autumn) and decays (collapses) fast at the onset of winter in December-January-February (DJF). The study also established that IOD peak can seasonally vary. Positive IOD is illustrated by warmer SST anomalies than the usual temperatures in the western basin in the EWIO and cooler conditions than the usual SSTs in the eastern basin close to Sumatra in the EEIO (Figure 1) (Ratna *et al*., 2021). Further, the study revealed that a negative IOD is indicated by warmer SST anomalies in the eastern basin and cold anomalies in the western tropical Indian Ocean.

IOD is responsible for the SST variability in the tropical Indian Ocean where it influences the climate around the region. Ratna *et al*. (2021) revealed that IOD significantly influenced precipitation variance in EWIO and EEIO. The IOD events and the maturity of IOD vary seasonally in August-September-November (ASN), whereas the event is the primary driver of seasonal rainfall variability and droughts in East Africa. Furthermore, FAO (2022) identified two rainfall seasons as MAM and OND in the East African region.

According to Funk *et al*. (2014) the Indian Ocean SSTs along the coast of East Africa are linked to droughts that were experienced in 2000, 2009 and 2011. Meanwhile, Han *et al*. (2022) associated the warming SSTs trend in the Indian Ocean with decrease in MAM precipitation in East Africa. Therefore, influence of IOD on drought conditions in East Africa is evident. McKenna *et al*. (2020) revealed spatial diversity and complexity in nature and characteristics of IOD as a result of varied internal processes in the Indian Ocean thereby making IOD modelling a major challenge.

The spatiotemporal rainfall distribution and patterns in Kenya are influenced by Indian Ocean SSTs where IOD is linked to droughts (Sagero *et al*., 2018; Uhe *et al*., 2018). The study also attributed the SST variability along the coast of Kenya to the abundance of ocean water and topography. Moreover, Toreti *et al*. (2022) established that the Indian Ocean SSTs were associated with MAM and OND seasonal rainfall covariance in Kenya. Notably, variation in SSTs influences sea surface winds (circulations) and the thermocline temperatures.

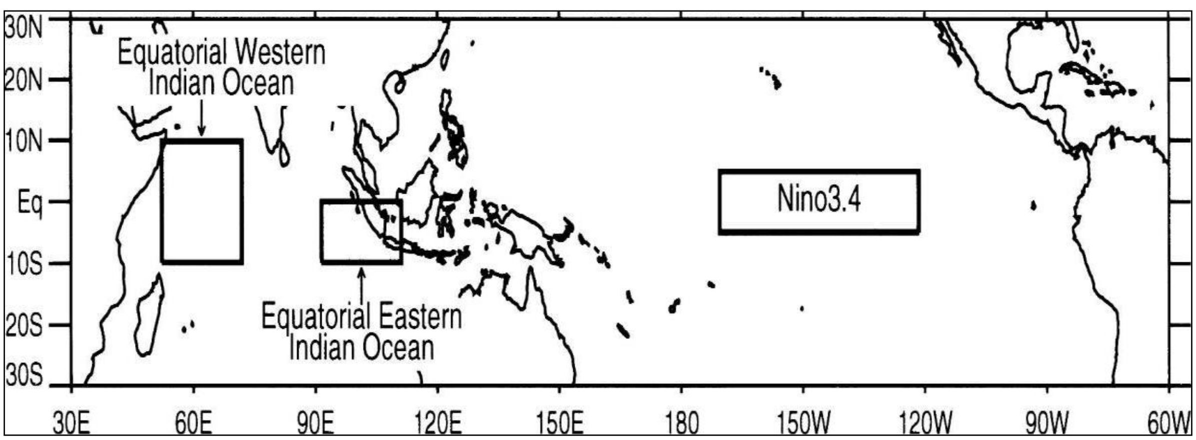

Figure 1. Regions in the Indian Ocean are shown by squares.

Source: Nagura and Konda (2007).

Variation in Indian Ocean SSTs influence wind patterns in East Africa where Nying'uro *et al*. (2022) and Ndiwa (2012) established that strong South-easterly winds originating from the South-western parts of the Indian Ocean or WIO are significantly influenced by seasonal monsoon winds over the Indian Ocean. The study established that the winds are oceanic in nature and blow over the area resulting in accumulation of water vapour in the atmosphere hence forming cumulous clouds. Ndiwa's study also revealed that the winds have a continental trajectory and that they are arid in nature during the dry periods and years. On the other hand, a maritime trajectory was exhibited by winds during wet seasons and years. These maritime winds were characterized by high moisture content over land. Further, the study noted that the study area predominantly experiences cumulous clouds over the wet season in OND. The cumulous clouds are caused by strong South-easterly winds. The study also found that cumulonimbus clouds were common in the region during a typically wet OND season.

According to Mutua *et al*. (2016) and Nyangena (2020) Makueni County experiences frequent droughts. However, gaps on the drivers and quantitative effects of droughts on cereals in the county were yet to be addreeseed hence the focus of this study. This study fills the gap by determining the influence of IOD on drought occurrence, nature, and trends in Makueni County, which provides information which can enable improvement in drought adaptation and data-based decision-making. These efforts can improve cereal production and yields, hence food security in the region.

2.4 Effects of Drought on Cereal Yields

Global food demand was projected to increase by 60% to 111% from 2005 to 2050 due to a rapid increase in the global population (Ittersum *et al*., 2016; Tilman *et al*., 2011). On the other hand, Agnes (2020) projected a reduction in tropical cereal yields by between 15% and 22% in Sub-Saharan Africa (SSA) by 2050 due to climate variability where drought was established as a significant factor. This projected increase in food demand despite a supply deficit, is a major concern to governments in ASAL regions around globally. A deficit in global food supply has also been compounded by uncertainity in climatic conditions and consequent fluctuations in cereal yields in the past few decades.

Fluctuations in food supply in various regions globally result in food insecurity, famine and malnutrition (Krishnaswamy *et al.,* 2023). In addition, Wang *et al*. (2023) revealed that droughts have resulted in approximately 650,000 human deaths globally over the past 50 years. In a bid to suffice the large annual demand for food globally, rain-fed food production is widely practiced where drought-resilient cereals such as sorghum, finger millet, and some varieties of maize among other cereals are popularly grown (Mukami *et al*, 2019; Mwangoe *et al*., 2022; Qi *et* *al.*, 2023). Even though the cereals are used to manage food insecurity in varied AEZs including ASALs such as Makueni County, frequent droughts and poor soil conditions result in low yields.

According to Bhavya *et al*. (2024) and Queiroz *et al*. (2019) drought limits starch reactions; seed reactivation, metabolic processes, chemical composition and tegument permeability in cereal crops. Mukami *et al*. (2019) and Queiroz *et al*. (2019) also observed that drought limits germination of cereal crops by reducing available soil water below 35 to 45% of the cereal seed dry mass which is a requirement for germination. The studies also noted that germination and shoot growth stages are critical whereby only 80% of the processes are attained under drought stress. The limited germination arising from drought stress results in a reduced count of cereal crops per hectare. Limitations on phenological and chemical processes result in reduced shoot biomass and nutrient composition thereby limiting cereal crop health and seed quality. In addition, reduced cereal nutrient composition leads to low-quality biomass and affects panicle development and straw weight (Poudel, 2023; Széles *et al*., 2023) hence affecting stalk and biomass development (Poudel, 2023).

Even though Xiong *et al*. (2019) found that drought-resilient cereal crops have physiological adaptations of long roots that can withstand drought stress, severe drought limits root water uptake and nutrient capture from the soil. These limitations affect the yields of ASAL cereals. Schittenhelm and Schroetter (2014) established that drought reduces the above-ground dry weight of cereal crops by 37%. A reduction in above-ground dry weight results in reduced fodder and bio-energy potential. Széles *et al*. (2023) also revealed that drought affects cereal crop leaf chlorophyll synthesis resulting in reduced leaf area and weight which limits photosynthetic and nutrient processing hence low grain quality. In addition, Mukami *et al*. (2019) pointed out that droughts in ASALs reduce the phenological growth and chlorophyll content of cereal crops. Mi *et al*. (2018) established that cereal yields significantly reduce by 18.6% to 26.2% in China when droughts occur during the vegetative stage. In addition, Széles *et al*. (2023) and Qi *et al*. (2022) reported that drought limits grain filling thereby leading to reduced grain count. Drought also reduces grain size, weight and quality (Batista *et al*., 2019). A reduction in protein content and grain quality as a result of the drought was also observed by Poudel (2023).

According to Eggen *et al*. (2019) drought negatively affects cereal crop flowering which is the most delicate phenological stage thereby limiting reproduction. Drought also leads to a decrease in head size at floral initiation and flower destruction hence reduced reproduction of the cereal crops (Hadebe *et al.,* 2017; Tack *et al*., 2017). Széles *et al*. (2023) also pointed out that maize yields may reduce by 30% to 90% under varying drought intensities. Drought also affects the vegetative and reproductive phases with varying negative results whereby the study by Széles established 8% to 10% and 18% reductions in content of chlorophyll and reproductive stages, respectively. In addition, Mi *et al*. (2018) found reductions in cereal yields in China ranging from 41.6% to 46.6% when droughts occur during the reproductive phases. The decrease in cereal crops' floral reproductive activities limits cereal pollination resulting in low yields.

Nhamo (2019) and Yahaya *et al*. (2023) associated the low cereal yields in Africa with frequent and severe droughts which negatively affect nutrient development and composition. NEMA (2019) attributed 68% of crop loss to climate variability and change in Eastern Kenya where droughts have been recurrent since 1994. The study also found that cereal yields reduced by 70% to 90% in 2013 due to droughts thereby increasing levels of vulnerability and food insecurity in the region. Mutua *et al.* (2016) determined that social effects of the droughts are felt by approximately 40% of the populace in Makueni County thereby increasing the vulnerability of the smallholder cereal farmers in the region.

Even though ASALs experience adverse pedo-climatic conditions (Hadebe *et al*., 2017; Mundia *et al*., 2019) whereby drought significantly affects cereal production and yields, drought-resilient crops such as sorghum, finger millet and some varieties of maize withstand the harsh conditions. These drought-resilient crops are also grown as drought adaptation measures and to manage food insecurity in the county. NEMA (2019) established that rain-fed crop farming is a popular agricultural practice among 80% of the cereal producers thereby improving food security in Makueni County.

Sorghum is the fifth most important cereal after wheat, maize, rice, and barley and serves as a staple food for more than 500 million people globally (Lubadde *et al.,* 2019; Ondiko & Recha, 2022). Sorghum originated from HoA (Sudan and Ethiopia) where the crop developed from its wild species progenitor *S. bicolor* subsp *verticilliflorum* (Ananda *et al*., 2020). The grain developed from the Poaceae grass family and it was cultivated for the first time about 3700 to 4000 years ago in North-eastern Africa (Xiong *et al*., 2019). Mundia *et al*. (2019) and Popescu *et al*. (2018) established significant fluctuations in sorghum yields averaging 62 to 63 million metric tonnes (MMT) from an acreage of 42 million ha, globally. Mundia *et al*. (2019) observed that the USA is a leading sorghum producer with 17% of global yields from a small area of 6% of the total global sorghum area. In addition, Hansen *et al*. (2018) noted an increase in exportation by USA as accounting for up-to 77% of global sorghum export share in the past 5 years. However, fluctuations in trends of sorghum yields which were associated with drought events and market price fluctuations were recorded.

According to Njagi *et al.* (2019) and WFP (2018) ASALs have the potential to produce between 1.5 and 5.0 tonnes per hectare (tha^{-1}); however, Njagi *et al*. (2019) reported low sorghum yields in Africa at 0.65 $tha\text{-}^{1}$. In spite of fluctuations in yields, an increase in sorghum production from 18.4 MMT in 2000 to 24.3 MMT was reported in Africa in 2007 (Okeyo *et al*, 2020; United States Department of Agriculture [USDA], 2016). In addition, sorghum production doubled in Africa from 13 to 29 MMT between 1980 and 2018 (Orr *et al*., 2020). Mundia *et al*. (2019) and Popescu *et al*. (2018) established that Nigeria is a major global producer and exporter of sorghum and accounts for approximately 40% of the continental yields. However, Liebig (2016) reported low sorghum yields in the country at about 1.0 tha^{-1}. Zalkuwi *et al*. (2015) also linked a decline in sorghum yields in 2014 to the adoption of more profitable crops and the recurrence of drought in the North and North-eastern parts of Nigeria.

Popescu *et al.* (2018) noted that sorghum is a very important cereal in Sudan making the country the fifth producer after China, India, Nigeria, and the USA and accounts for 6.51% of total sorghum yields globally. Further, Okeyo *et al*. (2020) indicated that Sudan is the second largest sorghum producer in Africa after Nigeria where it accounts for approximately 21% of continental sorghum produce. Mitaru *et al.* (2012) also noted that sorghum accounted for 65% of all cereal yields in Sudan and that it was the principal staple food for the rural population in the country. The study also indicated that 90% of sorghum yields were under rain-fed conditions. Ehab (2016) noted fluctuations in sorghum yields in Sudan in the past five decades despite the significance and the large area under the crop in the country. Further, Mitaru *et al.* (2012) determined that drought significantly affects sorghum yields in Sudan where a 10% decline in average annual rainfall led to a 5.4% decline in sorghum yields. Drought-driven sorghum fluctuations in Sudan pose a major challenge to food security considering the important role played by the crop as a staple cereal in the HoA and East Africa.

Agriculture is a vital sector of Kenya’s economy by contributing 26% directly and 27% indirectly through multisectoral linkages to the national Gross Domestic Product (GDP) (Kerubo, 2021) and accounts for 65% of the national export. However, sorghum contributes between 1%

and 3.8% only of total grain produce notwithstanding the high percentage (80%) of suitable ASAL land (GoK, 2007; Venton, 2018). The annual production of sorghum in Kenya is approximately 113,485 metric tonnes (MT); however, Kilambya and Witwer (2013) established annual sorghum yield fluctuations averaging 109,414 MT from 1990 to 2011. Mwadalu *et al*. (2022) also corroborated the fluctuation in trend whereby 150,000 MT of sorghum was produced in 2017. The fluctuations in grain production and low hectarage were associated with frequent droughts and the adoption of alternative crops such as oil seeds and pulses which were more profitable in Kenya. Chepng'etich (2013) recorded growth in the area under sorghum from 122, 368 ha in 2005 to 173, 172 ha in 2009. In addition, Njagi *et al*. (2019) reported the population of sorghum farmers in Kenya at 240,000. A big number of the sorghum farmers is found in Eastern Kenya which is the leading producer of sorghum in the country.

Okeyo *et al*. (2020) and WFP (2018) reported that ASALs in including Eastern Kenya cultivated several sorghum varieties including Seredo, Gadam, Serena, KARI Mtama 1, Sila and KM 32-1. Further, Bosire *et al*. (2018) noted that sorghum is grown both in MAM and OND seasons whereby the latter is the main rainfall season in the region. Moreover, Eastern region of Kenya produces approximately 68,527.26 MT (Njagi *et al.*, 2019), which accounts for 42.5% of the national annual sorghum production. The study also revealed that the comparatively high sorghum production in Eastern region of Kenya is largely attributed to the nature of the AEZs of the ASALs despite the adverse pedo-climatic conditions. Even though the region is leading in the production of cereal in Kenya, low productivity was recorded where most sorghum farmers (32.1%) produced between 0.151 and 0.25 tha^{-1} in Makueni County (Kagwiria *et al*., 2019). However, the region can produce between 2.0 to 5.0 tha^{-1} of sorghum (Njagi *et al.*, 2019).

Even though finger millet which originated from the HoA (Western Uganda and Ethiopia) about 5000 years ago is a popular crop globally, its production averages 30.73 MMT (Odeph *et al.,* 2020). Finger millet is a popular cereal in Asia and India where the latter produces approximately 37% of the global produce, though its production fluctuates (Ceasar *et al*., 2018; Mbinda *et al*., 2021).

Finger millet is commonly grown in Africa in the semi-arid tropics where its production is approximately 19 MMT from 16 million ha which is 19% of the total area under cereals in the continent (Ceasar *et al*., 2018; Macauley & Ramadjita, 2015). Further, Handschuch (2014) established a low farm area (0.1 million ha) under finger millet in Kenya in 2012. In addition, Odeph *et al*. (2020) and Wafula *et al*. (2016) revealed that even though the crop is drought-resilient and therefore suitable for ASALs, production was done on small-sized farms in Kenya which range from 0.04 to 1.0 ha. Odeph *et al*. (2020) also indicated fluctuation in finger millet production area where only 77, 890 ha were under the crop in Kenya. Odeph *et al*. (2020) also pointed out that the Western region was the leading producer of the crop in the country. Further, Mbinda *et al*. (2021) decried the low yields of the cereal in Kenya that ranges from 0.5 to 0.75 tha^{-1} despite the high yield potential of 2.5 tha^{-1}. Meanwhile, Ondiko and Karanja (2021) decried the increased frequency of droughts in ASALs in Kenya; though the regions are the principal cereal-producing areas thereby affecting output and hence national food security (Odeph *et al.*, 2020 and Wafula *et al*., 2016).

Maize is a significant cereal making it the second most popular crop after wheat globally where its demand increases annually due to rapid population growth. The cereal is believed to be a wild grass that originated from Central Mexico approximately 7,000 years ago (Ranum *et al*., 2014). The study revealed that the crop was transformed into a more useful food source by Native Americans. The study also pointed out that the cereal has a high starch, protein, and fat content at approximately 72%, 10%, and 4% respectively. Even though the cereal is a source of food and industrial beverages, it can also be used as animal feed (Grote *et al*., 2021). The crop is also a source of biofuel (ethanol). Maize grows in varied AEZs hence its potential to ensure food security. The annual production of maize globally is approximated at between 1, 070 and 1,127 MMT (Grote *et al*., 2021; Széles *et al*., 2023) from approximately 184 million ha with a global average yield of 5.0 tha^{-1} (Ntabakirabose, 2017).

According to Tigchelaar *et al*. (2017) USA, China, Brazil and Argentina are the top four producers of maize and account for approximately 68% of the produce globally, though production is significantly affected by frequent droughts. Meanwhile, Széles *et al*. (2023) found that drought can result in 30% to 90% reduction in maize yields depending on the intensity and duration of the event. Maize growing season is also affected by onset and period of droughts and cessation of the phenomenon thereby influencing yields. Ortiz-Bobea *et al*. (2019) also established that drought determines cereal yields where a 12% decline was recorded at a 20% drop in soil moisture in the USA. Even though a high potential of maize yields ranging from 7.0 to 12.0 tha^{-1} annually can be achieved, Belete (2020) established that Ethiopia yielded 3.06 tha^{-1}, where 97% of the production of the cereal was under rain-fed conditions. These low yields of maize were associated with frequent droughts in Africa.

Maize production in Kenya is affected by drought where annual production is approximately 3.6 MMT and production ranges from 37 to 40 million bags despite an annual demand of 42 million bags (Alessandro *et al.*, 2015; Aoko, 2023; Njoroge *et al*., 2019). However, a positive maize production trend was recorded by GoK (2020) which revealed that the country produced 47.7 million bags in 2018 which translated to approximately 4.3 MMT.

The GoK (2022) established fluctuation in maize production area in Kenya from 2,092,459 ha, 2,196, 136 ha and 2,168, 603 ha in 2017, 2019 and 2021 respectively. Fluctuations in maize production area in Kenya results in fluctuating yields, hence creating a production-demand deficit which makes the country a net importer of the cereal. Alessandro *et al.* (2015) also revealed that the cereal is produced by 3 million smallholder farmers whose output from less than 2 ha is about 70% of the total national produce annually. The study also established that drought results in significant reduction in maize production among smallholder farmers where low yields about 1.6 tha^{-1} were recorded in 2012. However, Széles *et al*. (2023) revealed a high maize productivity potential above 6.05 tha^{-1}.

Low and worrying projections of maize yield reductions ranging between 10% and 20% by 2050 have been linked to frequent droughts (Omoyo *et al.*, 2015). These significant fluctuations in cereal yields due to droughts are a major concern to GoK, CGoM and smallholder cereal farmers in ASALs in Kenya. However, DT maize varieties withstand the adverse pedo-climatic conditions in ASALs where the cereal improves food security.

Maize is a very popular cereal in Makueni County, though climate variability more particularly droughts significantly affect yields (Mohamed & Chege, 2019). However, some popular DT maize varieties such as PANNAR, DUMA43, DK8031, DH02-04, PIONEER, KISHINDO F1, KDV1-6, SIMBA41 and SUNGURA (Berre *et al*., 2016; Schroeder *et al.*, 2013) are grown. Other drought-resilient varieties that can also be up-scaled in ASALs include TEGO (Berre *et al*., 2016), Makueni DLC1 and Katumani Composites (Schroeder *et al*., 2013; WFP, 2018). Recha *et al*. (2016) established low maize yields in Makueni County where the study revealed that only 0.4 tha^{-1} was produced annually by a majority (53%) of the farmers. NEMA (2019) also indicated that drought led to a decline in maize yields where only 37 $kgha^{-1}$ was produced in Makueni County. The study advised improvement in climate and cereal yield projection in the County to enable drought adaptation hence improvement in maize yields. Further, NEMA advised the adoption of DT maize varieties and irrigation farming to improve yields and to manage food insecurity. Crop production in Makueni County is supported by the AEZ which comprise suitable soil conditions for production of DT cereals.

Makueni County has moderately deep volcanic soils in the hilly undulating landscapes with gentle slopes comprising high fertility cambisols and luvisols. The area also has deep, red, strongly weathered acidic acrisols and ferrasols with low fertility in low-lying undulating landscapes (Munyao, 2018). These pedological conditions support production of DT cereals.

A study conducted in South-eastern region of Kenya by Gevera *et al.* (2020; 2023) established that Makueni County is located within the metamorphic Mozambique Mobile Belt (MMB). The geological belt comprises of predominant metamorphic rocks and soils that are metasediments which include Fluorine (F) rich minerals such as apatite, biotite and muscovite. Hornblende schists are also weathered to form soils. The study indicated that a large area in Makueni County is under gneiss and migmatite rocks which are metamorphic in nature. Metamorphic rocks are broken down to form laterites. Intrusive igneous granitic rocks have also undergone metamorphism resulting in formation of granitoid gneiss rocks and soils. Makueni County has igneous rocks which are located in the central part of county. The igneous rocks undergo weathering to form volcanic soils which support production of multiple cereals.

According to Gevera *et al.* (2020; 2023) soils in Makueni County are clayey, sandy, clay-loam and sandy-clay with generally rough texture and porous structure. Sandy-loam and clay-loam soils are also found in the low-altitude areas of the county (CGoM, 2017). Barren rocky surfaces are also found in the area (CGoM, 2019). Basalt and pyroclastic unconsolidated rocks which are weathered over time, are also found in the south-eastern part of the area and at the foot of the hills.

Syano *et al.* (2023) revealed varying soil nutrient levels in Makueni County where Soil Organic Carbon (SOC) and Total Nitrogen (TN) are higher in woodlots compared to lowlands and pasture lands in Makueni County. The study found that Phosphorus was comparatively higher in parklands compared to grazing lands and woodlots in Makueni County. Drylands such as Makueni County are characterized by poor soil conditions with limited soil nutrients and mineral contents. The soils are also dry and poorly drained resulting in low crop output per hectare. Soils in drylands are also degraded or eroded resulting in low mineral and nutrient content hence growth and development of few scattered vegetation. The poor dryland soil conditions are exacerbated by anthropogenic forcing which include overuse. Overcultivation and uncontrolled use result in reduction in soil nutrients and moisture content. Limited soil nutrients and moisture limit crop production, hence food insecurity in Makueni County.

Poor soil conditions support the growth and development of few drought-resilient plants including grass, dense shrubs or woodlands (Syano *et al*., 2023). The study pointed out that the ASAL land comprises of ferrosols which include either rhodic (red colour) or xanthic (yellow colour) and few acrisols. The ferrosols and acrisols naturally have insufficient Nitrogen (N), Phosphorus (P) and Total Organic Carbon (TOC) matter making them less fertile for agricultural production. These soils have high salinity levels. The soils are poorly drained and they have limited soil nutrients and low organic matter. These poor pedological conditions increase soil vulnerability to physio-chemical and biological erosion which result in land degradation, hence increasing the chance of reduction in cereal yields in Makueni County. Limited soil nutrients and desiccated geomorphological conditions discourage growth and development of crops, though DT sorghum, finger millet and maize varieties are cultivated in Makueni County. In addition, beans, pigeon peas and cowpeas are also cultivated in the study area.

The lowlands of Makueni County have nutrient and mineral-deficient soils, however, the AEZ provides pedo-climatic characteristics that can support livestock production, fruit production and cotton farming (Omollo *et al*., 2018). In addition, the study found that the highlands of Makueni County can support cash crop production whereby horticulture can be undertaken. Further, dairy farming can be sustained in the highlands in the county.

Various studies on farmers' perceptions on droughts identified the effects of the events on cereals such as sorghum (Kagwiria *et al*., 2019; Mailu & Mulinge, 2016; Muui *et al*., 2019), finger millet (Mbinda *et al*., 2021; Wekha, 2017) and maize (GoK, 2022; Mbinda *et al*., 2021) in various AEZs in Kenya. However, there was barely any study that quantitatively evaluates the effect of drought on multiple types of cereals in Makueni County. Therefore, this study fills the gap through correlational evaluation of the effects of droughts on the cereals in the county. The information from the study can be used to improve production and yields of the cereals hence improving food security in ASALs in Kenya.

2.5 Drought Adaptation Strategies

Garrick (2018) and Holman *et al*. (2021) revealed that adaptations to effects of natural phenomena may include human, agricultural, environmental, and economic, to increase resilience.

Agricultural adaptations to droughts are of key concern to GoK, CGoM and the smallholder cereal farmers since effects of drought are evident in poor cereal production in the region. In addition, the effect of drought is experienced in fluctuating cereal yield levels or total crop failure, hence food insecurity in the affected regions. Agricultural adaptations enable complementary human, environmental and economic adaptations in the affected regions therefore enhancing cereal productivity. Cereal production varies spatiotemporally due to varying AEZs and cereal varieties for these regions. In addition, drought affects various AEZs differently. Besides, there is no single approach that can suitably fit all drought adaptation needs hence location specific adaptations are advised.

Even though fluctuations in frequency and severity of droughts have been noted globally, many drought adaptation strategies have been put in place by several regional governments and organizations to increase cereal yields. Drought adaptation is a process where actual and projected impacts of the phenomenon are responded to, intently to limit negative environmental, agricultural, economic and social effects (Akinnagbe & Irohibe, 2014; Intergovernmental Panel on Climate Change [IPCC], 2015).

Garrick (2018) noted that increasing the size of sorghum farm increased the chance of positive yields due to increase in seedling count per hectare in USA. McNeeley *et al*. (2016) established that CBA to droughts in South-East Dakota, the interior of the USA; among local communities was determined by social, ecological, economic, and political situations at the local level. These determinants of CBAs were considered at the local community level since pedo-climatic conditions vary from one region to another. Further, socio-economic status of communities also varies depending on the economic activities undertaken in a given region. In addition, the level of political involvement also determines decision-making and implementation at the local level.

Xu *et al.* (2017) attributed 56% of crop yields to improved science and technology in China. Bio-technological drought adaptation measures are practiced by farming communities through the adoption of regionally and AEZ suitable technology to improve cereal yields in China. Bio-control measures limit cereal destruction by pests and diseases hence increase in cereal yields. The technological and bio-technological drought adaptation measures are influenced by availability of capital and technical know-how. On the other hand, Wang *et al*. (2016) noted that increasing farming capital resulted in improvement in accessibility to modern agricultural mechanization and human productivity. Increasing capital also enables the purchase of required farm input and expansion of farm size. Furthermore, Lei *et al.* (2013) found that a local Chinese community in Beidian village in Northern China adjusted land use patterns as CBA to droughts. The study revealed increased adoption of coarse cereals to improve drought adaptation hence cereal yields.

According to Khan *et al*. (2022) rainwater harvesting, soil conservation and variation in crop planting dates were useful responses to droughts in ASALs in Pakistan. Adhikari (2018) found that promotion of climate smart agricultural techniques, practicing agroforestry, crop diversification, rainwater harvesting and early drought warning information significantly improved drought adaptation thereby improving agricultural production in ASALs in Western Nepal. Further, Ogundeji and Okolie (2022) revealed that rainwater harvesting and consequent supplementary irrigation, adoption of short-season crops, and income diversification significantly improved drought-resilience and crop production in ASALs in Sub-Saharan Africa.

Adaptation to drought entails adoption of measures towards limiting the negative effects of the phenomenon. Lovelli (2019) indicated that drought adaptations can reduce level of vulnerability of the smallholder farmers practicing rain-fed crop production in drought-prone ASALs in Africa. Nguyen and Nguyen (2018) found that drought adaptation can be short, medium, or long-term; however, this study focused on micro-scale level and short and medium-term drought adaptations which require minimal financial investments while focusing on CBA and IK. Further, the study reported that drought adaptations are influenced by factors that are either autonomous or planned actions. Furthermore, Garrick (2018) noted a slow onset, unpredictability, natural occurrence, and frequent droughts which demand a range of strategic approaches to improve cereal yields.

Even though irrigation is an effective drought adaptation strategy in different cereal-producing regions, the strategy is limited by inadequacy of capital, variable water sources, quantities, and low levels of technology. However, Kool *et al.* (2014) established existence of successful irrigation farming in Gezira irrigation scheme in Sudan. The study pointed out that though cereal production under irrigation is undertaken; cereal yields are still low in the country despite abundance of water from Blue Nile and White Nile rivers. The study revealed that low cereal yields in Sudan are linked to variable water supply, poor agronomic practices, poor soil moisture conservation practices, controlled cereal farming and low prioritization of cereal production in addition to droughts. Therefore, the study advised improving irrigation farming to improve cereal yields in the scheme. In as much as irrigation farming is undertaken in these regions, ASAL communities in Sudan also adapted to droughts by increasing water harvesting thereby increasing chances of supplementary irrigation, hence increase in cereal yields.

Madege *et al*. (2017) observed that diversification of income and rural economies spread drought risks. In addition, diversification of income leads to stabilization of prices through alternative income generating activities and reduction of overreliance on specific cereals. Further, Komba and Muchapondwa (2015) established that smallholder farmers in Tanzania adopted short-season cereal varieties. Radeny *et al*. (2019) found that local farming communities in Tanzania predicted drought conditions using traditional meteorological techniques such as interpretation of the conditions of the sky, frequency of drizzles and lightning, and prevailing temperature conditions. These IK techniques were used to identify cessation of rainfall and the onset of droughts. The strategies included promoting alternative systems of agriculture, improving agronomic practices, improving water harvesting and conservation, adopting early maturing and drought-resilient cereal varieties, and integrating cereal production and pest management.

Asiimwe *et al.* (2020) established that adoption and integration of camels into mainstream livestock keeping, significantly improved household resilience to droughts by 20% in ASALs in Uganda. Further, Ndiritu (2021) found that improved access to market, education of farmers and adoption of private livestock ranching in Laikipia County improved resilience to droughts among smallholder farmers. Consequently, improvement in livestock production in ASALs in the county was reported.

Julia (2015) revealed that improving agronomic practices such as prediction of drought, variation in drought-resilient cereal varieties, and varying dates of planting improved conservation of soil thereby increasing yields. While in agreement with the study, Muthee *et al*. (2019) argued that mixed cropping and improving cultivation methods and farm management practices improve cereal yields in Kenya. Improvement in cereal yields improves food security in different regions of Kenya where the most affected ASALs can be shielded from famine. Mutua *et al*. (2016) advised drought awareness among smallholder cereal farmers to improve yields in Makueni County.

Muthee *et al.* (2019) found that bio-control of pests by practicing agro-forestry, sustainable use of land and soil conservation through the application of animal (farm) and compost manure;

increase soil moisture retention and fertility hence improving cereal yields. In addition, planting cover crops and contour ploughing were practiced to control soil erosion and to maintain the quality of soil and soil moisture, hence increase in cereal yields. Further, Madege *et al*. (2017) reported that the promotion of traditional vector control by adoption of pest-resistant cereals and other drought-resilient cereal landraces increases cereal yields. Spraying vegetables with pepper as a pest bio-control measure, soaking sorghum and finger millet seeds in water to fasten germination process, and ash sprinkling on farms to control pests such as weevils; are useful IK practices by most communities in rural areas of Kenya.

Majority of the smallholder cereal farmers in Makueni County practiced mixed cropping which resulted in increase in yields of sorghum, pigeon peas, green grams, and beans (Kagwiria *et al*., 2019). Besides, cereal yields also improved through the use of ZAI pit cultivation in Makueni County. Gichure (2017) and Masya (2016) found that some smallholder farmers in Makueni County adopted irrigation farming. Adjusting cereal sowing time which depends on rainfall patterns in Makueni County; was also observed (Kagwiria *et al*., 2019). In addition, the study established that majority of the farmers in Makueni County used family seed stores and local markets as sources of farm inputs alongside animal and crop residue manure which increased cereal yields.

Even though cereal production is affected by frequent droughts in Makueni County (Amwata *et al*., 2016; Musa & Onono, 2021; Mutua *et al*., 2016), a gap was identified on community-level IK drought adaptation strategies practiced in Makueni County. Kagwiria *et al*. (2019) also focused on crop-specific drought adaptations, thoughthe effect of droughts on multiple types of cereals was yet to be addressed. In light of these gaps, the study evaluated outcomes of drought adaptations practiced by smallholder cereal farmers in Makueni County. Therefore, this study focused on evaluation of CBA and IK drought adaptation strategies in Makueni County. These efforts will provide information which can be used to improve policy formulation, data-driven decision-making and drought adaptation in Makueni County. The information can also improve cereal production and food security in Makueni County.

2.6 Outcomes of Drought Adaptations

According to a study conducted in Yobe State in Northern Nigeria (Gana, 2018) local communities adopted CBA to droughts thereby improving cereal yields. Yakubu *et al*. (2021) reported the adoption of early maturing cereal varieties which were planted in water-stressed environments to improve water and nutrient use and cereal yields. In addition, these CBAs reduce the level of vulnerability of smallholder cereal farmers. Muthelo *et al.* (2019) found that restricting use and improvement in water management, use of a multi-prong approach including socio-economic investments improved drought resilience in South Africa. In addition, Orimoloye *et al*. (2021) reported that spatial incorporation of biophysical resources resulted in improvement in ecosystem management and services in South Africa.

The adoption of DT cereals such as sorghum, finger millet and maize varieties was advised because the cereals improve adaptation to droughts in the HoA (FAO, 2022; Ghebrezgabher *et al*., 2016). The study also advised availing information on drought predictions to improve awareness about the event and to enable preparedness. Despite the study revealing the recurrence of severe droughts in the past eight decades in the HoA, however, the ASALs still produced significant amounts of cereals.

Madege *et al*. (2017) observed widespread use of IK-based drought adaptations in Tanzania. The study found that integration of IK in drought adaptation improves land tillage and hence cereal yields in ASALs. In addition, animal wastes such as cow dung or urine, and plants such as Aloe *spp* (Asphodelaceae), red pepper, and ash are useful pest control measures. Further, cereal seed preservation and storage are also done by application of dried plants such as tobacco, Eucalyptus *ssp* (Myrtaceae), and ash. These practices limit the destruction of cereal seeds by pests and they are non-toxic preservation measures, unlike chemical preservation methods. The traditional cereal preservation and storage practices ensure the existence of a grain seed bank for the next planting season. Traditional seed storage is regarded as affordable and accessible due to affordable storage structures besides eco-friendly storage conditions and a long seed life. The pest control measures are either used with one or multiple animal or plant products.

Ochieng' *et al*. (2021) established that adoption of indigenous drought projection strategies by pastoral communities in ASALs in Kenya improved livestock safe guarding and production due to availability of farm manure. Njagi *et al.* (2019) established that ASALs in the HoA can produce between 2.0 to 5.0 tha^{-1} of sorghum, whereas the yield potential for finger millet is 2.5 tha^{-1} (Mbinda *et al*., 2021) while Onono *et al*. (2013) revealed that maize can yield up-to 6.0 tha^{-1} annually.

Soil conservation can be improved through mulching whereby foliage and crop stalks cover soil thereby reducing rate of evaporation in addition to controlling water and wind erosion. Further, Mwende *et al*. (2019) established that cereal yields increased by approximately 37% through effective soil moisture conservation in ASALs in Kenya. Kagwiria *et al*. (2019) also advised adoption of hybrid and short-period cereal varieties such as gadam which mature fast under ASAL conditions in the country. These drought adaptation strategies increase cereal yields in Makueni County.

2.7 Summary of Knowledge Gaps

Han *et al.* (2022), Kew *et al*. (2019), Nyangena (2020), Spinoni *et al*. (2019) and Venton (2018) established recurrence of single to multi-year droughts in Kenya from 1900s. In addition, the studies found occurrence of severe droughts in Kenya in 1930s, 1940s, 1950s 1980s, 1990s, and 2000s. Ondiko and Karanja (2021) reported a reduction in the drought-return period in the country from five to three years. The high frequency of droughts in the county is a major concern to the GoK, CGoM and the local stakeholders due to fluctuations in cereal yields despite steadily rising annual demand and food insecurity in Makueni County. Limited projection of drought events hinders planning, adaptation and mitigation. Besides, it may result in increase in vulnerability of smallholder cereal farmers thereby leading to increase in yields in ASALs such as Makueni County. It is on the basis of inadequacy in drought projection and limitation that this study sought to project drought in Makueni County using ARIMA models for 2024 to 2054. The information can be used to improve cereal production and food security in the County. In addition, drought modeling enables improvement in drought-related data-driven policy formulation and decision making thereby improving cereal yields hence food security in Makueni County.

Several climatic drivers influence occurrence and nature of drought along EWIO. ITCZ (Liu *et al*., 2020a), El Niño (Dong & McPhaden, 2018) and La Niña (Koesuma *et al.,* 2021) were linked to droughts in East Africa. However, IOD was established as the principal driver of droughts around the Indian Ocean and the East African region (Funk *et al*., 2018; Ratna *et al.,* 2021; Uhe *et al*., 2018). Two rainy seasons, MAM and OND which support growing of cereal crops in Makueni County were also reported (Amukono, 2016; Omondi *et al*., 2013). However, increasing frequency and severity of droughts in Makueni County (Mutual *et al*., 2016) pose a significant challenge to cereal production and food security in the region. Increased frequency of droughts also results in degraded soil and water conditions which significantly affect the biotic and abiotic environments in Makueni County. Spatiotemporal rainfall distribution and patterns in Kenya are influenced majorly by Indian Ocean SSTs where IOD is linked to droughts (Sagero *et al*., 2018; Uhe *et al*., 2018). Han *et al*. (2022) associated the warming SST trend in the Indian Ocean with the potential decrease in MAM precipitation in East Africa in recent decades. Fluctuations in rainfalls in the region is therefore a major concern to the stakeholders in the agro-production systems in Makueni County. Further, Mutua *et al*. (2016) and Nyangena (2020) analysed the frequency and effect of the frequent droughts in Makueni County. However, this study fills a gap in the level of relationship between IOD and drought events in Makueni County.

Nyangena (2020) assessed the macro-level frequency of droughts in various regions in Kenya where the study advised a lower-scale determination of the effects of drought on various sectors of the economy. Frequent and severe drought events impact food security (Nyangena, 2020; Ondiko & Karanja, 2021; Uhe *et al*., 2018). In addition, Gichure (2017), Mwende *et al*. (2019), Muui *et al*. (2019) and Queiroz *et al*. (2019) reported low annual sorghum, finger millet and maize yields in Makueni County which was linked to frequent severe droughts in the County. Even though Széles *et al*. (2023) pointed out that maize yields may reduce by between 30% to 90% under varying drought intensities in different agro-production environments globally, a gap was established on the effect of the phenomenon on DT cereal varieties such as sorghum, finger millet and maize in ASALs within the tropics. Makueni County, an ASAL, is leading in the production of DT cereal varieties in Kenya, though, low productivity was recorded in the County (Kagwiria *et al*., 2019; Mailu & Mulinge, 2016; Mbinda *et al*., 2021; Muui *et al*., 2019; Wekha, 2017). However, the level of association of droughts and production of multiple cereals in Makueni County was yet to be addressed hence the focus of this study. Therefore, this study fills the drought-cereals gap through correlational evaluation of the effects of the events on the cereals in the county. The information from this study can be used to improve production and yields of the cereals hence improving food security in ASALs in Kenya.

Hadebe *et al*. (2017), Mundia *et al*. (2019), Mundia *et al*. (2019), Nhamo (2019), (Xiong *et al*. (2019) and Yahaya *et al*. (2023) associated low and fluctuating cereal yields in Africa with frequent and severe droughts which negatively affect growth and development hence cereal production conditions and yields. The increase in frequency and severity of droughts in ASALs in Africa and more particularly in Kenya where ASALs cover 80% of the surface area of the country (GoK, 2007; Venton, 2018), is a major concern to crop-production stakeholders. Besides, Han *et al*. (2022), Kew *et al*. (2019), Nyangena (2020), Spinoni *et al*. (2019) and Venton (2018) revealed an increasing trend of droughts in Kenya where ASALs are the most affected. However, Gichure

(2017), Kagwiria *et al*. (2019) and Radeny *et al*. (2019) realized that drought adaptation results in improvement in cereal yields at different rates in different agro-production environments. Even though CBA and IK are adopted in drought adaptation in Makueni County, Aoko (2023); Kagwiria *et al*. (2019) and Radeny *et al*. (2019) established inadequacy of information on CBAs and IK-based drought adaptation thereby limiting achievement of full cereal production potential in Makueni County. In that regard, to improve cereal production in Makueni County which is an ASAL and a region which frequently experiences food insecurity, this study investigated CBA and IK drought adaptations practiced in the region. This study provides information which may be used to identify the most drought-appropriate adaptation strategies. This study also provides information that may be used to improve drought resilience and adaptation policy formulation, data-driven decision-making and management of food security in the region.

2.8 Theoretical Framework

This study is informed by Adaptation Theory (Eisnack & Stecker, 2010) and Sustainable Livelihoods Framework (Tapiwa, 2023). Adaptation Theory or the Survival Theory, which is also known as the survival for the fittest, is a theory detailing the ability of a living organism to functionally and temporally adapt to the physiological changes in a given environment (Eisnack & Stecker, 2010). The theory which is linked to Charles Darwin who studied organisms in the Galapagos Islands in 1830s; found a rooted relationship between the living organisms and their habitats. The theory applies to the study where smallholder cereal farmers can respond, adjust and adapt to drought in ASAL environments to improve the chances of survival through increased cereal production and yields hence food security.

Mairs (2007) reported that nature is a limiting factor in the survival of living organisms such as human beings. The study also argued that since living organisms develop and diversify over time in a given environment, they can adapt to the limiting environmental conditions. These limiting climatic and environmental conditions stimulate human beings to adapt to survive. The Adaptation Theory may be complex and it may involve other pedo-climatic factors within a given environment whose productivity may be impeded by consistent variation in climatic conditions such as drought (Brown *et al.*, 2011). The study also indicated that adaptation to spatiotemporal variations in climatic conditions may require significant financial investment besides consistent adaptive capacity building and efforts which remain a major challenge in drought-prone ASALs such as Makueni County. However, the theory was identified as the most suitable for the study because CBAs to drought in ASALs such as Makueni County may not necessarily require large technological investment compared to other forms of adaptations.

Adaptation to drought can be based on CBA and IK techniques thereby involving the use of affordable, tested, and useful indigenous adaptation strategies as adopted in the study. The study evaluated the CBA strategies among smallholder cereal farmers in Makueni County. The CBAs adopted in the county increase cereal yields in adverse pedo-climatic conditions. Furthermore, due to the spatiotemporal variation in climatic conditions, various regions can adapt to droughts variedly to improve cereal yields. Adaptation Theory guides the study to establish the effects of drought on cereal yields and to evaluate the adaptation practices by smallholder cereal farmers in Makueni County. All these efforts improve drought adaptation hence cereal yields and food security in the study area.

Sustainable Livelihoods Framework (Tapiwa, 2023) was also identified as an appropriate theoretical framework for this study. The principles of Sustainable Livelihoods Framework advocate for a holistic set of values such as equity, participatory approach in decision making, creative and quality endeavours, healthy and mutually beneficial interactions between people and their environments for sustainable development. The framework also advocates for the dynamic use and management of agrobiodiversity for productivity and sustainability. The framework indicates that vulnerability of smallholder cereal farmers may be influenced by drought shocks or stress, trends and seasonality. These factors may also influence natural, physical, human, social and financial capital thereby limiting productivity hence affecting livelihoods. This theory informs the CBA and IK drought adaptation strategies that are practiced in the study area and result in reduction in the levels of vulnerability hence improvement in resilience and adaptability by smallholder cereal farmers in Makueni County.

Even though drought stress or shocks, trends and seasonality influence productivity and livelihoods, factors such as policies, institutional frameworks and processes may significantly influence these drought adaptation factors hence livelihoods of smallholder cereal farmers. In addition, livelihood strategies such as CBAs to drought may result in significant positive livelihood outcomes such as: increase in cereal yields and improvement in food security, more income, improvement in well-being and reduction in level of vulnerability of the smallholder cereal farmers. Further, livelihood strategies may result in increased access to natural resources (Abraham, 2021).

The GoK, MoA and other stakeholders in crop production sector in ASALs in Kenya have responded to droughts through some programmes to improve the livelihoods of smallholder farmers in Makueni County. These efforts were to contribute towards improving productivity and profitability of key cereals such as maize, sorghum, millet, and associated pulses. However, the extent to which these strategies have been adopted and their outcomes in ASALs such as Makueni County were still unclear. Though the information on outcomes of the drought adaptation strategies is necessary in order to upscale the most useful ones in other ASALs in similar AEZs. Therefore, this study focused on outcomes of drought adaptation strategies practiced by smallholder cereal farmers in Makueni County.

2.9 Conceptual Framework

Time is considered as an independent variable which influences the occurrence of drought events. Therefore, drought is considered as a dependent variable as addressed in objective 1. Indian Ocean SSTs were used in this study as independent variables which influence occurrence of rainfall hence droughts in Makueni County as addressed in objective 2 (Figure 2). Indian Ocean SSTs were the unit of analysis to establish their influence on occurrence and nature of drought in Makueni County from 1990 to 2020. Annual rainfall amounts were the units of analysis to establish the nature and to project the trend of droughts in Makueni County for the period 2024 to 2054 based on the mean annual rainfall data for the period between 1990 and 2020.

Droughts were considered as independent variables that influence cereal production and yields as addressed in objective 3. Cereal yields were considered as dependent variables that are affected by droughts in Makueni County. Annual cereal yields were the unit of analysis for the period between 1990 and 2020. Cereal yields are dependent on rainfall where deficits result in droughts in Makueni County hence low yields. However, cereal yields are also influenced by the intervening variables that may possibly lead to an increase or decrease in yields.

Droughts were considered as independent variables that influence drought adaptation strategies that were considered as dependent variables as addressed in objective 4 (Figure 2). The drought adaptations include: the adoption of quality cereal seed varieties and adoption of short-season cereal varieties, increasing farm size and adoption of CBA and IK, and adoption of irrigation were also indicated as key drought adaptation strategies among other measures. The drought adaptation strategies were the unit of analysis for the survey where the unit of observation was individual smallholder cereal farmers in Makueni County. The livelihood strategies are regarded as dependent variables that are influenced by policies, institutions and processes hence productivity and production conditions as well as the livelihood outcomes. The indicators of vulnerability including drought shocks, trends and seasonality are also regarded as independent variables that influence livelihood assets which in-turn influence policies, institutions and frameworks hence livelihood strategies and outcomes.

Socioeconomic characteristics of heads of households which include age, gender, level of education and experience were considered as independent variables which influence drought adaptation and cereal yields which were considered as dependent variables as addressed in objective 4.

Intervening variables which are external factors, may influence the inter-relationship between the independent and dependent variables, positively or negatively hence the research results. In this study, the UN and GoK policies and NGOs, CBOs, and SHGs development programmes are considered the intervening variables (Figure 2). The implementation of the intervening variables including UN policies such as SDGs 2 and 13 and UNFCCC and GoK policies such as NDMA Act, 2016; NCCRS, 2010; Climate Change Act, 2016 and NCCAP (Kenya) 2018-2022. In addition, programmes such as KCEP-CRAL can influence cereal production and yields in Makueni County.

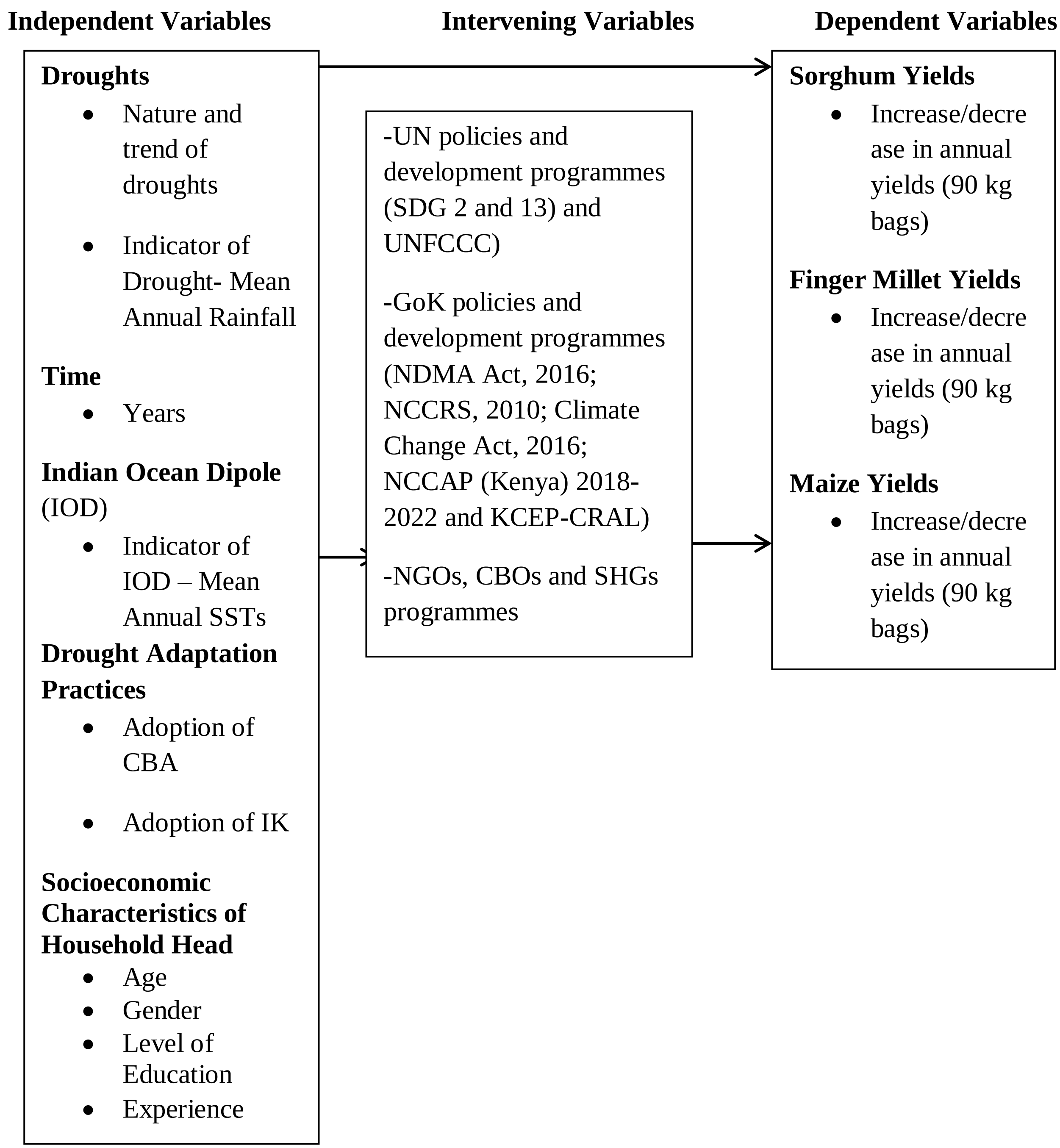

Figure 2. Conceptual Framework on Factors Influencing Household Cereal Production in drylands.

Source: Modified from Chijioke et al. (2011).

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the description of the study area, research design, sampling procedures and sample size, data collection, validity and reliability, data analysis and ethical considerations.

3.2 Study Area

This section covers the location of the study area, AEZs in the study area, soils and vegetation, demographic characteristics of the study area, socio-economic activities undertaken in the study area and the research design. It also covers target population, sampling procedures, data collection, data analysis and ethical considerations.

3.2.1 Location of the Study Area

This study was conducted in Makueni County, located 200 kilometres Southeast of Nairobi city, Kenya. The County is located between latitudes 1^0 35' and 3^0 00'S and between longitudes 37^0 10' and 38^0 30'E (Figure 3). The County is bordered by Machakos County to the North, Kitui County to the Northeast and East, Kajiado County to the West and Southwest and Taita Taveta County to the South. Makueni County has a surface area of 8,177 square kilometres (km^2) (Kenya National Bureau of Statistics [KNBS], 2019a). The County has six Sub-Counties namely: Mbooni, Kilome, Kaiti, Makueni, Kibwezi West, and Kibwezi East (Amukono, 2016; CGoM, 2023a; 2023b). The sample study sites were Kibwezi West sub-County, Kibwezi East sub-County, Makueni sub-County and Kilome sub-County.

3.2.2 Agro-Ecological Zones in the Study Area

Makueni County is classified as AEZ 5 which is an ASAL in Eastern Kenya (Kitinya *et al.*, 2012). The county experiences similar agro-ecological conditions and Tropical Semi-Desert climate of the Central and Northern areas with bimodal rainfall regimes. The long rainfall season is MAM while the short rainfall season, which is the main rainfall season is OND (Amukono, 2016). Rainfall received in the study area ranges from 800 to 1200 mm per annum in the Northern highlands of the county and 300 to 400 mm per annum in the lowlands mostly in the Southern lowlands of the county (CGoM, 2023a; 2023b; Kitinya *et al.*, 2012). The county also experiences frequent droughts that significantly influence cereal yields hence food security (Gichure, 2017).

The four study sub-Counties include Makueni, Kibwezi West, Kibwezi East and Kilome (CGoM, 2023a; 2023b). The sample study sites were Kibwezi West sub-County, Kibwezi East sub-County, Makueni sub-County and Kilome sub-County.

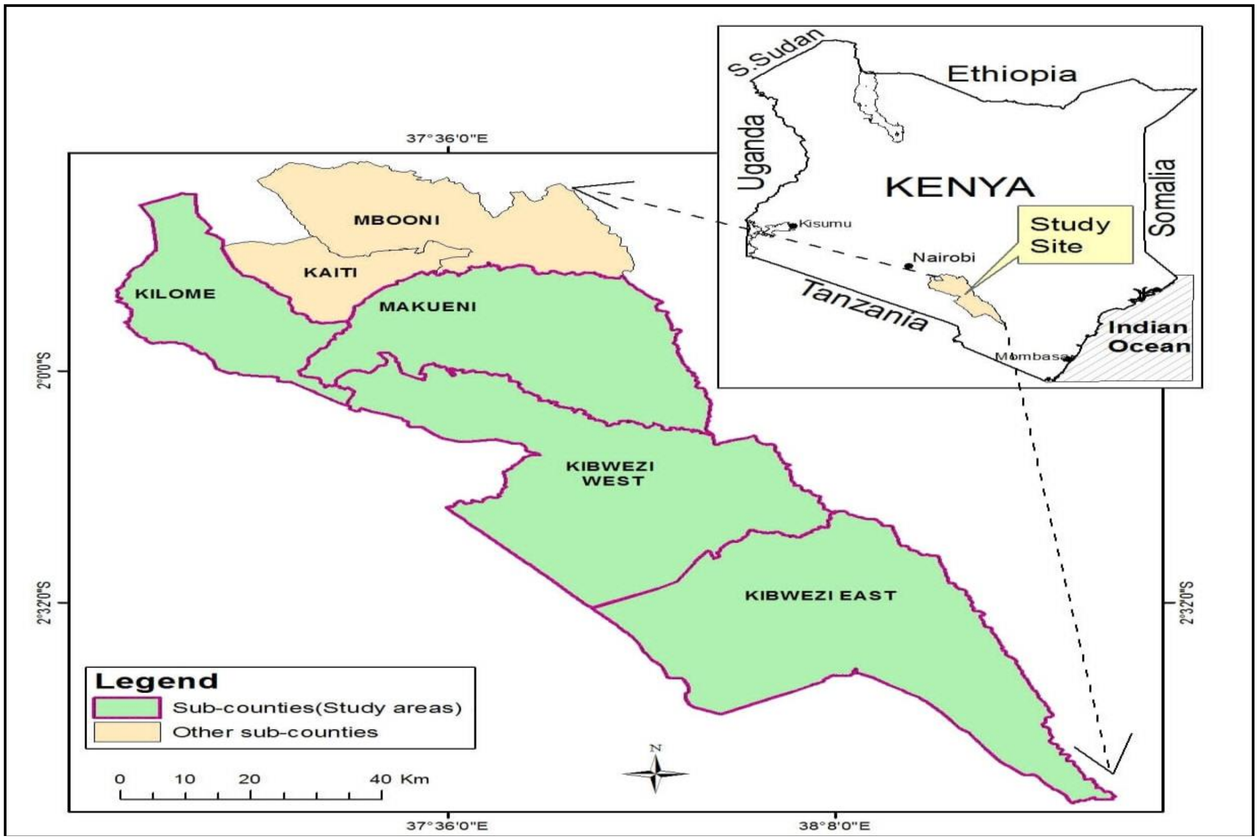

Figure 3. Map of the Study Area Showing the Study Sites.

Rainfall received in the study area ranges from 800 millimetres (mm) to 1200 mm per annum in the Northern highlands of the county and an average of 500 mm per annum mostly in the Southern lowlands of the county (CGoM, 2016). The county experiences high temperatures with a mean ranging from 24.0^0 Celsius (C) to 35.8^0C (CGoM, 2016; GoK, 2013). High temperatures in the lowlands of Makueni County result in hot climatic conditions (GoK, 2014).

Altitude of the study area ranges from 600 metres (m) to 1900 m above sea level with a generally low-lying terrain (CGoM, 2017). Similarity in conditions of the soil and climate of the AEZ make the county a leading producer of varieties of DT cereals. The county experiences low-level winds in the areas around the equator where North-easterlies of 4.9 metres per second (ms^{-1}) wind speeds are common over the dry periods in OND (Ndiwa, 2012). Ndiwa also found that South-easterly winds with speeds of 6 ms^{-1} are common during the wet season in OND.

3.2.3 Soils and Vegetation

Makueni County has moderately deep volcanic soils in the hilly undulating landscapes with gentle slopes comprising high fertility cambisols and luvisols. The area also has deep, red, strongly weathered acidic acrisols and ferrasols with low fertility in low-lying undulating landscapes (Munyao, 2018). In addition, sandy-loam and clay-loam soils are also found in the low-altitude areas of the county (CGoM, 2017). Barren rocky surfaces are also found in the area (CGoM, 2019).

Vegetation in Makueni County comprises bush and thicket that are predominantly common in areas receiving low rainfall approximately 375mm to 625 mm. The areas that receive less than 375 mm of rainfall are predominantly covered by semi-desert and desert scrub vegetation which are short and scattered. The grass in the region is scattered in the lowlands. Spiny shrubs, cacti, aloe vera, and acacia are also common (Cheruto, 2017). The highlands are located in the northern part of the county and they consist of forests and savannah vegetation with indigenous short grasses and bushes comprising thorns and thistles (CGoM, 2019). The study area is predominantly covered by natural vegetation with a large coverage of indigenous vegetation in the lowlands.

3.2.4 Demographic Characteristics of the Study Area

The population of Makueni County is 987,653 people spread over an approximate area of 8,177 km^2 (KNBS, 2019a). In addition, the area has a population density of 121/ km^2. The structure of the population comprised of 489,691 males and 497,942 females.

Approximately 92.2% of the population in Makueni County are rural dwellers (KNBS, 2019a). The large population of rural dwellers is attributed to agro-pastoralist activities of the inhabitants. In addition, CGoM (2021) reported that Kibwezi East, Kibwezi West, Kilome and Makueni sub-Counties have a total of 140,089 smallholder cereal farmers. Smallholder finger millet, sorghum, and maize farmers in the four sub-Counties were distributed in Makueni sub-County, Kibwezi West sub-County, Kibwezi East sub-County and Kilome sub-County as follows: 48,630; 39,144; 29,260 and 23,055, respectively (Sub-County Agriculture Office [SCAO], 2021). The county is dominated by the Kamba community who are agro-pastoralists with a comparatively small population residing in urban areas. Minor communities including the Asian, Somali, Kikuyu, Luhya and Luo communities who live in the urban areas are doing businesses or they are employed in government or in the private sector or some of them are residents by intermarriage (National Gender and Equality Commission [NGEC], 2018). The report also revealed that the Maasai community is a minority community found in the rural areas.

3.2.5 Socio-Economic Activities of the Study Area

Makueni County is an agro-pastoral region where rain-fed arable farming, livestock keeping, and commercial sisal farming are practiced. Crop production is mainly under rain-fed conditions through irrigation farming undertaken along the Athi River (Amukono, 2016; Cheruto, 2017; Kyalo *et al*., 2019). Makueni County has a total of 180,639; 157,946 and 15,313 households that practice crop production, livestock, and irrigation farming, respectively (KNBS, 2019b). Drought-resilient cereals such as sorghum, finger millet, cassava and some maize varieties are grown. In addition, fruits such as mangoes and watermelons are also grown (CGoM, 2017).

3.3 Research Design

The study was based on Explanatory Sequential Mixed Methods Research Design. The collection and analysis of quantitative data was undertaken first followed by collection and analysis of qualitative data. Quantitative data comprised of rainfall data which was used to establish the historical drought trend from 1990 to 2020 and to project drought trends in Makueni County from 2024 to 2054. Quantitative data was also used to determine the influence of IOD on the occurrence of droughts and to examine the effect of drought on cereal yields in Makueni County.

Content analysis of SSTs, rainfall and cereal data from secondary sources and household surveys on smallholder cereal farmers were conducted in the study. Triangulation was used to collect cereal data from multiple secondary sources in order to create a complete cereal data set and to bridge any gaps in cereal data which arose due to incomplete data sources in the County.

A household survey and interviews of key informants on adaptations to drought by smallholder cereal farmers were also conducted in the study. A household survey was used to collect data on perceptions and experiences of the smallholder farmers on drought occurrences and effects and CBA and IK adaptation strategies. The qualitative data was used to evaluate the drought adaptation strategies among smallholder cereal farmers and to explain the drought adaptations in Makueni County.

Purposive sampling was used on SSTs, rainfall, key informants and AEZ to avoid the limitation of researcher and data collection biases. Purposive sampling was used in the selection of the study sites in Makueni sub-County while systematic random sampling was used to select the participants in the study to avoid imprecise participant selection and sampling biases. Semi-structured questionnaires were used to collect primary data. The questionnaires were administered to all the participants to avoid the limitation of participant bias.

3.4 Target Population

The target population in this study included all smallholder farmers practicing sorghum, finger millet and maize production in Makueni County. The target population also included key informants who had vital information about drought, cereal production and CBA and IK drought adaptation techniques in Makueni County.

3.5 Sampling Procedures and Sample Size

This section covers sampling procedures for rainfall, SSTs, cereals, smallholder cereal farmers and key informants in the study area.

3.5.1 Rainfall

According to Tsang (2013), a large sample size adequately represents the target population thereby enabling accuracy and reliability of the responses. Therefore, to achieve adequate representation and to ensure accuracy and reliability, rainfall data was obtained from KMD for four meteorological stations that were purposively sampled. The sampling of rainfall data was based on availability of data and the location of the meteorological stations in the study area. The meteorological stations were Salama Meteorological Station in Kilome sub-County, Makindu Meteorological station in Kibwezi West sub-County, Makueni sub-County and Dwa Sisal Estate in Kibwezi East sub-County (Table 1). Total annual rainfall data from the four meteorological stations covered the period from 1990 to 2020. The annual rainfall amount was recorded in millimetres.

Table 1

Weather Stations in the Study Area

Station Name	Station ID	Latitude (^{0})	Longitude (^{0})	Altitude (m)	Sub-County	Ward
Makindu Meteorological Station	9237000	2.284171	37.820833	1004	Kibwezi West	Nguumo
Salama Meteorological Station	9137033	-1.85	37.25	1524	Kilome	Kiima Kiu / Kalanzoni
Kathoonzweni – Makueni	9137077	-1.98	37.76	914	Makueni	Kathonzweni
Dwa Sisal Estate	9237002	-2.24	37.98	914	Kibwezi East	Kikumbulyu

3.5.2 Indian Ocean Sea Surface Temperatures

Indian Ocean SSTs data was obtained from NOAA website. The sample population included SST data from Blocks A and B for 1990 to 2020. The SSTs data was used to determine the influence of IOD on the nature and trend of drought in Makueni County. Purposive sampling technique was used to enable the identification of the cases with information that is logical and suitable to the study objectives (Robinson, 2014). Purposive sampling technique was based on judgment where suitable data was collected based on the relevant phenomenon. The technique was identified as being suitable and significantly improves the study by enabling theoretical, analytical and logical generalizations and conclusions about a study sample (Sharma, 2017). Therefore, the technique was used for SSTs sampling because they are the principal factor influencing drought occurrence, nature, and trends in the study area.

3.5.3 Cereal Yields

Data on annual cereal yields for 1990 to 2020 was collected from MoA in Makueni County. Purposive sampling technique was used for identification of suitable information on DT cereals in Makueni County as recommended by Robinson (2014). Therefore, purposive sampling helped in dentification of DT cereals for this study which included sorghum, finger millet and maize.

3.5.4 Household Survey

A survey was conducted on smallholder cereal farming households in Kibwezi East, Kibwezi West, Kilome and Makueni sub-Counties in Makueni County. Purposive sampling was used for the identification of the study sub-Counties. The units of analysis were smallholder cereal farmers.

Systematic random sampling was used to select the smallholder cereal farming households that had practiced cereal farming in the study area for at least five years. After defining the population, the sample size was established using systematic random sampling. Then listing and assigning numbers to the population and calculation of the sampling fraction was done followed by selection of the first unit. Thereafter every K^{th} number in the population was selected to form the study sample. Systematic random sampling spreads the sample evenly over the population and provides an equal chance (probability) of selecting any of the units in the target population hence avoiding sampling bias (Sharma, 2017). Further, Sharma reported that the technique is precise in unit selection and increases the distribution and representation of respondents thereby increasing the validity of the collected data. The technique was also chosen for the study due to the availability of a list of cereal farmers in the study area (CGoM, 2021).

This study adopted the formula by Creswell (2014) to determine the sample size of the smallholder cereal farmers. The formula was adopted because it provides a large sample size for the study. A large sample size is advisable for studies to improve validity and reliability. The formula is indicated in Equation 1.

$$n = \frac{\mathrm{NC}^2}{\mathrm{C}^2 + (\mathrm{N}-1)e^2} \quad \textbf{(Equation 1)}$$

Where:

n = Sample size

N = Target population (140,089)

C = Coefficient of variation (30% is acceptable according to Creswell (2014)

e = Standard error (0.02)

The calculation of the sample size is indicated in Equation 2.

$$n = \frac{140{,}089 \quad (0.3)^2}{(0.3)^2 + (140{,}089 \quad -1)\,(0.02)^2} \quad \textbf{(Equation 2)}$$

n = 225

A sampling error of 0.02 was chosen for this study because a lower sampling error increases validity and reliability of the results of a study. The 225 smallholder cereal farmers were distributed as follows: Kathonzweni ward (78), Mukaa ward (37), Makindu ward (63) and Ivingoni / Nzambani ward (47) (Table 2).

Table 2

Sample Size of Smallholder Cereal Farmers Distributed across Various Wards in Makueni County

Sub-County	**Ward**	**Total Cereal Farmers**	**Percentage of the Target Population (%)**	**Sample Size (% of 225)**
Makueni	Kathonzweni	48,630	34.7	78
Kilome	Mukaa	23,055	16.4	37
Kibwezi West	Makindu	39,144	28.0	63
Kibwezi East	Ivingoni/ Nzambani	29,260	20.9	47
Total		**140,089**	**100%**	**225**

A list of smallholder cereal farmers was obtained from the department of agriculture, Makueni County. The list was used to create the sampling framework for selection of the 225 respondents where the first respondent was selected randomly followed by a survey interval-based selection of the remaining respondents. The selected smallholder cereal farmers were administered with questionnaires (Appendix A) for collection of drought adaptation data.

3.5.5 Key Informants

Selection of key informants was based on their administrative position, age, knowledge and experience of drought adaptations in Makueni County. Key informants were 16 and consisted of SCAO, chiefs, village elders and NGO/Parastatal/MoA officials in the sub-Counties (Table 3). Key informants are respondents who have knowledge and experience about a particular issue of interest in a study (Karanja, 2018). Therefore, the key informants were used to provide informed responses on effects of drought on cereal production in Makueni County and to establish the reliability of the information collected using surveys.

Key informant interviews were conducted on representatives from the following organizations and institutions in Makueni County: Kenya Agricultural and Livestock Research Organization (KALRO) (Kibwezi West sub-County), Makueni Farmers Sacco (Makueni sub-County), Kenya Forestry Research Institute (KEFRI) (Kibwezi East) and MoA (Kilome Sub-County). Two SCAO officers from Kilome sub-County agriculture took part in the study due to inaccessibility of an NGO or parastatal representative in the study area.

Table 3

Sample Population of Key Informants

Key Informants	Number per sub-County	Total Sampled
Chiefs	1	4
Village Elders	1	4
Agriculture Extension Officers (Sub-County Agriculture Officers)	1	4
NGO/Parastatal/MoA officials	1	4
Total		**16**

3.6 Data Collection

The researcher collected four data sets which include annual rainfall data, annual Indian Ocean SST data, annual cereal yields data and data on household drought adaptation strategies. Indian Ocean SST data for blocks A and B for 1990 to 2020 was obtained through extraction from secondary sources from NOAA website. Annual rainfall data for 1990 to 2020 was acquired through extraction from secondary sources from KMD for Salama Meteorological Station in Kilome sub-County, Makindu Meteorological station in Kibwezi West sub-County, Kathoonzweni Meteorological Station in Makueni sub-County and Dwa Meteorological station in Kibwezi East sub-County. Annual cereal yields data for 1990 to 2020 was extracted from secondary sources from MoA in Makueni County. Content analysis and triangulation of annual cereal yields data from annual cereal yield reports, crop performance reports, and agricultural review reports from MoA were also conducted. Triangulation was adopted for the acquisition of cereal data due to potential gaps in the data from a single secondary source as recommended by Bengtsson (2016). Data on drought adaptation strategies was collected using semi-structured questionnaires (Appendix A) which were administered to 225 heads of smallholder cereal farming households and key informant interview guides (Appendix B) which were administered to 16 key informants in Makueni County.

3.7 Validity and Reliability

3.7.1 Validity

Validity is the degree to which results of data analysis in a given study represent the phenomenon under study (Haradhan, 2017). Validity for rainfall and Indian Ocean SSTs data was tested to establish if the data meet the multiple linear regression assumptions including Linearity, Multicollinearity, Autocorrelation, Homoscedasticity, Normality and existence of outliers that may influence the model based on Statistical Package for Social Sciences **(**SPSS) Version 22. This study assessed occurrence of outliers in the time series SSTs and rainfall data and found that outliers in SSTs data did not influence the central tendency and variability of the data, hence the study outcomes. Non influence of the outliers was attributed to the long duration of time series data covering three decades and to non-extreme values. Outliers established in the rainfall and cereals data was treated by moving average smoothing. Normalization of the datasets ensured that they are valid for regression and correlation analysis. A pilot study was conducted in Muvau/Kikumini Ward in Makueni sub-County where 20 smallholder cereal farmers were selected using systematic random sampling method. To improve the validity of the study, natural factors such as similar AEZ and agro-ecological conditions (Kitinya *et al*., 2012) and agronomic practices that might have influenced cereal yields were held constant as recommended by Gracely (2014).

3.7.2 Reliability

Reliability is the measure of consistency, repeatability, precision and trustworthiness of an instrument (Haradhan, 2017). Reliability was computed using Cronbach Alpha. The study also pointed out that a reliability coefficient of 0.7 is sufficient and was used to check the internal consistency of the instrument. Thereafter, appropriate adjustments of the data collection instrument were made before using the questionnaire in actual data collection in the field. Missing Indian

Ocean SSTs, rainfall and cereal yields data from Makueni County were filled by use of the MI method which produces the most accurate and multiple imputations for each missing data (Lloyd *et al.*, 2013). Methodological triangulation was used to improve reliability and validity of the research. Honorene (2017) revealed that methodological triangulation is the application of multiple methods to collect data about a phenomenon and the method was used to triangulate the cereal yields data from secondary sources and semi-structured questionnaires.

According to Gracely (2014) holding variables (factors) that can affect the outcome of a study constant improves the reliability of a study. Therefore, the following natural factors were held constant: Agro-ecological conditions of cereal production were similar (AEZ 5), the cereals were produced under similar rainfall conditions (rain-fed cereal production), a similar period of exposure (seasons) and amount of sunshine, similar temperatures, and similar humidity conditions. Other factors that were held constant were similar pedological conditions, a similar period of production (annually from 1990 to 2020), similar types of crops whereby DT cereals are used, and similar farm size (less than 2 ha). In addition to these natural factors, the following agronomic practices were held constant: A similar unit of observation (smallholder cereal farmers), a similar unit of analysis of cereal yields in $kgha^{-1}$, and CBAs and IK farming practices in Makueni County.

3.8 Data Analysis

This section covers data analysis methods for drought trend, drought projection, regression of SSTs and annual amount of rainfall, correlation analysis for relationship between drought and cereals and descriptive statistical analyses for drought adaptations and their outcomes in Makueni County.

3.8.1 Nature of Drought

Total annual rainfall in millimetres for 1990 to 2020 was collected from KMD and analysed based on March 12-month time series in which SPI (Kimaiyo *et al.,* 2023; WMO & Global Water Partnership [GWP], 2016) was used in the study to establish the nature of droughts in Makueni County. The SPI is used to establish occurrence and meteorological droughts using time series data (Diani *et al*., 2019).

The annual rainfall data used in this study based on Y: 1=1, 2, 3… n was assumed to be independent and distributed identically. The independent observations were used as the source of data at specified data points. Further, SPI varies from -2.0 to 2.0 where SPI<-1.0 or less is an indication of the existence of drought events. A drought episode is recorded when SPI is negative while the episode ends when the SPI becomes positive. The SPI uses the gamma function for descriptions of precipitation changes (Lin *et al*., 2020). SPI was developed by McKee *et al*. (1993) with an index which is used for drought categorization (Table 4). The table was used to identify the nature of droughts. The equation for SPI is indicated in Equation 3.

$$SPI = \frac{X - \bar{X}}{\sigma} \quad \textbf{(Equation 3)}$$

Where: X - Precipitation

$\bar{x}$ - Mean Precipitation

σ – Standard Deviation

Table 4

Drought Categorization Using Standardized Precipitation Index

SPI Range Value	Drought Category
>2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near-normal
-1.00 to -1.49	Mild drought
-1.50 to -1.99	Severe drought
<-2.00	Extreme drought

Source*:* McKee *et al*. (1993).

3.8.2 Trend Analysis using ARIMA Models

ARIMA Models were used to project drought trends in the study area between 2024 and 2054. The ARIMA models were fitted and a goodness of fit was examined by plotting Autocorrelation Function (ACF) of the residuals of the fitted model for the time series data for Makueni County, Makueni sub-County, Kibwezi East sub-County, Kibwezi West sub-County and Kilome sub-County. ACF is the coefficient of correlation between two values in a given set of time series. Most of the sample autocorrelation coefficients of the residuals were within the limits of $\pm 1.96\sqrt{N}$ where, N denotes the number of observations made on the model.

Selection of the parameters for ARIMA model projection was based on ACF and Partial Autocorrelation Function (PACF) of the time series. Once the significant lags were identified from ACF and PACF, ARIMA models were established where models with the lowest Mean Squared Errors (MSE) which indicated the mean or average of the square of the difference between actual and estimated ARIMA values and Mean Average Error (MAE) which indicated the mean of the absolute values of the projection errors, were selected for projection. All the details of the ARIMA models which were used for projection accuracy of MSE and MAE; primary performance evaluation criteria, were used to explain the details of the results of the time series data.

3.8.3 Association of IOD and Drought Occurrence

Mean annual SST data from Blocks A and B in the Indian Ocean were considered as independent variables where annual SST mean were used for the study. Rainfall data which was collected from KMD was considered as a dependent variable in the regression where annual rainfall mean was used. Multiple Linear Regression Analysis of IOD annual SST mean and annual rainfall mean for 1990 to 2020 was performed based on SPSS Version 22. The Multiple Linear Regression Analysis model is indicated in Equation 4.

$$Y= \beta_o + AX_1 + BX_2 + \epsilon \quad \text{(Equation 4)}$$

Where:

Y is the dependent variable (the predicted rainfall trend)

$\mathbf{B_o}$ is the constant (Intercept)

$\mathbf{X_1}$ and $\mathbf{X_2}$ are the independent (explanatory) variables (mean SSTs from Block A and B)

A and **B** are the slopes

ϵ is the Residual (error)

3.8.4 Effect of Drought on Cereal Yields

Annual rainfall means of the rainfall data from KMD for the period 1990 to 2020 was correlated with annual cereal yields at 5% levels of significance, based on SPSS version 22. Karl Pearson's Coefficient of Correlation (PCC) (Pearson, 1957), which is also referred to as bivariate correlation, was used for analysis based on the coefficient of determination Pearson's *r*. The correlation analysis examined the effect of drought on cereal yields where the strength of the association and direction of the relationship was identified. PCC varies from -1 to 1. A PCC>0 is an indication of the existence of a positive correlation between the two variables. On the other hand, a PCC<0 is an indication of the existence of a negative correlation between the two variables, while PCC=0 indicates the non-existence of a correlation between the two variables. The analysed data was presented using descriptive statistics.

3.8.5 Drought Adaptation Strategies

Data on drought adaptation strategies practiced by the smallholder cereal farmers in Makueni County was organized, tabulated, coded, and analysed using descriptive techniques and cross-tabulations. Descriptive statistics consisted of analysis of measures of central tendency including mean, frequencies and percentages of the adaptation practices based on SPSS (Version 22).

3.8.6 Outcomes of Drought Adaptation Strategies

Data on outcomes of drought adaptation strategies practiced by the smallholder cereal farmers in Makueni County was tabulated, coded and analysed using descriptive techniques and cross-tabulations. Descriptive statistics consisted of analysis of measures of central tendency including frequencies and percentages of the outcomes of the adaptation practices based on SPSS (Version 22). The outcomes were based on cereal yields.

3.9 Ethical Considerations

An introduction letter to National Commission for Science, Technology and Innovation (NACOSTI) was obtained from Graduate School. A research permit was obtained from NACOSTI. The researcher then sought consent from the 225 respondents before the survey. The respondents were also assured of the confidentiality of their responses.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents results on rainfall and drought trends and projection in Makueni County. Results on influence of IOD on drought occurrence and effects of drought on cereal yields in Makueni County are also covered in this section. This section also presents results on demographic characterization of the smallholder cereal farmers, CBA and IK drought adaptation strategies in Makueni County. This section also contains results on outcomes of CBA and IK drought adaptation strategies among smallholder cereal farmers in Makueni County.

4.2 Drought Occurrence and Trend in Makueni County

This section covers annual rainfall trend, seasonal rainfall trend, annual drought trend, seasonal drought trend, frequency and projection of drought in Makueni County.

4.2.1 Annual Rainfall Trend in Makueni County

Rainfall trend revealed fluctuations in amount of rainfall from 1990 to 2000. There was a significantly high amount of rainfall in 1997 and 1998 due to El Niño event. On the other hand, fluctuations were recorded in the amount of rainfall received between 2008 and 2017 (Figure 4).

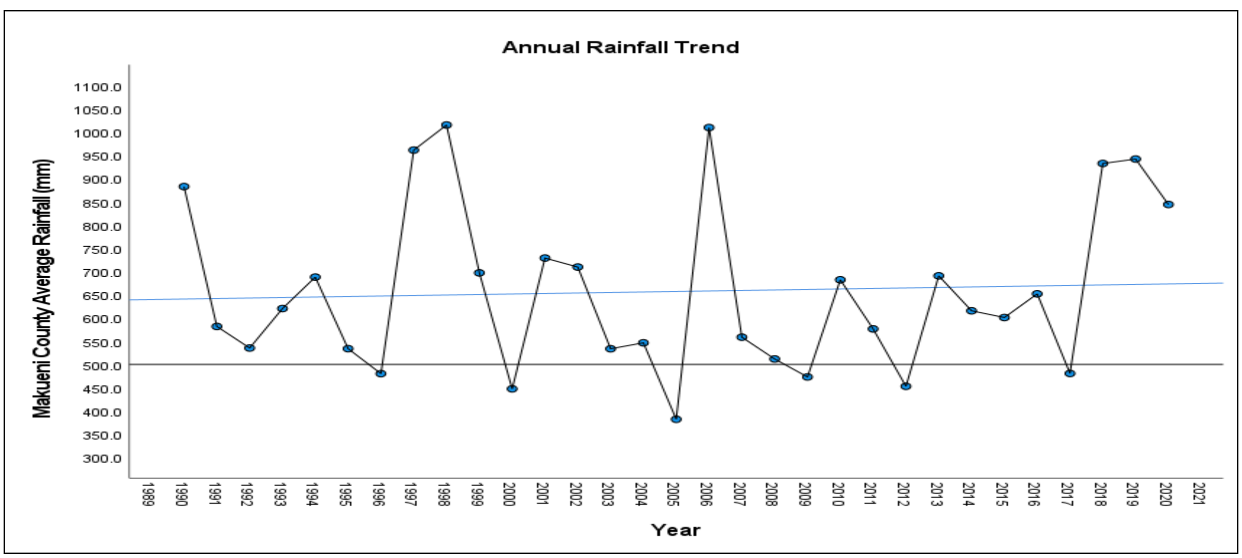

Figure 4. Annual Rainfall Trend in Makueni County

Even though a fluctuating amount of annual rainfall was recorded, a slight positive trend was established. In addition, rainfall amounts showed an increasing trend from 2018 to 2019 then a declining trend in 2020.

4.2.2 Seasonal Rainfall Trend in Makueni County

Results in Figure 5 show that OND season received more rainfall compared to MAM rainfall season. The results of the study indicate that 1997 OND season experienced comparatively high amounts of rainfall which subsided in January and February 1998 thereby coinciding with the EL Nino event in Kenya. The study found an even distribution, reliable, and effective nature of the short rains in OND.

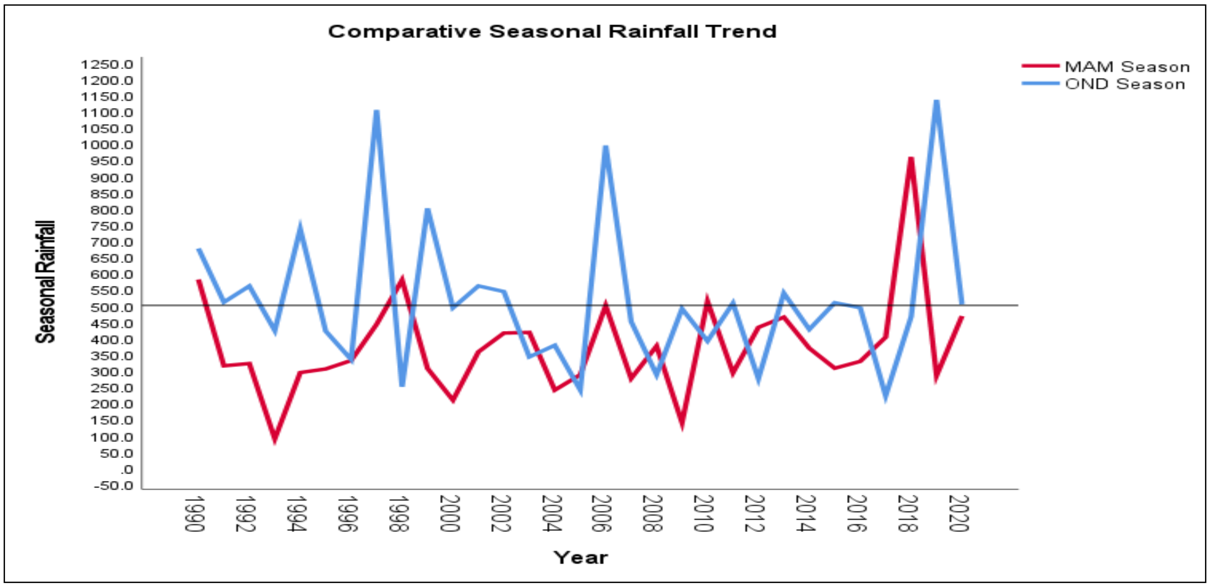

Figure 5. Seasonal Rainfall Characteristics in Makueni County

The results also revealed that OND has a more reliable and effective rainfall compared to MAM rainfall. The effective and reliable nature of OND rainfall make the season the main rainfall and cropping season in Makueni County.

4.2.3 Annual Drought Characterization in Makueni County

This study established 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts which were experienced in Makueni County between 1990 and 2020 (Figure 6). Mild droughts occurred in 1992, 1996, 2000, 2005 and 2012. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008, and 2011 to 2016. This study established an upward trend of droughts in Makueni County from 1990 to 2020.

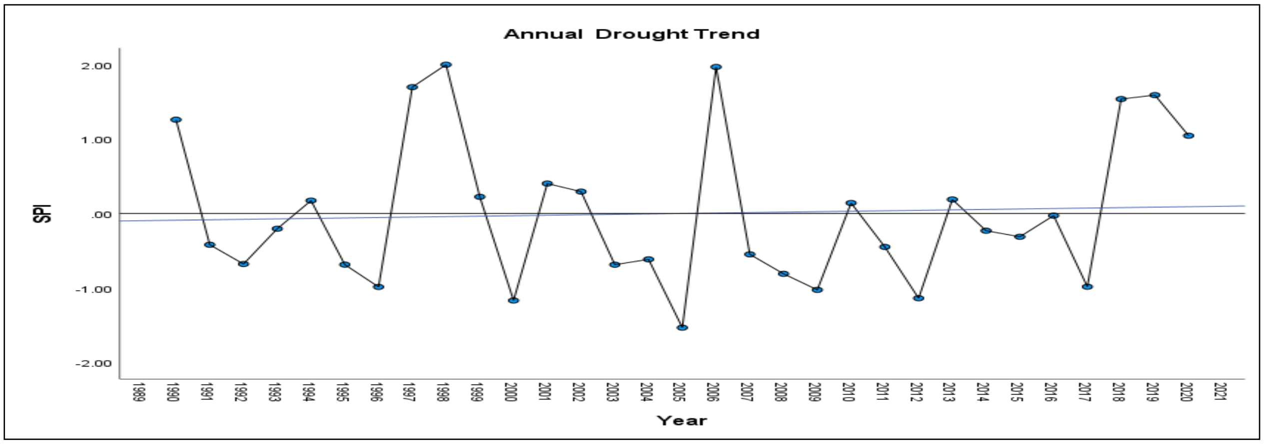

Figure 6. Annual Drought Trend in Makueni County

Near annual drought conditions were also exacerbated in the study area by recurrence of mild droughts in 2000, 2009 and 2017. Furthermore, multi-year droughts occurred from 2003 to 2005 and from 2007 to 2009. These drought conditions are an indication of erratic, unpredictable and fluctuating rainfall which significantly impacted cereal production and yields in Makueni County.

4.2.4 Seasonal Drought Trend in Makueni County

Results in Figure 7 show Makueni County experienced higher frequency of droughts in MAM season compared to OND season. The results indicate that Makueni County experienced multiple droughts between 1990 and 2020. The results also indicate that Makueni County experienced 12 episodes of severe drought in MAM season between 1990 and 2020.

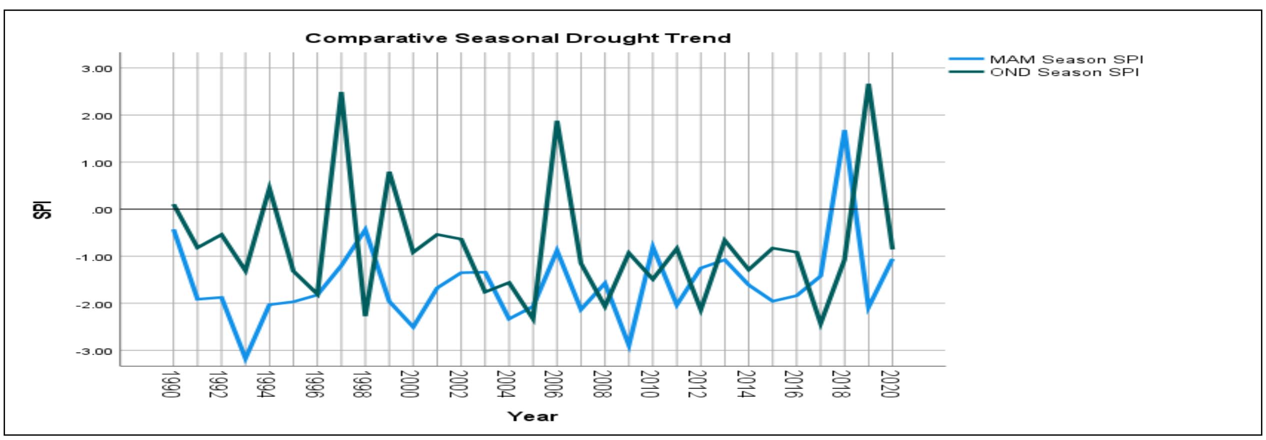

Figure 7. Seasonal Drought Trend in Makueni County

Results of the study also reveal that Makueni County experienced droughts in OND season between 1990 and 2020. The study also established that Makueni County experienced 6 episodes of severe drought between 1990 and 2020.

4.2.5 Perceptions of Smallholder Farmers on Frequency of Drought in Makueni County

A survey was conducted on the smallholder cereal farmers in Makueni County to establish the frequency of droughts in the region. Based on the perceptions, experiences and observations on the frequency of drought in Makueni County, 97% of the smallholder farmers believed that near-normal droughts recur yearly, while only 2% believe that near-normal droughts recur every three years in the study area. This study also found that the farmers believe that severe to extreme droughts recurred after every four to five years in the study area. Further, the study established that 42% of the smallholder farmers believe that mild drought recurs every year while 43% believe that mild drought recurs after every two years and 11% believe that mild drought recurs after every three years (Table 5).

Table 5

Frequency of Drought in Makueni County

Drought Frequency	Yearly	After every two years	After every three years	After every four years	After every five years	After every ten years	Total
Near-normal Drought	97%	1%	2%	0%	0%	0%	100%
Mild Drought	42%	43%	11%	3%	0%	1%	100%
Severe Drought	21%	13%	31%	13%	10%	13%	100%
Extreme Drought	9%	5%	1%	13%	21%	51%	100%

It was established that majority (31%) of the smallholder farmers believe that severe drought recurs after every three years. However, 13% of the smallholder farmers believe that severe drought recurs after after a decade (Table 5). The study also revealed that 51% of the smallholder farmers believe that extreme drought recurs after a decade, while 21% of the farmers believe that extreme drought recurs after every five years. However, only 5% of the farmers believe that extreme drought recurs annually and after every two years (Table 5).

Perceptions of the smallholder cereal farmers in Makueni County mirror SPI results which established occurrence 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts between 1990 and 2020.

4.2.6 Annual Drought Projection in Makueni County using ARIMA Models

This study found that ARIMA (12, 3, 0) model (Table 6) provides the best performance for projection of the time series for Makueni County based on the ACF (Figure 8) and PACF (Figure 9). The residual ACF and residual Partial ACF for the time series data are shown by Figure 10.

Table 6

ARIMA Model Description

				Model Type
Model ID	Mak Rainfall (mm)	C	Averaged	Model_1	ARIMA (12,3,0)

Autoregressive aspect of the ARIMA model (Table 6) is the dependence of the actual observation on past observations. Autoregressive aspect of ARIMA assumes that values of a time series at any given point is related to its previous values in a linear manner. The value 12 in the ARIMA (12, 3, 0) model is a representation of the number of lagged terms used in autoregression in ARIMA model.

Moving average signifies the relationship between the error term and the previous errors. Moving average assumes that the 0 value in the ARIMA (12, 3, 0) model is a representation of the number of lagged error terms which have been used in the moving average in ARIMA model (Table 6).

Figure 8 shows that autocorrelation decreases over time. This implies that all autocorrelations are within the confidence interval. Order of the model refers to the most extreme lag of a given set of time series data that is used as a predictor in ARIMA model.

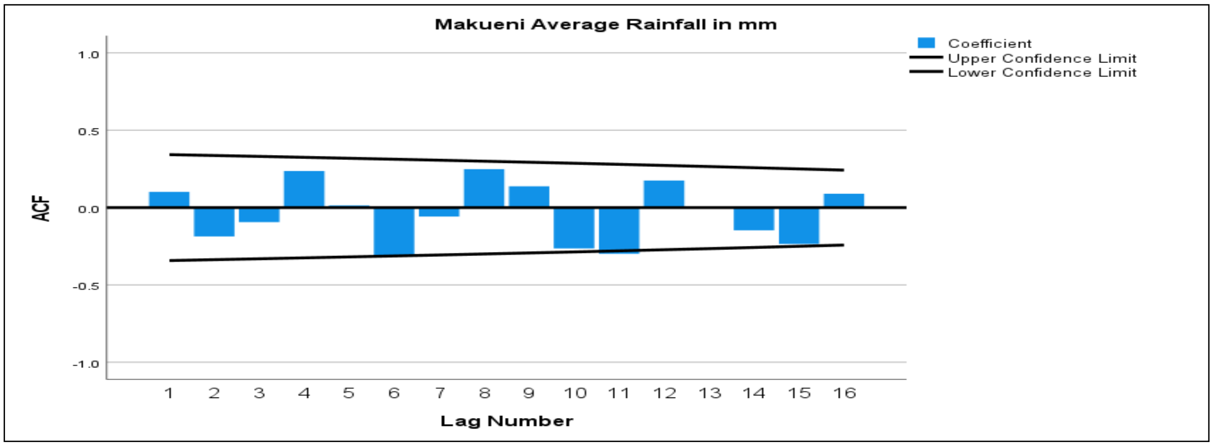

Figure 8. Autocorrelation Function for Rainfall

ACF is the coefficient of correlation in a given set of time series rainfall data in Makueni County. The autocorrelation indicates the degree of similarity between a set of time series and a lagged set of the same time series over successive trials over time.

Figure 9 shows existence of significant partial autocorrelation at lag 3 and then decreases over time. The partial correlation at lag 3 means that the autocorrelation has slightly passed the significance interval. This implies that after lag 3, all the partial autocorrelations are within the confidence interval. This implies that the PACF was suitable to be used to determine order of the partial autoregressive term.

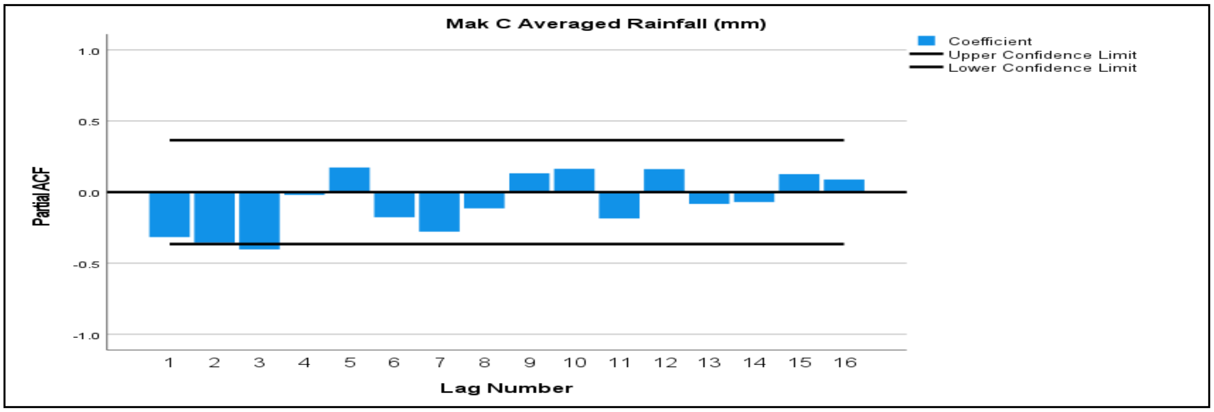

Figure 9. Partial Autocorrelation Function for Rainfall

The PACF is used to determine the order of autoregressive (AR) and/or moving average (MA) terms. Order of the model refers to the most extreme lag of a given set of time series data that is used as a predictor in ARIMA model. PACF helps in establishing the order and the best model for a given set of time series data. PACF explains existence of partial correlation between a given set of time series data and and a lagged set of the same time series over successive trials over time.

Figure 10 shows residual ACF and residual PACF. Residual ACF is the difference between observed values and the predicted values of time series rainfall data for autocorrelations in ARIMA models and regression analysis. It is the deviation of actual points of the time series data from the estimated values for autocorrelations in the ARIMA model.

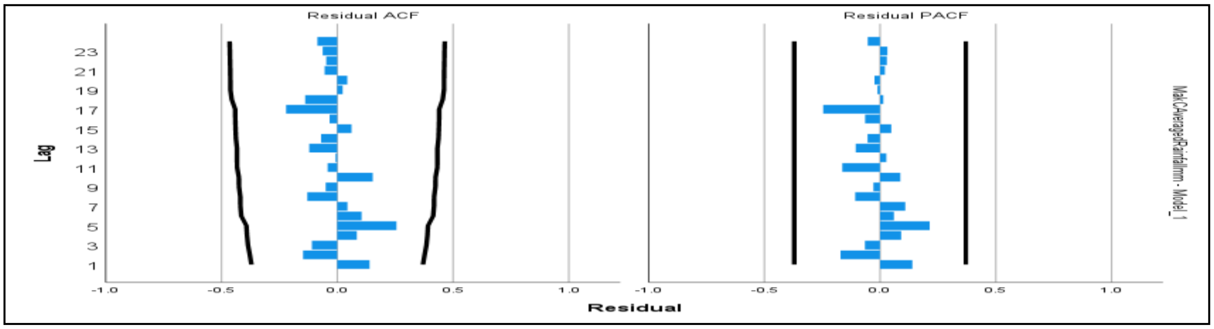

Figure 10. Residual Autocorrelation Function and Residual Partial Autocorrelation Function for Rainfall

Residual PACF is the difference between observed values and the predicted values of time series rainfall data for partial autocorrelations in ARIMA models and regression analysis. It is the deviation of actual points of the time series data from the estimated values for partial autocorrelations in the ARIMA model.

This study projected an upward annual drought trend in Makueni County from 2024 to 2054 (Figure 11). This implies frequent recurrence of droughts in Makueni County from 2024 to 2054.

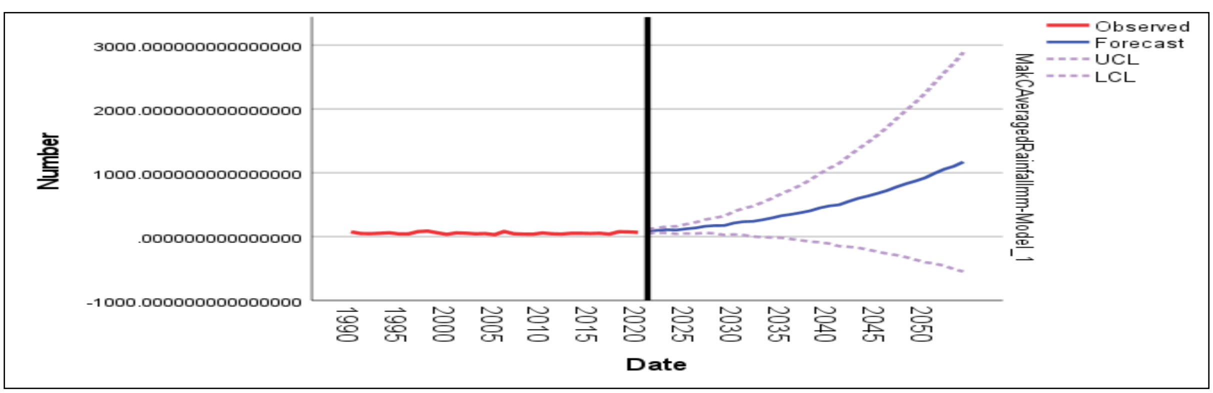

Figure 11. Annual Projection of Drought Trend in Makueni County for 2024 to 2054

The projected increase in frequency of droughts is an indication of impending drought risk in the three decades spanning 2024 to 2054. This implies that the effects of drought on cereal production will be more pronounced in the study area.

4.2.7 Seasonal Drought Projection in Makueni County using ARIMA Models

This study found that ARIMA (4, 3, 1) model provided the best performance for projection for seasonal time series for Makueni County based on ACF (Figure 12) and PACF (Figure 13). Table 7 shows ARIMA model description for seasonal time series rainfall data in Makueni County.

Table 7

ARIMA Model Description

			Model Type
Model ID	MAM Season	Model_1	ARIMA (4,3,1)
	OND Season	Model_2	ARIMA (4,3,1)

Moving average assumes that the 1 value in the ARIMA (4, 3, 1) model is a representation of the number of lagged error terms which have been used in the moving average aspect of the ARIMA model.

Figure 12 shows ACF occurrence of a significant lag at 1 and then autocorrelation decreases over time for ARIMA for MAM seasonal time series data in Makueni County. This implies that all autocorrelations after lag at 1, are within the confidence interval.

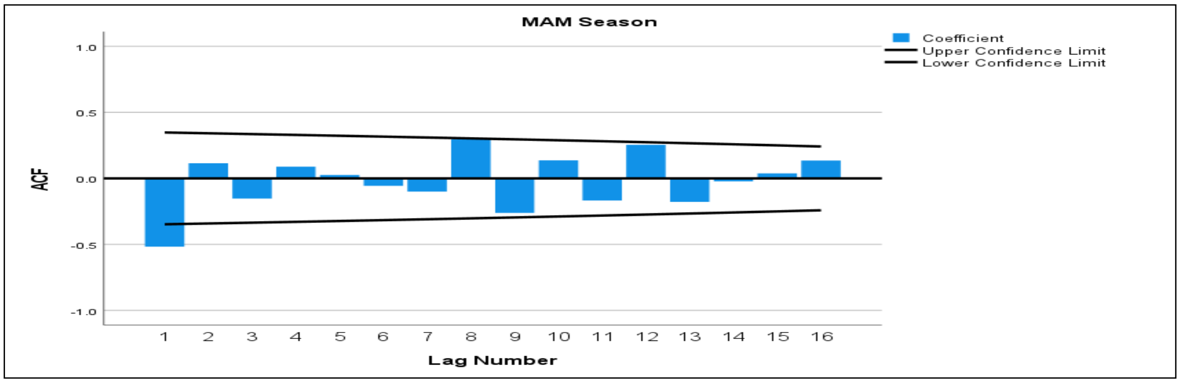

Figure 12. Autocorrelation Function for MAM season

The confidence interval in Figure 12 is indicated by two lines on either side of the trendline at 0.0 of the ACF for MAM season. Occurrence of all autocorrelations within the two trendlines after lag 1, implies that the values lie within the confidence interval.

Figure 13 shows existence of significant partial autocorrelation at lag 1 and then decreases over time. The partial autocorrelation at lag 1 means that only one partial autocorrelation has slightly passed the significance interval. This implies that after lag 1, all the partial autocorrelations are within the confidence interval.

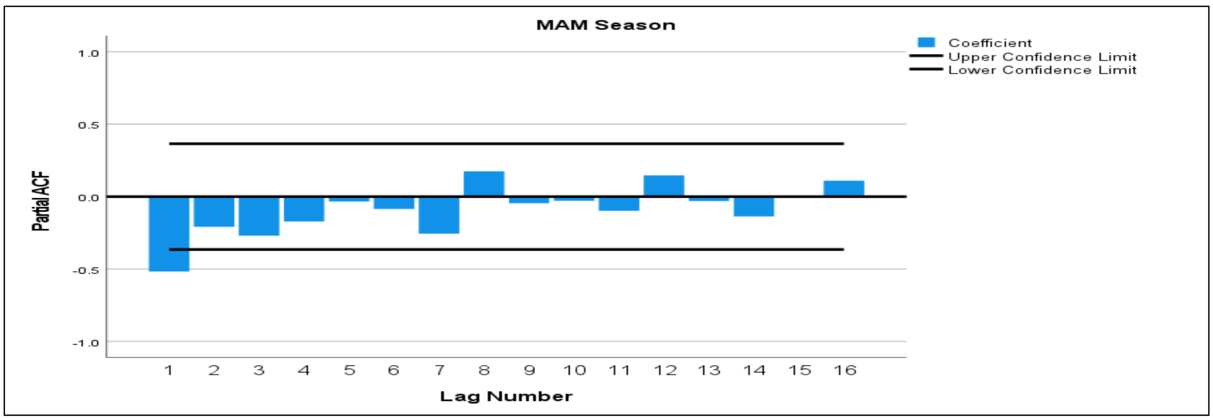

Figure 13. Partial Autocorrelation Function for OND Season

The PACF lag at 1 indicated that the PACF was suitable to be used to determine order of the partial autoregressive term. PACF is used to determine the order of autoregressive (AR) and/or moving average (MA) terms.

Figure 14 shows that ACF indicates occurrence of a significant lag at 1 and then autocorrelation decreases over time for ARIMA for OND seasonal time series data in Makueni County. This implies that all autocorrelations after lag at 1, are within the confidence interval.

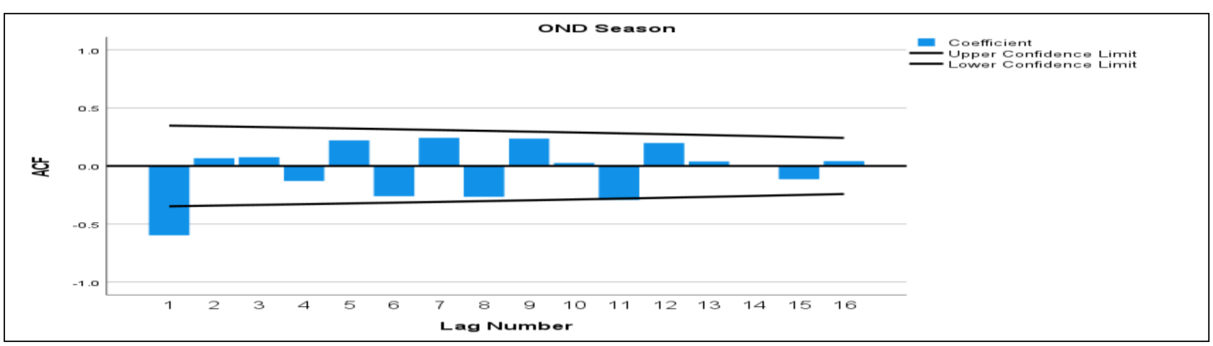

Figure 14. Autocorrelation Function for OND Season

The confidence interval in Figure 14 is indicated by two lines on either side of the trendline at 0.0 of the ACF for OND season. Occurrence of all autocorrelations within the two trendlines after lag 1, implies that the values lie within the confidence interval.

Figure 15 shows existence of significant partial autocorrelation at lags 1 and 2 and then decreases over time. The partial autocorrelation at lags 1 and 2 means that two partial autocorrelations have slightly passed the significance interval.

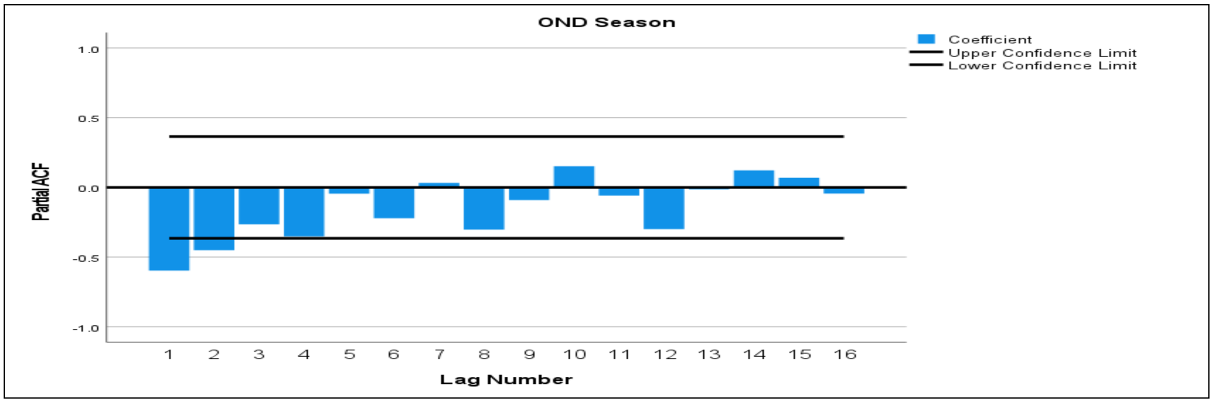

Figure 15. Partial Autocorrelation Function for OND Season

This implies that after lag 2, all the partial autocorrelations are within the confidence interval. PACF is used to determine the order of AR and/or MA terms.

Figure 16 shows a combined graph for residual ACF and residual PACF for ARIMA model for time series rainfall data for MAM and OND seasons in Makueni County. The residual ACF shows the deviation of actual points of the time series data from the estimated values for autocorrelations in the ARIMA model for the time series data for MAM and OND seasons in Makueni County.

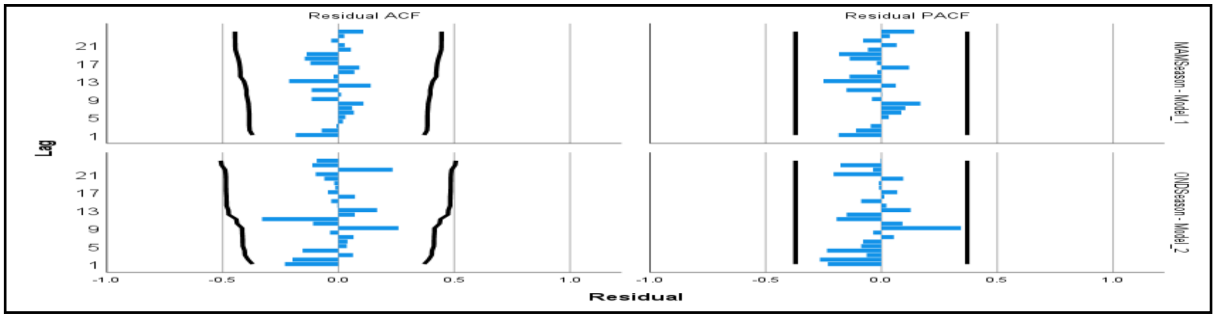

Figure 16. Residual ACF and Residual PACF for Seasonal Rainfall

Residual PACF indicates the difference between observed values and the predicted values of time series rainfall data for MAM and OND seasons in Makueni County, for partial autocorrelations in ARIMA models and regression analysis.

This study projected reduction in MAM seasonal rainfall amounts in Makueni County between 2024 and 2054 (Figure 17). This implies a projected frequent recurrence of droughts in MAM season. Therefore, the projected frequent droughts portent projected drought risk in MAM season in Makueni County. On the other hand, this study projected increase OND seasonal rainfall amount between 2024 and 2054.

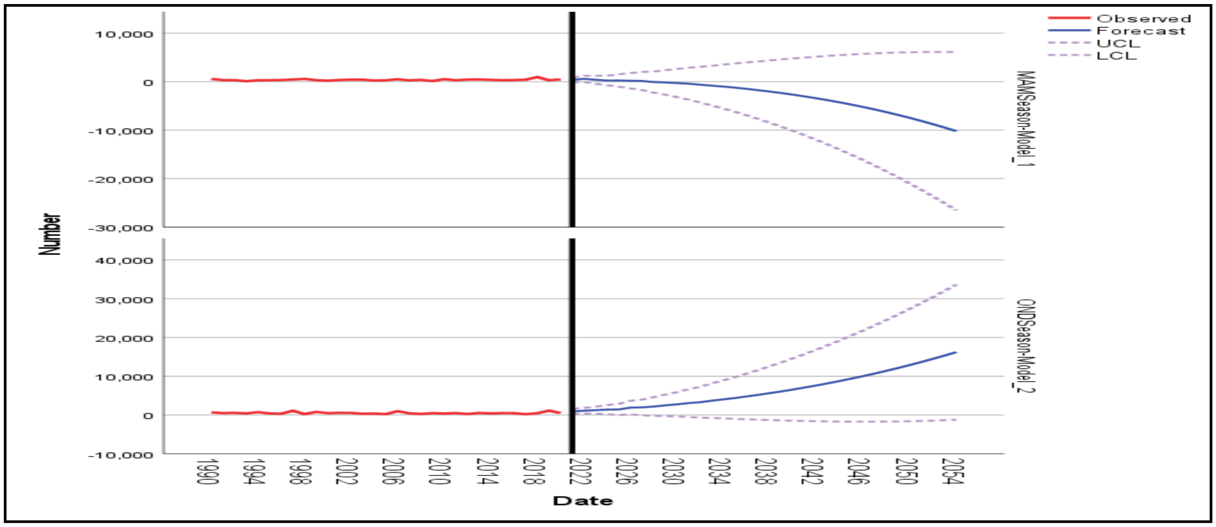

Figure 17. Projection for Seasonal Rainfall in Makueni County from 2024 to 2054

This implies a reduction in drought occurrence in Makueni County during the seasons. Therefore, projected decline in drought risk in Makueni County signifies the reliability of the short OND rainfall season in Makueni County. This makes the season a reliable cropping season. Therefore, intensive production of food crops is advisable for OND season in Makueni County.

4.3 Influence of Indian Ocean Dipole on Drought occurrence in Makueni County

This section covers the influence of IOD on occurrence of drought in Makueni County between 1990 and 2020. It also covers comparative influence of EWIO and EEIO SSTs on occurrence of drought in Makueni County between 1990 and 2020.

4.3.1 Multiple Linear Regression Modelling of SST in EWIO

Results in Table 8 show a model summary for the multiple linear regression. The model summary provides details about the characteristics of the model. The R value is 0.762, which indicates the correlation between drought (dependent variable) and SST (independent variable). The R value 0.762 is good for regression analysis.

Results in Table 8 indicate that R-square (R^2) value is 0.580 which is greater than 0.5. This implies that the model is sufficient to determine the relationship between the predictor and dependent variables. The R-square indicates the total variation for a dependent variable that can be explained by the predictor variable. Therefore, R-square value of 0.580 is good for regression analysis.

The R^2 value of 0.580 is closer to 1, implying that 58% of the variance in the rainfall amount (dependent variable) is explained by EWIO IO SSTSs (predictor variables) in the linear regression (Table 8).

Results in Table 8 show that the adjusted R-square value is 0.550 which is closer to R-square value of 0.580. The adjusted R-square value of 0.550 indicates the generalization of the results which includes the variation of the results of the sample from the population in multiple linear regression.

Table 8

Multiple Linear Regression Model Summary for EWIO

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.762[a]	.580	.550	38.1662	1.693

a. Predictors: (Constant), SST 10^0N-70^0E, SST -10^0S-50^0E

b. Dependent Variable: Makueni County Average Rainfall (mm)

Adjusted R-square value of 0.550 is good for regression analysis. Therefore, the multiple linear regression model summary table indicates that the values are satisfactory to be used in regression analysis.

Table 9 shows the Analysis of Variance (ANOVA) for the multiple linear regression. ANOVA determines whether a model is significant enough to determine the outcome of a multiple linear regression analysis. The ANOVA indicates that the p-value is 0.000 which is less than 0.05. Therefore, the results are significant at 95% confidence interval (5% level of significance). Hence, was used for the regression analysis.

The F- ratio in the ANOVA table is 19.329 which is greater than 1, therefore, it was used to yield efficient model. Therefore, F- ratio of 19.329 is good for regression analysis. The F-ratio is a representation of an improvement in level of prediction of the variable by fitting the model after a consideration of the inaccuracy in the model (Table 9).

Table 9

Multiple Linear Regressions ANOVA

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	56310.548	2	28155.274	19.329	.000[b]
	Residual	40786.411	28	1456.658		
	Total	97096.959	30			

a. Dependent Variable: Makueni County Average Rainfall (mm)

b. Predictors: (Constant), SST 10^0N-70^0E, SST 10^0S-50^0E

The ANOVA table indicates that p-value is 0.000 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model (Table 9).

Results in Table 10 show that SST at 10^0S-50^0E p-value is 0.043 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 10^0S-50^0E is a statistically significant variable. This implies that changes in SSTs (predictor variables) are associated with changes in drought occurrence (dependent variables) in Makueni County.

Results in Table 10 show that SST at 10^0N-70^0E p-value is 0.003 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 10^0N-70^0E is a statistically significant variable. This implies that changes in SSTs (predictor variables) are associated with changes in drought occurrence (dependent variables) in Makueni County.

Results in Table 10 show that positive coefficients in both SST 10^0S-50^0E and SST at 10^0N-70^0E are indications that as the value of SSTs (Predictor variables) increase, the means of rainfall (drought indicators) which is the dependent variable, also increase.

Table 10

Multiple Linear Regression Coefficients

Coefficients[a]							
Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
(Constant)	6061.614	895.239		6.771	.000		
SST 10^0S-50^0E	74.168	35.000	.331	2.119	.043	.614	1.628
SST 10^0N-70^0E	122.801	37.603	.510	3.266	.003	.614	1.628

a. Dependent Variable: Makueni County Average Rainfall (mm)

Results in Table 10 show that the coefficient value in the model signifies how much the mean of rainfall (drought indicator) and dependent variable changes given a one-unit change in SST (predictor variable) while holding the other factors in the model constant.

4.3.2 SST Trend in EWIO

Figure 18 indicates a positive relationship between EWIO locations at 10^0S-50^0E and at 10^0N-70^0E. The positive relationship is indicated by a similarity in the fluctuating patterns of SSTs as indicated in EWIO. The results indicate that a rise in SST at 10^0N-70^0E is accompanied by a similar rise in SST at 10^0N-70^0E in the EWIO.

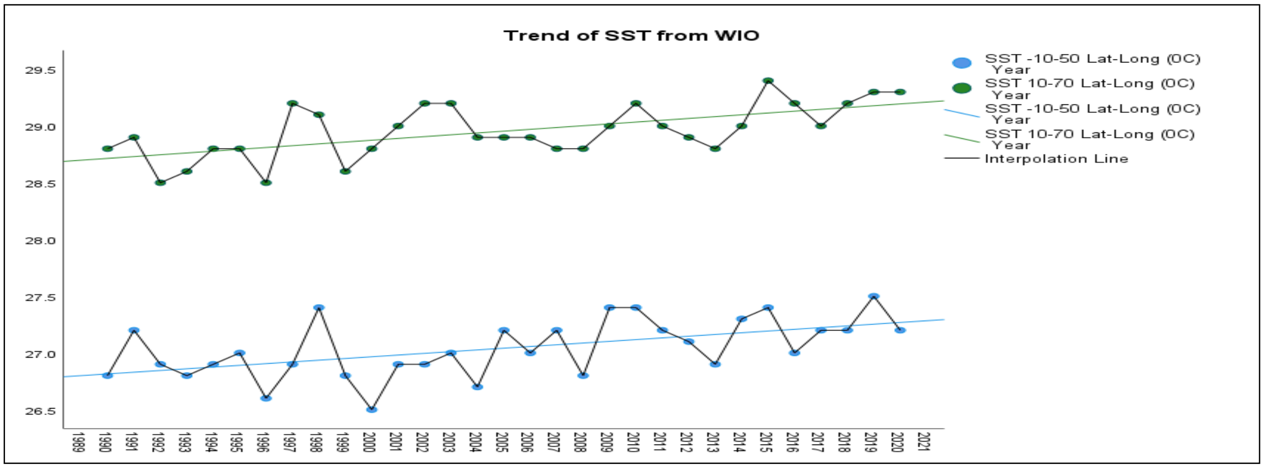

Figure 18. Comparative Trend of SSTs at 10^0S-50^0E and at 10^0N-70^0E

Figure 18 indicates that 10^0N-70^0E experienced comparatively higher SSTs compared to 10^0S-50^0E. The study found that the highest SST value at 10^0N-70^0E was 29.4^0C while the lowest SST value was 28.5^0C. However, 27.5^0C and 26.5^0C were the highest and lowest SSTs at 10^0S-50^0E, respectively.

4.3.3 Multiple Linear Regression Modelling of SST in EEIO

Results in Table 11 show a model summary for the multiple linear regression. The model summary provides details about the characteristics of the model. The R value is 0.821, which indicates the correlation between drought (dependent variable) and SST (independent variable). The R value 0.821 is good for regression analysis.

Results in Table 11 indicate that R-square (R^2) value is 0.674 which is greater than 0.5. This implies that the model is sufficient to determine the relationship between the predictor and dependent variables. The R- square indicates the total variation for a dependent variable that can be explained by the predictor variable. Therefore, R-square value of 0.674 is good for regression analysis.

The R^2 value of 0.674 is closer to 1, implying that 67.4% of the variance in the rainfall amount (dependent variable) is explained by IO SSTSs (predictor variables) in the linear regression.

Table 11

ARIMA Model Summary for EEIO

Model Summary[b]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.821[a]	.674	.651	33.6005	1.595

a. Predictors: (Constant), SST 10^0S-90^0E, SST 0^0-110^0E

b. Dependent Variable: Makueni County Average Rainfall (mm)

Results in Table 11 show that the adjusted R-square value is 0.651 which is closer to R-square value of 0.674. The adjusted R-square value of 0.651 indicates the generalization of the results which includes the variation of the results of the sample from the population in multiple linear regression. Therefore, Adjusted R-square value of 0.651 is good for regression analysis. Therefore, the model summary table indicates that the values are satisfactory to be used in regression analysis.

Table 12 shows the ANOVA for the multiple linear regression. ANOVA determines whether a model is significant enough to determine the outcome of a multiple linear regression analysis. The ANOVA indicates that the p-value is 0.000 which is less than 0.05. Therefore, the results are significant at 95% confidence interval (5% level of significance). Hence, was used for the regression analysis.

Table 12

ANOVA for EEIO

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	65485.052	2	32742.526	29.001	.000[b]
	Residual	31611.906	28	1128.997		
	Total	97096.959	30			

a. Dependent Variable: Makueni County Average Rainfall (mm)

b. Predictors: (Constant), SST 10^0S-90^0E, SST 0^0-110^0E

The F- ratio in the ANOVA table is 19.329 which is greater than 1, therefore, it was used to yield efficient model. Therefore, F- ratio of 29.001 is good for regression analysis. The F-ratio is a representation of an improvement in level of prediction of the variable by fitting the model after a consideration of the inaccuracy in the model (Table 12). The ANOVA table indicates that p-value is 0.000 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model (Table 12).

Results in Table 13 show that SST at 0^0-110^0E p-value is 0.011 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 0^0-110^0E is a statistically significant variable. This implies that changes in SSTs (predictor variables) are associated with changes in drought occurrence (dependent variables) in Makueni County.

Results in Table 13 show that SST at 10^0S-90^0E has a p-value of 0.000 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 10^0S-90^0E, is a statistically significant variable. This implies that changes in SSTs (predictor variables) are associated with changes in drought occurrence (dependent variables) in Makueni County.

Results in Table 13 show that positive coefficients in both SST at 0^0-110^0E and 10^0S-90^0E are indications that as the value of SSTs (Predictor variables) increases, the means of rainfall (drought indicators) which is the dependent variable, also increases.

Table 13

ARIMA Coefficients for EEIO

Coefficients[a]								
		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	6025.839	725.713		8.303	.000		
	SST 0^0-110^0E	65.325	23.912	.348	2.732	.011	.716	1.397
	SST 10^0S-90^0E	129.514	28.416	.581	4.558	.000	.716	1.397

a. Dependent Variable: Makueni County Average Rainfall (mm)

Results in Table 13 show that the coefficient value in the model signifies how much the mean of rainfall (drought indicator) and dependent variable changes given a one-unit change in SST (predictor variable) while holding the other factors in the model constant.

4.3.4 SST Trend in EEIO

Results in Figure 19 indicate a positive relationship between EEIO locations at 0^0-110^0E and at 10^0S-90^0E. The positive relationship is shown by a nearly similar fluctuating patterns of SSTs at 0-110^0C latitude-longitude and at 10^0S-90^0E in the EEIO. The results indicate that a rise in SST at 0^0-110^0E is accompanied by a similar rise in SST at 10^0S-90^0E in the EEIO. However, the magnitude of the temperatures at the two locations varied.

Results in Figure 19 indicates that a rise in SST was experienced at 0^0-110^0E in 1997 which peaked in 1998 at 29.9^0C. The results show that 0^0-110^0E experienced comparatively higher SSTs which peaked at 29.9^0C while the lowest SST was 28.6^0C.

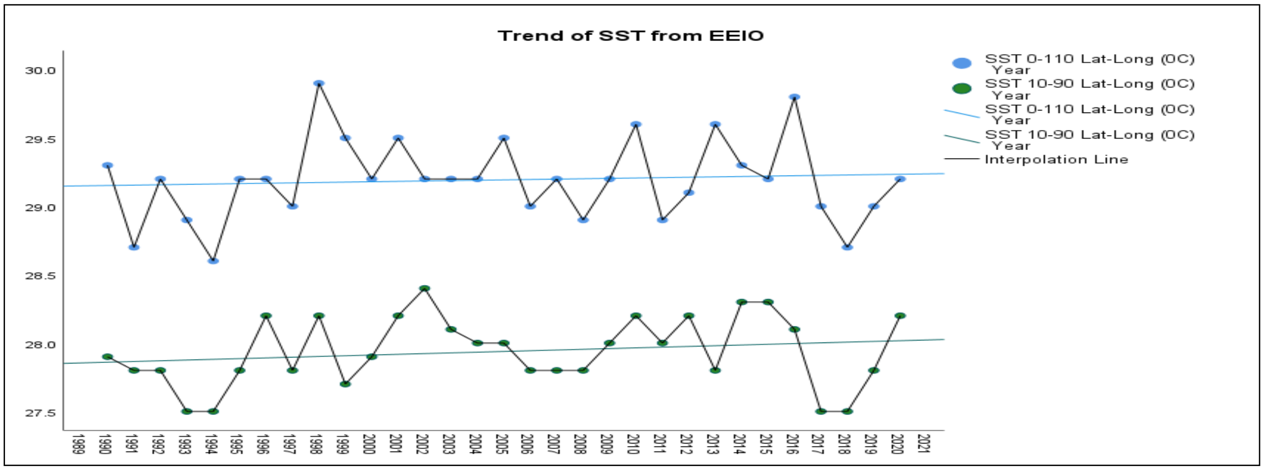

Figure 19. Comparative Trend of SSTs at 0^0-110^0E and at 10^0S-90^0E

Comparatively lower SSTs were experienced at 100S-900E whereby the highest value in SST was 28.40C while the lowest SST was 27.50C. However, the results indicate that the highest SST were experienced in 1997 and 1998. The results revealed that the lowest SSTs which reached a low of 27.50C were experienced at 100S-900E in 1993, 1994, 2017 and 2018 (Figure 19).

4.3.5 Comparative SST Trend in EWIO and EEIO

This study established that EEIO experienced comparatively higher SSTs than EWIO. The highest and lowest SSTs at 0^0-110^0E in the EEIO were 29.9^0C and 28.6^0C, respectively (Figure 20).

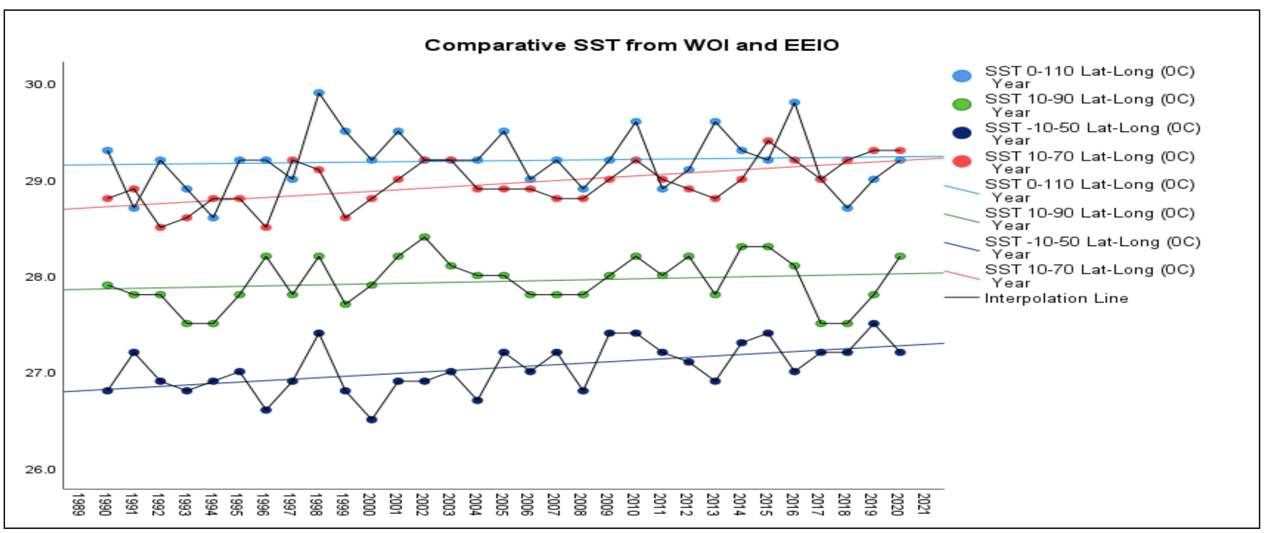

Figure 20. Comparative SST Trends in EWIO and EEIO

The highest and lowest SSTs at 10^0N-70^0E in the EWIO were 29.4^0C and 28.5^0C, respectively. Even though this study undertook a comparative analysis of the SSTs in the EWIO and EEIO, the cause of the variation in SSTs between the two points has not been explained.

4.3.6 Comparative Influence of EWIO and EEIO SSTs on Occurrence of Drought

This study established that the relationship between IO SSTSs in EWIO and rainfall in Makueni County returned R^2 value of 0.580, which is closer to 1. This implies that 58% of the variance in the rainfall amount (dependent variable), hence drought in Makueni County is explained by IO SSTSs in the EWIO (predictor variables) in the linear regression. This study also found that the relationship of IO SSTSs and rainfall indicated R^2 value of 0.674, which is closer to 1 (Table 8). This implies that 67.4% of the variance in the rainfall amount (dependent variable), hence drought in Makueni County is explained by IO SSTSs in EEIO (predictor variables) in the linear regression (Table 11). Therefore, IO SSTSs in EEIO have a more significant effect on occurrence of drought in Makueni County compared to IO SSTSs in EWIO. The lower influence of IO SSTSs in the EWIO are linked to the lower temperatures experienced in EWIO compared to EEIO.

Multiple linear regression analysis was done using mean annual SSTs data from Blocks A and B in the Indian Ocean and total annual rainfall data from Makueni County for 1990 to 2020. The R^2 value of 0.580 is closer to 1, implying that 58% of the variance in the rainfall amount (dependent variable) is explained by IO SSTSs (predictor variables) in the linear regression (Table 8).

Figure 21 indicates that IO SSTSs have a significant influence on occurrence of droughts in Makueni County. The results indicate that a reduction in the value of SSTs in Block A and Block B in the Indian Ocean leads to a similar reduction in the amount of rainfall received in Makueni County. On the other hand, an increase in the value of SSTs lead to a similar increase in amount of rainfall in Makueni County. Therefore, increasing SSTs in the Indian Ocean results in increase in amount of rainfall and events while a reduction in the SSTs results in deficit or low amount of rainfall which may be accompanied by drought events in Makueni County.

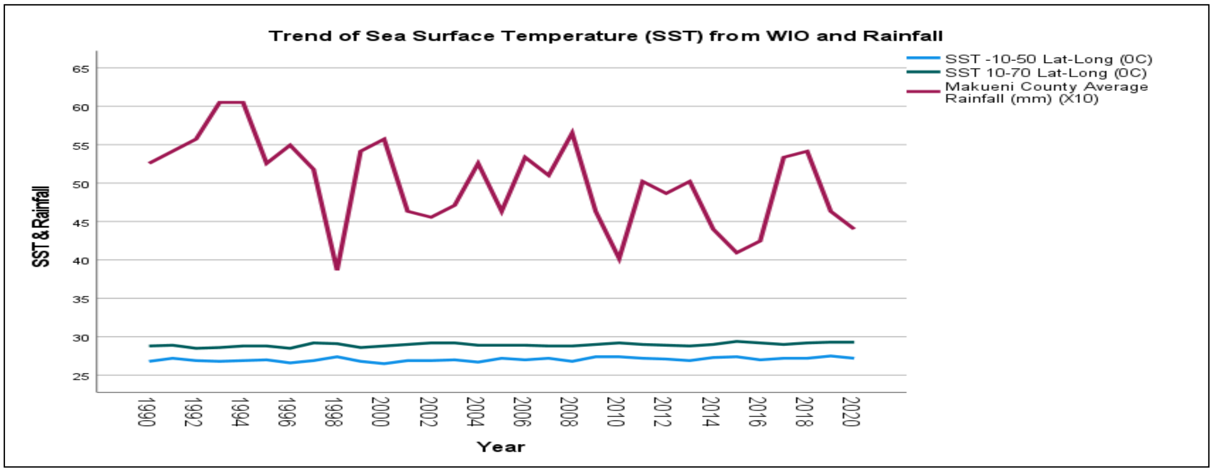

Figure 21. Sea Surface Temperature Trend at EWIO and EEIO.

Figure 21 indicates that high SSTs in the Indian Ocean resulted in higher-than-normal amounts of rainfalls in 1997 and 1998 which was marked as an El Nino event. Further, higher than normal SSTs in the Indian Ocean resulted in higher rainfall amounts in 2010, 2015 and 2016. However, low SSTs resulted in droughts in 1996, 2000 and 2004.

4.4 Influence of Drought on Cereal Yields

This section presents information on the influence of drought on cereal yields in Makueni County.

4.4.1 Annual Cereal Yields

Results in Table 14 show that most, (43%) of the smallholder farmers produced 1 to 10 bags, while only 3% produced 11 to 20 bags of sorghum annually. Another 42% of the smallholder farmers produced 1 to 10 bags while only 4% produced 11 to 20 bags of finger millet annually.

Table 14

Annual Cereal Yields

Type of Cereal	Production (90 kg bags)							
	1-10	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**>70**
Sorghum	43%	3%	1%	0%	0%	0%	0%	1%
Millet	42%	4%	1%	0%	0%	0%	0%	0%
Maize	60%	16%	5%	4%	1%	1%	1%	1%

This study found that a comparatively larger population, 60% of the smallholder farmers produced 1 to 10 bags while 16% produced 11 to 20 bags of maize annually as indicated in Table 14.

4.4.2 Cereal Production Trends

There was significant fluctuation in sorghum, finger millet and maize yields in Makueni County between 1990 and 2020 (Figure 22). However, a significant increase in millet yields was recorded between 2008 and 2011 followed by a decline in yields between 2011 and 2012. Though, sorghum and maize yields fluctuated over a similar period. Sorghum, finger millet and maize yields were consistently low between 2012 and 2014, however, a significant increase in maize yields was recorded between 2014 and 2015.

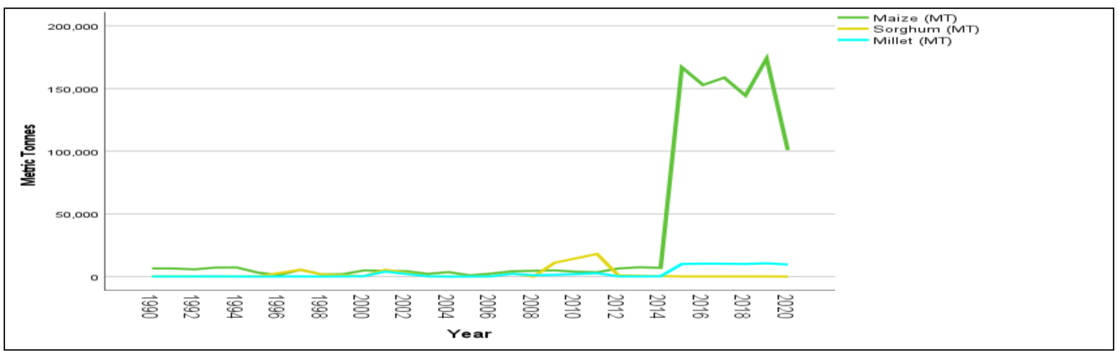

Figure 22. Comparative Line Graphs of Cereal Yields in Makueni County

A consistent and gradual increase in sorghum and finger millet yields was recorded between 2016 and 2020. A decline in maize yields was indicated from 2015 to 2016 followed by fluctuations up-to 2018. There was an increase in maize yield from 2018 to 2019 followed by a sharp decline in maize yields from 2019 to 2020.

4.4.3 Correlation of Drought and Cereal Yields

Results of the correlation analysis of rainfall and cereal yields (Table 15) show that there was a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, r (29) = .699, $p<0.01$. Existence of a strong positive correlation between rainfall and sorghum yields is an indication that reduction in amount of rainfall, leads to reduction in sorghum yields in Makueni County and vice versa.

The results in Table 15 show that there was a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, r (29) = .359, $p<0.01$. The weak positive correlation between rainfall and finger millet yields shows that a reduction in amount of rainfall which depicts drought, leads to a reduction in finger millet yields in Makueni County and vice versa.

Results in Table 15 indicate that there was a significant, weak, positive correlation between rainfall and maize yields in Makueni County, $r(29) = .346$, $p<0.01$. Existence of a weak positive correlation between rainfall and maize yields shows that increase in amount of rainfall leads to an increase in maize yields in Makueni County and vice versa. The positive correlation between rainfall and cereal yields in Makueni County shows that drought events which are indicated by deficit in rainfall, usually the statistical means received in a given geographical area in a season or a year, significantly affect cereal yields.

Results of drought and cereal correlation analysis are corroborated by analysis of rainfall trend from 1990 to 2000 (Figure 23); which had a significant effect of fluctuating sorghum yields in Makueni County over the same period. Even though 1998 had significantly high rainfall from the El Niño event. There were fluctuations in amount of rainfall received between 2008 and 2017. That notwithstanding, there was a significant increase in millet yields between 2008 and 2011 followed by a decline between 2011 and 2012. On the other hand, sorghum and maize yields fluctuated over a similar period.

Table 15

Correlation between Rainfall and Cereal Yields

Correlations

		Makueni County Averaged Rainfall (mm)	Maize (MT)	Sorghum (MT)
Makueni County Averaged Rainfall (mm)	Pearson Correlation	1	.175	-.072
	Sig. (2-tailed)		.346	.699
	N	31	31	31
Maize (MT)	Pearson Correlation	.175	1	-.244
	Sig. (2-tailed)	.346		.186
	N	31	31	31
Sorghum (MT)	Pearson Correlation	-.072	-.244	1
	Sig. (2-tailed)	.699	.186	
	N	31	31	31
Millet (MT)	Pearson Correlation	.171	.958**	-.089
	Sig. (2-tailed)	.359	.000	.634
	N	31	31	31

Rainfall amounts showed an increasing trend from 2018 to 2019 then declining in 2020 (Figure 23). Sorghum, finger millet and maize yields were consistently low between 2012 and 2014, however, a significant increase in maize yields was recorded between 2014 and 2015.

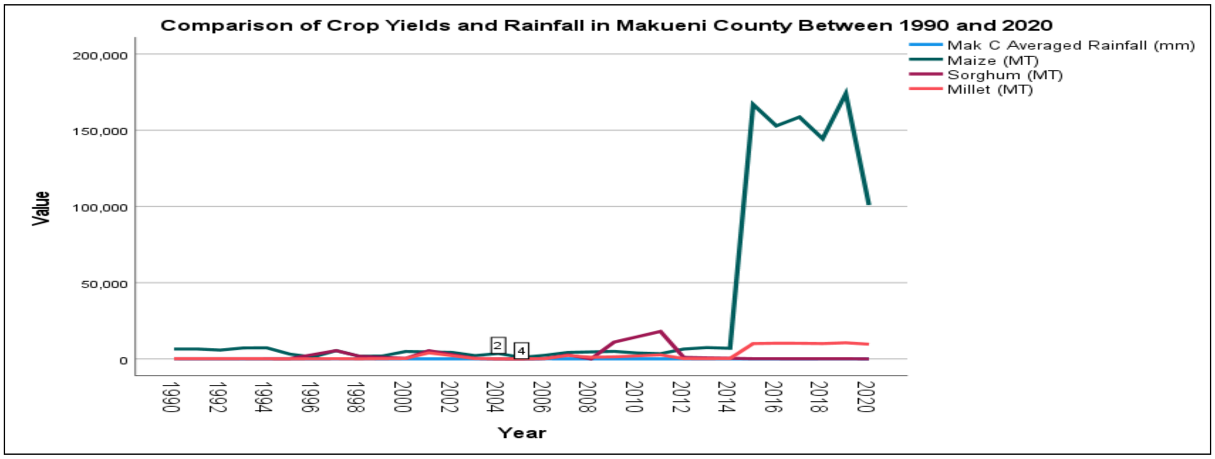

Figure 23. A comparative Line Graph of Rainfall and Cereal Yield Trends in Makueni County

A consistent and gradual increase in sorghum and finger millet yields was recorded between 2016 and 2020. Meanwhile, a decline in maize yields was indicated from 2015 to 2016 followed by fluctuations up-to 2018. There was an increase in maize yield from 2018 to 2019 followed by a sharp decline in maize yields from 2019 to 2020.

4.4.4 Effect of Drought on Cereal Yields

A survey was conducted on smallholder cereal farmers to find out their perceptions on the effect of drought on cereal yields in Makueni County from 1990 to 2020. The study established that majority, 91% of the smallholder cereal farmers recorded a reduction in cereal yields during drought periods. Only 4% of the smallholder farmers recorded an increase in yields during the drought periods (Table 16).

Table 16

Effect of Drought on Cereal Yields

Effect of the drought on cereal yields	**No. of Respondents**	**No. of Respondents %**
Reduction in yields	193	91.1
No change	10	4.9
Increase in yields	9	4.0
Total	**212**	**100.0**

The high frequency of droughts in Makueni County affected cereal production and yields in the region between 1990 and 2020. The effect of drought on cereal yields in Makueni County is shown by low cereal yields whereby majority, 43% of the cereal farmers produced between 1 to 10 bags of sorghum (Table 14). In addition, the effect of drought is also shown by the small farm sizes used for cereal production whereby majority, 32.9%, 30.2% and 24.4% of the smallholder cereal farmers produced sorghum, finger millet and maize respectively on 0.1 to 0.5 ha of land (Table 17). The use of small hectarage for cereal production in Makueni County is a precursor to low yields; a situation caused by frequent droughts in the region.

This study also revealed that drought negatively affected the production and yields of finger millet in Makueni County. The study revealed that majority, 42% of the finger millet farmers in the study area produced between 1 to 10 bags of the cereal, whereas only 5% of the farmers produced above 11 bags of the cereal in Makueni County (Table 14). The low annual finger millet yields were associated with frequent drought episodes in Makueni County. Therefore, frequent and severe droughts significantly affected finger millet yields in Makueni County.

Even though majority, 60% of the cereal farmers produced 1 to 10 bags of maize annually in Makueni County, the low yields are a key challenge to food security in the region. This study also revealed that only 29% of the cereal farmers produced above 11 bags of maize annually (Table 14); signifying depressed maize yields under frequent drought conditions. The frequent near-normal drought episodes resulted in small hectarage under maize where 24.4% of the smallholder cereal farmers produced the cereal on only 0.1 to 0.5 ha of land in Makueni County (Table 17). A high frequency of near-normal droughts results in adverse soil conditions and limited soil moisture thereby limiting cereal production.

This study showed constrained use of farmlands in Makueni County where low hectarage under cereal production was recorded. The study indicated that majority, 32.9%, 30.2% and 24.4% of the smallholder cereal farmers produced sorghum, finger millet and maize respectively on 0.1 to 0.5 ha of land (Table 17). The small farm sizes used for cereal production are an indication of the significant negative effect of drought on cereal production and yields in the study area.

The study established that 43% of the cereal farmers produced between 1 to 10 bags annually while 3% produced 11 to 20 bags and only 1% of the farmers produced 21 to 30 bags of sorghum (Table 14). However, only 1% of the sorghum farmers produced above 70 bags of sorghum annually in the study area. This study also revealed that 42% the finger millet farmers in the study area produced 1 to 10 bags of the cereal, while 4% of the farmers produced 11 to 20 bags of sorghum. The low annual cereal yields were associated with frequent drought episodes in Makueni County.

This study found that 60% of the farmers produced 1 to 10 bags of maize while 16% of the farmers produced 11 to 20 bags of the cereal annually in Makueni County. Further, 5% of the farmers produced 21 to 30 bags of maize whereby only 4% of the farmers produced 31 to 40 bags of the cereal. In addition, only 1% of the farmers produced above 70 bags of maize annually (Table 14). The study showed constrained use of farmlands where low hectarage under cereal production was recorded.

4.4.5 Farm Size in Hectares

This study revealed that farmers used different farm sizes for sorghum, finger millet and maize. It was found that 32.9% of the smallholder sorghum farmers cultivate the crop on farm sizes ranging from 0.1 to 0.5 ha while only 1.8% cultivate the crop on farm sizes above 3.1 ha as indicated in Table 17.

Table 17

Farm Size in Hectares in Makueni County

	Sorghum		Finger Millet		Maize	
	No. of Farmers	**Percent**	**No. of Farmers**	**Percent**	**No. of Farmers**	**Percent**
No response	103	48.4	115	54.2	15	7.1
0.1-0.5	70	32.9	64	30.2	52	24.4
0.6-1.0	14	6.7	12	5.8	33	15.6
1.1-2.0	14	6.7	13	6.2	49	23.1
2.1-3.0	7	3.6	6	2.7	38	17.8
>3.1	4	1.8	2	0.9	25	12.0
Total	**212**	**100.0**	**212**	**100.0**	**212**	**100.0**

The study established that 30.2% of the smallholder millet farmers cultivate the crop on land sizes ranging from 0.1 to 0.5 ha while only 0.9% cultivate the crop on farm sizes above 3.1 ha. This study also found that 24.4% of the smallholder maize farmers cultivate the crop on farm sizes ranging from 0.1 to 0.5 ha while only 12% cultivate the crop on farm sizes above 3.1 ha

(Table 17). This implies that a large number of smallholder cereal farmers own small farms or that the production of the crop experiences significant challenges that discourage its production in the ASAL area. The small farm sizes for the production of sorghum, millet and maize significantly affect production of the cereals hence food security in the study area.

4.4.6 Effect of Drought on Livelihoods of Smallholder Cereal Farmers

This study established a high frequency of droughts in Makueni County whereby 20 near-normal droughts, 5 mild drought episodes and 3 severe droughts were experienced between 1990 and 2020. Consequently, the frequent droughts affected cereal production and yields significantly, in the region. The negative effect of drought on cereal yields in Makueni County is indicated by low cereal yields. Majority, (43%) of the cereal farmers produced between 1 to 10 bags of sorghum. In addition, the negative effect of drought is signified by small farm sizes ranging from 0.1 to 0.5 ha of land that was recorded by majority, 32.9%, 30.2% and 24.4% of the smallholder sorghum, finger millet and maize farmers, respectively. Low cereal yields that were associated with frequent droughts that was recorded by smallholder cereal farmers, affected livelihoods and income levels thereby increasing the vulnerability of the farmers in Makueni County. Further, low cereal yield levels recorded from the small farm sizes which were adopted as a drought adaptation strategy, affected production levels and income for the Farmers thereby increasing the level of vulnerability in Makueni County.

4.5 Socioeconomic Characteristics of the Smallholder Cereal Farmers

This section covers socioeconomic characteristics of the smallholder cereal farmers in Makueni County. The socioeconomic characteristics include gender, age, levels of education and occupation of the smallholder cereal farmers in Makueni County. This section also includes sizes of the farms used for cereal production by smallholder cereal farmers in Makueni County.

4.5.1 Questionnaire Response Rate

A total of two hundred and twenty-five (225) smallholder cereal farmers participated in this study, though only two hundred and twelve (212) which is 94.2%, returned the questionnaires.

4.5.2 Gender of the Smallholder Cereal Farmers

Results in Figure 24 show that 53% of the household heads were males while 47% were females. The study found that smallholder cereal farming in Makueni County is dominated by males. The large number of males in the smallholder farming was attributed to the land tenure systems, economic conditions and traditional practices that favour males as the traditional land owners in the area of study.

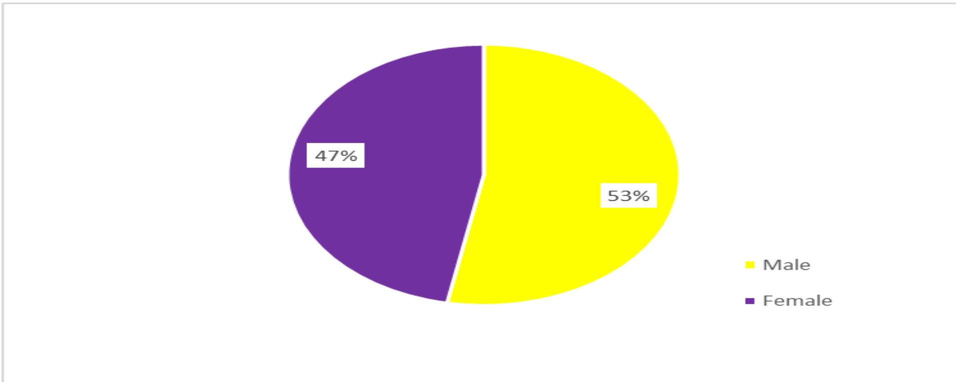

Figure 24. Gender of Smallholder Farmers in Makueni County

4.5.3 Age of the Smallholder Cereal Farmers

Results in Figure 25 show that 40% of the household heads were between 36 and 53 years old, 8% were between 18 and 35 years old, 24% were between 55 and 71 years old while 8% were above 71 years old.

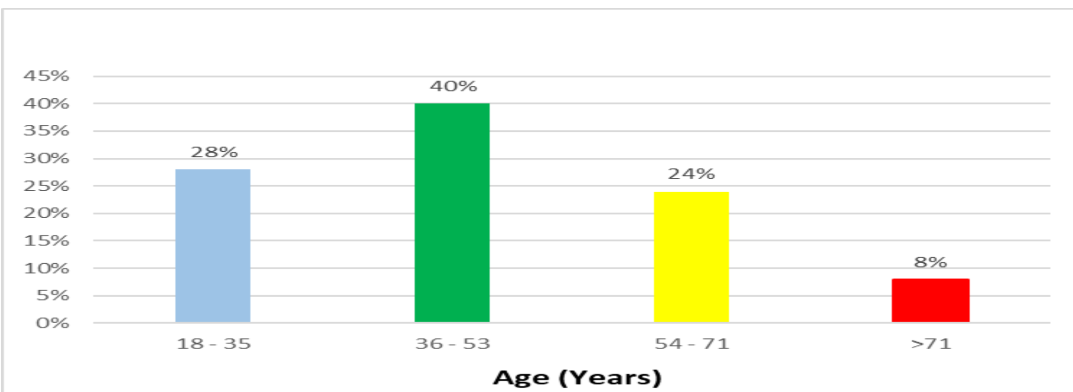

Figure 25. Age of the Smallholder Farmers in Makueni County

This implies that cereal farming is more popular among the advanced members of the society compared to the youthful cereal farmers. The large population of advanced smallholder farmers can be attributed to land tenure systems that favour the advanced members of the society.

4.5.4 Level of Education of the Smallholder Cereal Farmers

Results in Figure 26 show that 37.3% of the smallholder cereal farmers had primary education while 34.9% had secondary education. This implies that primary and secondary education undertaken by a high population of smallholder farmers may have significantly contributed to the adoption of drought-resilient cereals such as sorghum, millet and maize.

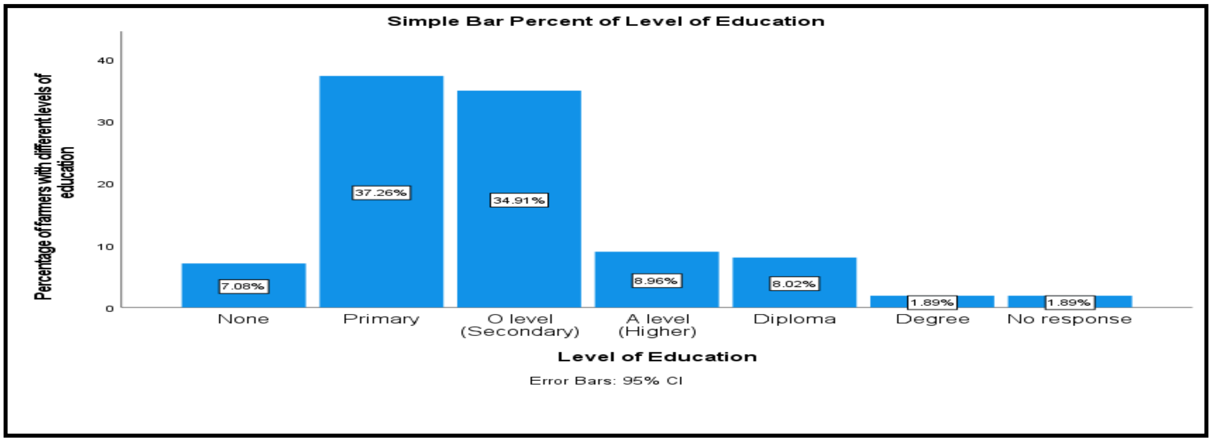

Figure 26. Level of Education of the Smallholder Farmers in Makueni County

4.5.5 Occupation of the Smallholder Cereal Farmers

Results in Figure 27 show that 66% of the respondents are smallholder cereal farmers, 15% are employed in the private sector, 11% are traders and 8% are agro-pastoralists. This implies that smallholder cereal production is a very popular economic activity in the study area.

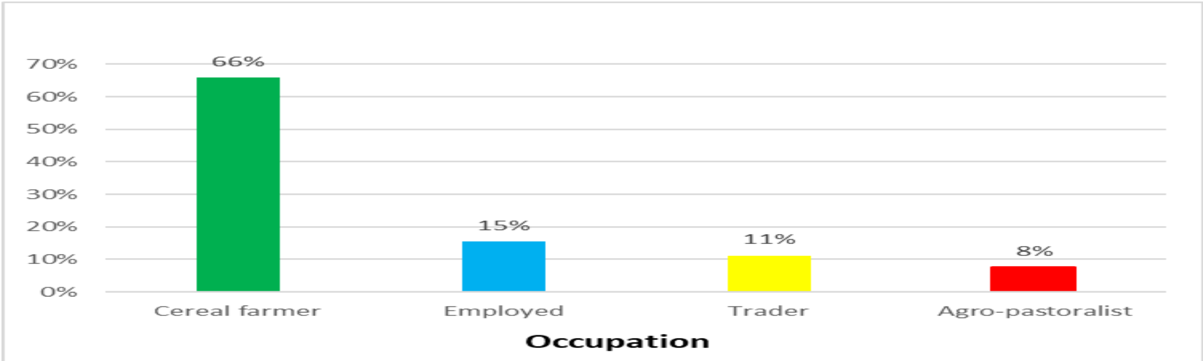

Figure 27. Occupation of the Smallholder Cereal Farmers in Makueni County

4.6 Drought Adaptation Strategies Practiced in Makueni County

This section covers the CBA and IK drought adaptation strategies practiced by smallholder cereal farmers in Makueni County.

4.6.1 CBA and IK Drought Adaptations Practiced by Cereal Farmers

The use of CBA and IK is to improve drought adaptations and to reduce cost of drought adaptations due to their popularity among the local community and to complement the scientific knowledge and adaptation strategies. The evaluation of drought outcomes covered factors that influence adoption of CBA and IK drought adaptations in Makueni County. These factors include gender, age, education, occupation and land ownership.

Table 18

Cross-Tabulation of Gender and Drought Adaptations (N=212)

Drought Adaptations	Gender %	
	Female	Male
IK drought prediction and monitoring	61	39
Supplementary irrigation	51	49
Early planting of cereal seeds	52	48
Late planting of cereal seeds	57	43
Use of farm manure	54	46
IK bio-control of weeds and pests	57	43
Use of improved seeds	48	53
Planting early maturing seeds	42	58
Planting Drought resistant seeds	46	54

Results in Table 18 show that more females than men adapted to droughts in Makueni County through IK drought prediction and monitoring (61%), late planting of cereal seeds (57%), supplementary irrigation (51%) and early planting of seeds (51%). This study found that more females adapted to droughts through adoption of bio-control of weeds (57%) and farm manure (54%). On the other hand, the results show that more males than females adapted to droughts in Makueni County through adoption of planting early maturing seeds (58%), planting drought resistant cereal seeds (54%) and use of improved seeds (53%).

Results in Table 19 shows that majority of the smallholder cereal farmers who adapted to droughts were below 53 years old. The study also revealed that the most popular drought adaptation strategies included: increasing farm size, use of farm manure and IK based bio-control of weeds by 55%, 50%, 49%, respectively.

Table 19

Cross-Tabulation of Age and Drought Adaptations (N=212)

Drought Adaptations	Age %			
	18-35 Years	36-53 Years	54-71 Years	Above 72 Years
IK drought prediction and Monitoring	29	44	20	**7**
Supplementary irrigation	30	44	17	9
Early planting of Seeds	24	41	27	8
Late planting of seeds	30	35	19	16
Use of farm manure	18	50	22	10
Increasing farm size	20	55	20	5
Decreasing farm size	26	40	23	11
IK bio-control of weeds and pests	27	49	17	7
Use of improved seeds	27	48	21	4
Adoption of farm mechanization	27	41	20	12
IK based sed preservation	16	44	32	8
IK based seed storage	15	45	30	10
Planting early maturing seeds	18	46	31	5
Planting Drought resistant seeds	22	39	32	7

Results in Table 19 also indicates that use of improved seeds and planting early maturing cereal seeds were practiced by 48% and 46% of the heads of households in 36 to 53 years age bracket, respectively. It is not clear why majority of the heads of households in 36 to 53 years age bracket practiced more drought adaptation strategies compared to the other age brackets.

Results in Table 20 indicate that most of the cereal farmers who practiced drought adaptations in Makueni County had primary education.

Table 20

Cross-Tabulation of Education Level and Drought Adaptations (N=212)

Drought Adaptations	Level of Education %					
	Informal Education	Primary	Secondary	A-Level	Diploma	Degree
IK drought prediction	4	50	26	10	9	1
Supplementary irrigation	8	43	30	7	8	3
Early planting of Seeds	9	34	36	10	9	3
Late planting of seeds	0	59	24	12	6	0
Use of farm manure	7	36	31	12	10	2
Increasing farm size	8	27	24	22	12	6
Decreasing farm size	11	32	40	9	9	0
IK bio-control of weeds and pests	5	42	26	12	11	3
Use of improved seeds	5	35	29	15	12	4

The results also revealed that late planting of seeds and IK based drought prediction and monitoring were practiced by majority of the cereal farmers with primary education at 59% and 50%, respectively. The results also show that decreasing farm size (40%), IK-based seed preservation (38%) and early planting of seeds (36%) were the most popular drought adaptation strategies among cereal farming households with secondary education.

Results in Table 21 indicate that majority of the cereal farming households were primarily farmers with 60% to 72% of the cereal farmers practicing different strategies of drought adaptation.

Table 21

Cross-Tabulation of Occupation and Drought Adaptations (N=212)

Drought Adaptations	Occupation %				
	Cereal Farmer	Agro-pastoralist	Teacher	Civil Servant	Trader
IK drought prediction	60	14	3	3	20
Supplementary irrigation	66	13	1	1	19
Early planting of Seeds	69	6	4	4	17
Late planting of seeds	66	14	0	3	17
Use of farm manure	63	8	3	5	21
Increasing farm size	72	4	6	4	14
Decreasing farm size	61	7	2	4	26
IK bio-control of weeds and pests	69	6	6	1	18
Use of improved seeds	71	6	6	1	16
Adoption of farm mechanization	69	10	4	2	15
IK based sed preservation	68	8	5	4	15
IK based seed storage	70	7	1	4	18

The study also revealed that IK-based drought prediction (14%), late planting of cereal seeds (14%) and supplementary irrigation (13%) were popular drought strategies among agro-pastoralists.

Results in Table 22 indicate that more male household heads than female household heads practice agronomic adaptations. The results show that the following agronomic adaptations were the most popular among the female cereal farmers as indicated: mono-cropping (60%), timely weeding (56%) and intercropping with cereals (56%). The results also show that intercropping with legumes (50%), improvement in land tillage (46%), improving seed spacing (46%) and practicing agro-forestry (46%) were the most popular agronomic adaptations among male cereal

Table 22

Cross-Tabulation of Gender and Agronomic Adaptations

Agronomic Adaptations	Gender %	
	Females	Males
Improving land tillage	54	46
Improving seed spacing	54	46
Timely weeding	56	44
Timely application of organic manure	55	45
Mono-cropping	60	40
Intercropping with legumes	50	50
Intercropping with cereals	56	44
Practicing agro-forestry	54	46

Results in Table 23 indicate that the most popular drought adaptation agronomic practices among cereal farmers in 36 to 53 years age bracket include intercropping with cereals (56%), timely application of organic manure (46%), timely weeding (45%) and improving cereal seed spacing (45%).

Table 23

Cross-Tabulation of Age and Agronomic Adaptations (N=212)

Agronomic Adaptations	Age % 18 - 35 Years	36 - 53 Years	54 - 71 Years	Above 72 Years
Improving land tillage	26	41	25	8
Improving seed spacing	32	44	15	9
Timely weeding	29	45	17	9
Timely application of organic manure	25	46	21	8
Mono-cropping	28	41	24	7
Intercropping with legumes	27	43	23	7
Intercropping with cereals	9	56	28	7
Practicing agro-forestry	34	41	13	12

Results in Table 24 indicate that agronomic drought adaptation practices were more common among cereal farmers with primary education compared with the other category of farmers. The results also indicate that mono-cropping, improving land tillage and improving seed spacing were the most common agronomic adaptations to drought among cereal farmers in the following percentages 45%, 42% and 39%, respectively.

Table 24

Cross-Tabulation of Education Level and Agronomic Adaptations

Agronomic Adaptations	Level of Education %					
	Informal Education	Primary	Secondary	A-Level	Diploma	Degree
Improving land tillage	4	42	31	11	9	3
Improving seed spacing	7	39	34	7	10	3
Timely weeding	7	36	34	11	9	3
Timely application of organic manure	3	36	38	10	10	3
Mono-cropping	4	45	28	13	8	2
Intercropping with legumes	6	31	25	15	18	5
Intercropping with cereals	6	29	25	24	10	6
Practicing agro-forestry	10	32	32	10	14	2

The results indicate that timely application of organic manure, improving seed spacing and timely weeding were the most popular agronomic drought adaptation practices among cereal farmers with secondary education in the following percentages 38%, 34% and 34%, respectively.

4.6.2 Agronomic Adaptations

Results in Table 25 reveal that agronomic drought adaptation practices were popular among majority of the farmers in the study area. The results revealed that intercropping cereals, timely application of organic manure, timely weeding and intercropping cereals with legumes were the most common agronomic practices undertaken by the cereal farmers in the following percentages 73%, 70%, 69% and 69%, respectively. The results also show that 68% of the cereal farmers practice agro-forestry and while 65% improve seed spacing.

The results of a survey conducted on smallholder cereal farmers in Makueni County indicated that majority (64%) of the smallholder cereal farmers adopted timely weeding as a measure of adapting to droughts and to limit the competition for soil moisture, minerals and space between the cereal crops and weeds during drought in Makueni County. Meanwhile, 60% and 52% of the smallholder cereal farmers improved seed spacing and timely application of organic manure and cow-dung, respectively (Table 25).

Table 25

Cross-Tabulation of Occupation and Agronomic Adaptations (N=212)

	Occupation %				
Agronomic Adaptations	**Cereal Farmer**	**Agro-pastoralists**	**Teacher**	**Civil Servant**	**Trader**
Improving land tillage	63	11	3	3	20
Improving seed spacing	65	10	4	2	19
Timely weeding	69	8	2	4	17
Timely application of organic manure	70	7	4	4	15
Mono-cropping	63	8	4	2	23
Intercropping with legumes	69	5	3	5	18
Intercropping with cereals	73	0	6	6	15
Practicing agro-forestry	68	11	5	2	14

This study established that 36% of the farmers intercropped cereals with pulses. The study also established that 26% of the smallholder cereal farmers adopted agro-forestry to adapt to droughts and to improve yields. Use of traditional drought prediction and monitoring techniques, variation in farm size, variation in planting time and adoption of drought resilient cereal seeds are important measures in adapting to drought in the study area.

4.6.3 Technical Adaptations to Drought

Results in Table 26 show that 66% of the farmers planted early while 16% planted late based on drought prediction whereas 44% of the farmers adopted supplementary irrigation. Besides, the study revealed that irrigation farming was practiced due to the unreliability the MAM seasonal rainfall while the OND rainfall is the major rainfall season with reliable rainfall thereby encouraging irrigation farming along perennial rivers such as River Thange and River Kaiti.

Table 26

Cross-Tabulation of Occupation and Technical Adaptations (N=212)

Technical Adaptations	Practicing		Not Practicing	
	No. of Respondents	%	No. of Respondents	%
Planting seeds early	140	66%	72	34%
Planting drought resistant cereal varieties	102	48%	110	52%
Rain water harvesting and supplementary irrigation	93	44%	119	56%
Planting early maturing/ short period sorghum cereals	85	40%	127	60%
Adoption of improved cereal seeds	76	36%	136	64%
Adoption of traditional drought prediction and monitoring	68	32%	144	68%
Adoption of farm mechanization	47	22%	165	78%
Planting seeds late	34	16%	178	84%

The study established that 48%, 40% and 36% of the farmers planted drought resistant cereal seeds, planted early maturing cereal seeds and used improved cereal seed varieties, respectively (Table 26). Further, the study revealed that capacity building and provision of timely climate information was done by KMD.

This study established that irrigation farming is encouraged in the study area due to availability of spring water from Kiboko Springs, Simba Springs, Makindu Springs, Kibwezi Springs and Thange Springs near Mtito Andei (Plate 1).

Plate 1. Maize Irrigation Farming, Kiboko Crops Research Station, Makueni County.

4.6.4 Indigenous Adaptation Practices

Table 27 shows that adoption of farm manure (55%), IK-based bio-control of weeds (41%), short period seeds (40%) were common among smallholder cereal farmers in Makueni County.

Table 27

Cross-Tabulation of Occupation and Indigenous Adaptations

Indigenous Adaptations	Practicing		Not Practicing	
	No. of Respondents	%	No. of Respondents	%
Adoption of farm manure	117	55%	95	45%
Adoption of traditional methods in bio-control of weeds/ pests	87	41%	125	59%
Planting early maturing/ short period sorghum cereals	85	40%	127	60%
Adoption of traditional seed storage	78	37%	134	63%
Adoption of traditional seed preservation	76	36%	136	64%
Adoption of traditional drought prediction and monitoring	68	32%	144	68%

The study established that 55% and 41% of the cereal farmers used farm manure to improve soil quality and to conserve soil, respectively. The study also revealed that 37%, 36% and 32% of the cereal farmers adopted traditional methods in bio-control of pests and diseases, used traditional seed storage methods, used traditional seed preservation methods and adopted traditional drought prediction and monitoring methods, respectively.

The study revealed that 32% of the cereal farmers adopted traditional drought prediction and monitoring methods which influenced cereal seed planting time. These results were supported by results of key informant interviews conducted in the study area. The results from key interviewees revealed that the farmers adapted to droughts by predicting the weather conditions through observation of conditions of the sky, the coloration of tree leaves and observation of the number of tree leaves.

4.6.5 Indigenous Land Preparation Methods

This study established that 43.1%, 12.4%, 5.3% and 0.9% of the smallholder cereal farmers practiced hand tilling, ox ploughing, bush clearing and seed broadcasting, respectively (Table 28).

Table 28

Indigenous Land Preparation Methods

Traditional Land preparation Methods	No. of Respondents	%
Hand tilling	92	43.1
Not Practicing	80	37.8
Ox Ploughing	26	12.4
Bush clearing	11	5.3
Broadcasting	2	0.9
Planting early	1	0.4
Total	**212**	**100.0**

4.6.6 Pest Control Strategies

This study found that intercropping is practiced by 62.7% while use of dogs to control pests and diseases is practiced by 30.7% of the smallholder cereal farmers in Makueni County (Table 29).

Table 29

Biological Pest and Disease control Strategies

Traditional biological pest and disease control strategies	No. of Respondents	%
Intercropping	133	62.7
use of dogs	65	30.7
Agroforestry	3	1.3
Mixed Farming	2	0.9
No idea	1	0.4
Not practicing	8	4.0
Total	**212**	**100.0**

Results in Table 29 show that agroforestry is practiced by 1.3% while mixed farming is practiced by 0.9% of the farmers. Mixed farming was practiced to diversify agro-production and to limit yield loss besides bio-control of pests. This study found that agro-forestry involved planting Melia volkensii (*Mukau*) which is a fast-growing multi-purpose tree that produces high value timber and, Neem tree (*Mwarobaini*), which has traditional medicinal value was also planted.

The two species of trees are popular for agro-forestry and are used for bio-control of pests in the study area. The trees are also popular due to their use of little water, shedding of leaves to reduce water intake and loss, deep roots for tapping water from the depths of soil and rocks and hard nature for production of valuable hard timber.

The study also found that 2.2% and 0.4% of the farmers used gourds and honey, respectively to preserve seeds. The study established that smearing seeds with cow dung and hanging above fire places were useful measures in preservation of cereal seeds.

4.6.7 Seed Preservation Methods

This study found that 19.1%, 17.3% and 15.6% of the farmers used smoking, granary and ash, respectively for seed preservation (Table 30).

Table 30

Traditional Seed Preservation Methods

Traditional seed preservation methods	**No. of Respondents**	**%**
Use of granary	40	19.1
Smoking	37	17.3
Use of ash	33	15.6
Use of guards	5	2.2
Use of honey	1	0.4
Not Practicing	96	45.3
Total	**212**	**100.0**

4.6.8 Mixed Cropping

This study established that smallholder cereal famers practiced mixed cropping of cereals with leguminous crops such as pigeon peas (*mbaazi*), green grams, and cow peas (Plate 2). The study also found that most farmers practiced intercropping whereby maize (*mbemba*) is intercropped with peas (*nzouu*), beans (*mboso*), cowpeas (*nthooko*) and chicken peas (*ndengu*).

Some farmers also intercropped millet (*muvya*) or sorghum (*mwee*) with oranges (*masungwa*), mangoes (*maembe*) and paw paws (*mavavai*). The farmers observed that intercropping cereals with leguminous crops resulted in improvement in productivity.

Plate 2. Mixed Cropping in Makueni sub-County

4.6.9 Technical Adaptations and Sorghum Yields

Table 31 shows that planting cereal seeds early (66.7%), application of farm manure (57.0%) and planting drought-resilient cereal seeds (44.7%) led to the highest sorghum produce between 1 to 10 bags in Makueni County.

Table 31

Cross-Tabulation of Technical Drought Adaptations and Sorghum Yields (N=212)

Technical Drought Adaptations	Practicing (%)				Total Practicing	Not Practicing (%)
	1 – 10 bags	11 – 20 bags	21 – 30 bags	>31 bags	(%)	
Planting seeds early	66.7	4.4	2.6	1.8	75.7	24.5
Planting seeds late	17.5	0.9	0.9	0.9	20.2	79.8
Planting drought resilient seeds	44.7	1.8	1.8	0.9	49.2	50.8
Planting short period seeds	34.2	4.4	0.9	1.8	41.3	58.7
Use farm manure	57	4.4	2.6	0.9	64.9	35.1
Increasing farm size	26.3	1.8	2.6	1.8	32.5	67.5
IK bio-control of weeds/ pests	40.4	3.5	2.6	1.8	48.3	51.7

The table 31 also shows that planting seeds early (1.8%), planting short period seeds (1.8%), increasing farm size (1.8%) and using IK-based weed and pest control strategies (1.8%) resulted in above 31 bags of sorghum in Makueni County. The identified drought adaptation strategies are commendable in order to increase food production in Makueni County.

4.6.10 Agronomic Drought Adaptations and Sorghum Yields

Table 32 shows that timely weeding (61.4%), improving land tillage (56.1%), seed spacing (55.3%) and timely application of organic manure (54.4%); were the most popular drought adaptations which resulted in sorghum yields between 1 to 10 bags in Makueni County.

Table 32

Cross-Tabulation of Agronomic Drought Adaptations and Sorghum Yields (N=212)

Agronomic Drought Adaptation Techniques	Practicing (%)				Total Practicing (%)	Not Practicing (%)
	1 – 10 bags	11 – 20 bags	21 – 30 bags	>31 bags		
Improving land tillage/ cultivation practices	56.1	2.6	2.6	0	61.3	38.7
Improving seed spacing	55.3	4.4	1.8	0.9	62.4	37.6
Practicing timely weeding	61.4	5.3	2.6	0.9	70.2	29.8
Timely application of organic manure	54.4	2.6	2.6	2.6	62.2	37.8
Practicing mono-cropping	47.4	3.5	2.6	0	53.5	46.5
Practicing intercropping with legumes	32.5	2.6	2.6	0.9	38.6	61.4
Practicing intercropping with finger millet or maize	28.9	3.5	2.6	0.9	35.9	64.1
Practicing agro-forestry	26.3	2.6	0.9	1.8	31.6	68.4

Embracing the mentioned drought adaptation strategies by all sorghum farmers in Makueni County will result in improvement in yields hence improvement in management of food insecurity in the county.

4.6.11 Agronomic Drought Adaptations and Finger Millet Yields

Table 33 shows that majority of the farmers practiced the following agronomic drought adaptations: timely weeding (54.4%) and improving seed spacing (50.0%) which resulted in production of finger millet ranging from 1 to 10 bags in Makueni County.

Table 33

Cross-Tabulation of Agronomic Drought Adaptations and Finger Millet Yields (N=212)

Agronomic Drought Adaptation Techniques	Practicing (%)				Total	Not
	1 – 10 bags	11 – 20 bags	21 – 30 bags	>31 bags	Practicing (%)	Practicing (%)
Improving land tillage/ cultivation practices	47.4	5.3	1.8	0	54.5	45.5
Improving seed spacing	50	4.4	0.9	0	55.3	44.7
Practicing timely weeding	54.4	6.1	0.9	0.9	62.3	37.7
Practicing timely organic manure application	47.4	4.4	0.9	0.9	53.6	46.4
Practicing mono-cropping	49.1	6.1	0.9	0	56.1	43.9
Practicing intercropping with legumes	26.3	4.4	0.9	0.9	32.5	67.5
Practicing intercropping with sorghum or maize	25.4	4.4	0.9	0	30.7	69.3
Practicing agro-forestry	22.8	5.3	0.9	0.9	29.9	70.1

4.6.12 Technical Drought Adaptations and Finger Millet Yields

Table 42 shows that majority of the smallholder farmers adopted the following drought adaptation strategies: planting seeds early (59.6%), application of farm manure (46.5%) and planting drought-resilient seeds (39.5%) which resulted in production of finger millet ranging between 1 to 10 bags

Plate 3. KALRO and CIMMYT water harvesting reservoir in Makueni County.

The study also pointed out that rain water harvesting and supplementary irrigation was practiced by 37.7% of the smallholder cereal farmers in Makueni County as indicated in Table 34 and Plate 3.

Table 34

Cross-Tabulation of Technical Drought Adaptations and Finger Millet Yields (N=212)

Technical Drought Adaptation Techniques	**Practicing (%)**				**Total Practicing (%)**	**Not Practicing (%)**
	1 – 10 bags	**11 – 20 bags**	**21 – 30 bags**	**>31 bags**		
IK drought prediction and monitoring	30.7	2.6	0	0.9	34.2	65.8
Rain water harvesting and supplementary irrigation	28.9	6.1	1.8	0.9	37.7	62.3
Planting seeds early	59.6	5.3	1.8	0.9	67.6	32.4
Planting seeds late	15.8	2.6	0.9	0.9	20.2	79.8
Planting drought resilient seeds	39.5	3.5	0.9	0	43.9	56.1
Planting improved seeds	30.7	4.4	0.9	0	36	64
Planting short period seeds	30.7	4.4	0	0.9	36	64
Use farm manure	46.5	7.9	1.8	0.9	57.1	42.9
IK bio-control of weeds/ pests	36.8	6.1	1.8	0.9	45.6	54.4

4.6.13 Drought Adaptations and Maize Yields

Supplementary irrigation was adopted by the smallholder cereal farmers in Makueni County (Plate 4). Supplementary irrigation was adopted to support growth and development of cereal crops during the phenological stages of vegetative development. It was adopted due to inadequacy of rainfall during drought periods.

Plate 4. Supplementary irrigation in Makueni County.

Table 35 shows that planting maize seeds early (48.5%), application of farm manure (39.2%), planting drought-resilient seeds (35.3%) and planting short period cereal seeds (30.4%) resulted in maize yields ranging from 1 to 10 bags in Makueni County (Table 35).

Table 35

Cross-Tabulation of Technical Drought Adaptations and Maize Yields (N=212)

Technical Drought Adaptation Techniques	Practicing (%)				Total	Not
	1 – 10 bags	11 – 20 bags	21 – 30 bags	>31 bags	Practicing (%)	Practicing (%)
Planting seeds early	48.5	12.3	3.4	4.9	69.1	30.9
Planting drought resilient seeds	35.3	10.8	2	3.4	51.5	48.5
Planting short period seeds	30.4	7.8	2.5	3.4	44.1	55.9
Application of farm manure	39.2	10.3	3.4	5.4	58.3	41.7
Increasing farm size	15.7	4.4	2.9	2	25	75
IK bio-control of weeds/ pests	25.5	10.8	2.5	3.9	42.7	57.3

The results also indicated that application of farm manure (5.4%), planting seeds early (4.9%) and IK-based bio-control of weeds (3.9%) resulted in production of above 31 bags of cereals.

4.6.14 Agronomic Drought Adaptations and Maize Yields

Table 36 shows that timely weeding (41.7%) and improving seed spacing (40.7%) resulted in production between 1 to 10 bags of maize in Makueni County. On the other hand, timely weeding (5.9%) and improving seed spacing (4.9%) resulted in production of above 31 bags of maize in Makueni County.

Table 36

Cross-Tabulation of Agronomic Drought Adaptations and Maize Yields

Agronomic Drought Adaptation Techniques	Practicing (%)				Total Practicing (%)	Not Practicing (%)
	1 – 10 bags	11 – 20 bags	21 – 30 bags	>31 bags		
Improving land tillage/ cultivation practices	38.7	7.8	2.9	3.4	52.8	47.2
Improving seed spacing	40.7	11.3	4.4	4.9	61.3	38.7
Practicing timely weeding	41.7	14.2	3.9	5.9	65.7	34.3
Timely application of organic manure	38.7	9.8	2.9	3.4	54.8	45.2
Practicing mono-cropping	28.9	8.8	2.5	2.5	42.7	57.3
Intercropping with legumes	28.9	5.9	2.9	1.5	39.2	60.8
Practicing intercropping with sorghum or finger millet	17.6	4.9	2	2	26.5	73.5
Practicing agro-forestry	16.2	6.4	1.5	3.4	27.5	72.5

The agronomic drought adaptation strategies mentioned above can be used to improve maize production in Makueni County.

4.7 Cereal Varieties

This section presents results on the sorghum, finger millet and maize varieties that are produced by the smallholder cereal farmeers in Makueni County.

4.7.1 Sorghum Varieties

A survey on key informants established that local varieties of sorghum were more adaptable to droughts hence more popular in Makueni County. A survey on cereal farmers also established that 38.2% of the smallholder farmers cultivated local landraces of sorghum, while Gadam was produced by 6.7% of the sorghum farmers (Table 37).

Table 37

Cultivated Sorghum Varieties

Sorghum Variety	No. of Respondents	%
Local variety	81	38.2
Gadam	14	6.7
Saredo	1	0.4
Serena	1	0.4
No Idea	115	54.3
Total	**212**	**100.0**

The study revealed that Saredo and Serena were produced by 0.4% of the farmers. However, a large number 51.1% of the sorghum farmers were not aware of the sorghum varieties that they planted. This study revealed that cereal farmers carefully chose drought resilient, short and fast yielding cereal varieties from KALRO-Kiboko to limit water loss hence recording improvement in productivity.

4.7.2 Finger Millet Varieties

This study found that 37.8% of the finger millet farmers planted local varieties. Meanwhile, 3.1% of the smallholder finger millet farmers produced U15 and some farmers also planted KAT FM1 and PM1 (Table 38).

Table 38

Millet Varieties

Millet Variety	No. of Respondents	%
Local variety	80	37.8
U15	7	3.1
No Idea	125	59.1
Total	**212**	**100.0**

The study found that 59.1% of the farmers were not aware of the finger millet varieties that they planted making choice of successful seeds a challenge. The study also found that finger millet and pearl millet perform very well in the higher altitudes of Kibwezi sub-county such as Emali and Mulala areas, though bird attack is a major menace to their production.

4.7.3 Maize Varieties

This study found that 36.9% of smallholder maize farmers produced DK 8031, while DUMA 43 accounted for 14.7% (Table 39). This study also found that 6.2% and 5.3% of the farmers planted Pioneer and Katumani maize varieties, respectively. However, local varieties of maize were planted by 10.2% of the farmers.

Table 39

Maize Varieties

Maize Variety	No. of Respondents	%
DK 8031	78	36.9
Duma 43	31	14.7
Local varieties	22	10.2
Pioneer	13	6.2
Katumani	11	5.3
No Idea	57	26.7
Total	**212**	**100.0**

Local maize landraces planted by the farmers included Sungura, Kishindo, Kikamba maize, Haraka, Panuah and Kinyanya. However, this study found that 26.7% of the maize farmers were not aware of the maize varieties that they planted making choice of successful seeds a challenge. Even though maize is produced all over the county, a large percentage of maize is produced in the higher altitude regions of the study area such as Emali and Mulala areas of Kibwezi West sub-County.

The study established that despite the fact that drought is frequent in the area, the farmers consistently plant maize annually with the hope of harvesting. However, the produce is often harvested early while still green therefore limiting recording of yields and improvement in food security.

4.8 Source of Cereal Seeds

This section consists of information on sources of sorghum, finger millet and maize seeds in Makueni County.

4.8.1 Source of Sorghum Seeds.

Majority, 31.6% of the smallholder cereal farmers sourced sorghum seeds from the local market while the family seed store accounted for 11.1% whereas MoA accounts for only 7.1% of sorghum seeds (Table 40). This study also established that only 4.4% and 2.2% of the smallholder cereal farmers sourced seeds from KALRO and NGO/CBOs, respectively.

Table 40

Source of Sorghum Seeds

Source of sorghum seeds	No. of Respondents	%
Market	67	31.6
Family seed store	24	11.1
Ministry of agriculture	15	7.1
KARLO	9	4.4
NGO/CBO	5	2.2
EABL/KBL	1	0.4
None	91	43.1
Total	**212**	**100.0**

A small percentage of 0.4% of the farmers sources cereal seeds from EABL/KBL. The high percentage of cereal farmers sourcing cereal seeds from the local markets indicate the significant role played by local markets and family seed banks in the production of cereals in the study area.

4.8.2 Source of Finger Millet Seeds.

This study found that 32.4% of the smallholder farmers sourced finger millet seeds from the local market while 7.1% source seeds from MoA (Table 41). This study also established that KALRO, NGOSs/CBOs and EABL/KBL account for 4.9%, 3.6% and 0.9% of finger millet seeds, respectively.

Table 41

Source of Finger Millet

Source of millet seeds	No. of Respondents	%
Market	69	32.4
Ministry of agriculture	15	7.1
KALRO	10	4.9
NGO/CBO	8	3.6
EABL/KBL	2	0.9
None	108	51.1
Total	**212**	**100.0**

4.8.3 Source of Maize Seeds.

This study established that local markets, MoA and family seed store account for 52.9%, 15.6% and 15.1% of sources of maize seeds, respectively (Table 42). This study also found that KALRO, NGOs/CBOs, and EABL/KBL accounted for 6.2%, 1.3% and 0.4% of sources of maize seeds, respectively.

Table 42

Source of Maize Seeds

Source of maize seeds	No. of Respondents	%
Market	112	52.9
Ministry of Agriculture	33	15.6
Family seed store	32	15.1
KALRO	13	6.2
NGO/CBO	3	1.3
Others	2	0.9
EABL/KBL	1	0.4
None	16	7.6
Total	**212**	**100.0**

4.9 Comparison of Drought Adaptations

This study established that the following drought adaptation strategies are the most popular in Makueni County: increasing farm size (72%), use of improved cereal seeds (71%), IK-based cereal seed storage (70%), intercropping cereals (73%), timely application of organic manure (70%), timely weeding (69%), agro-forestry (68%), planting cereal seeds early (66.7%), improving seed spacing (65%) and IK-based drought prediction and monitoring (61%). Other popular drought adaptation strategies included: planting early maturing seeds (58%), late planting of cereal seeds (57%), bio-control of weeds (57%), improving land tillage (56.1%), IK-based seed preservation (55%), and timely application of organic manure (54.4%), planting drought resistant cereal seeds (54%) and supplementary irrigation (51%).

This study pointed out that the following cereal varieties were popular among smallholder cereal farmers in Makueni County: 38.2% of the sorghum Farmers cultivated local landraces of sorghum, 37.8% of the finger millet farmers planted local varieties and 36.9% of smallholder maize farmers produced DK 8031. The study also revealed that IK-based drought prediction and monitoring (14%), late planting of cereal seeds (14%) and supplementary irrigation (13%) were popular drought adaptation strategies among agro-pastoralists.

4.10 Outcomes of CBA and IK Drought Adaptations

Results in Table 43 show that CBA and IK drought adaptations were popular strategies in Makueni County. It was found that majority, (50.2%) of the smallholder cereal farmers adopted CBA and IK adaptations to drought.

Table 43

CBA and IK Drought Adaptations

Outcome of CBA and IK Drought Adaptations Practiced	**No. of Respondents**	**%**
Increased yields	106	50.2
No change	82	38.7
Reduction in yields	24	11.1
Total	**212**	**100.0**

Majority of the farmers who adopted CBA and IK-based drought adaptations recorded an increase in cereal yields while 11.1% of the farmers recorded reduction in yields (Table 43). However, 38.7% of the cereal farmers recorded no change in cereal yields in the study area. The high percentage of farmers who practice CBA and IK cereal production with positive results is an indication of the significant role of CBA and IK techniques in managing food insecurity in the study area.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents discussions on rainfall and drought trends and projection in Makueni County. Discussion on influence of IOD on drought occurrence and effects of drought on cereal yields in Makueni County is also covered in this section. This section also discusses demographic characterization of the smallholder cereal farmers, CBA and IK drought adaptation strategies in Makueni County. This section also contains discussions on outcomes of CBA and IK drought adaptation strategies among smallholder cereal farmers in Makueni County. The discussions are based on the order of the study objectives.

5.2 Drought Occurrence and Trend in Makueni County

This section covers annual rainfall trend, seasonal rainfall trend, annual drought trend, seasonal drought trend and projection of drought in Makueni County. The section also covers the perceptions of the smallholder cereal farmers on occurrence and nature of drought in Makueni County.

5.2.1 Annual Rainfall Trend in Makueni County

This study established fluctuations in amount of rainfall from 1990 to 2020. The study found an even distribution, reliable, and effective nature of the short rains in OND, hence the main cropping season in Makueni County. Results of this study are in concurrence with those of a study done in Southern Ethiopia by Shibru *et al.* (2023) which revealed that high variability in rainfalls in Southern Ethiopia were exacerbated by rising temperatures experienced in the HoA. Further, the results of this study are in concurrence with those of a study done in Sudan by Yagoub *et al*. (2017) which established an association between increasing drought frequency with declining rainfall from 1961 to 2013.

5.2.2 Seasonal Rainfall Trend in Makueni County

This study found that OND season received more reliable and effective rainfall compared to MAM rainfall season in Makueni County. This study agrees with results of studies conducted in southeastern region of Kenya by Amukono (2016) and CGoM (2023a; 2023b) which established that OND which is the short rainfall season, is the main rainfall hence the main cropping season in the region. CGoM (2023a) also established that November is the peak rainfall month in OND season in Makueni County. Muia *et al.* (2024) also revealed existence of two rainfall seasons including MAM and OND in Makueni County.

5.2.3 Annual Drought Characterization in Makueni County

There were erratic, unpredictable and fluctuating rainfall patterns accompanied by 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts between 1990 and 2020. The study mirrors the results of a study conducted by Wang *et al.* (2023) which established that drought events were fewer in Southwest China before 1930s. However, the frequency of drought events increased in the region after 1930 whereby severe droughts were experienced from 1936 to 1937. In addition, South-western China experienced more severe droughts in 1962, 1963, 1967, 1987, 2009 and 2010. The severity of the 2009 and 2010 droughts had not been felt in the 120 years under study. Ayugi *et al*. (2022) also revealed that frequent and prolonged severe droughts were common in North Africa. This caused significant socioeconomic impacts and change in land use in the region rendering 70% of the land surface area a desert. Chivangulula *et al*. (2023) established that droughts accounted for 6% of total disasters globally where 7% of all economic loses were linked to the phenomenon. The study also established a high frequency of droughts in South Africa. This was indicated by a three to five-year return period from 1980 to 2007. Muia *et al.* (2024) also established a reduction in amount of rainfall in Makueni County between 1990 and 2020.

5.2.4 Seasonal Drought Trend in Makueni County

A high frequency of drought was experienced in Makueni County in MAM season compared to OND season. This study concurs with results of studies conducted in South Africa by Chivangulula *et al*. (2023) who established a high frequency of droughts that were indicated by a three to five-year return period in the region from 1980 to 2007. In addition, the study revealed an increase in frequency of droughts in South Africa which was accompanied by heat waves between 1970 and 2016. Ayugi *et al*. (2022) found that frequent, prolonged severe droughts are common in North Africa which cause significant socioeconomic impacts and change in land use in the region.

This study also agrees with results of a study conducted in IGAD region by Omay *et al.* (2023) which reported that various regions globally, including North-eastern USA, experience seasonal increase in frequency and a prolonged duration of drought. The study also revealed that prolonged seasonal drought episodes recur in East African region. This study also mirrors results of a study conducted in East Africa by Haile *et al.* (2019) which pointed out increasing frequency of seasonal droughts in the region thereby affecting crop production significantly. Results of this study concur with those of a study conducted in Kenya by Recha *et al*. (2016) who found a declining trend in rainfall amounts in the country from 1960.

5.2.5 Perceptions of Smallholder Farmers on Frequency of Drought

Majority of the smallholder farmers in Makueni County believe that near-normal droughts recur yearly while mild droughts recur every year and after every two years. Severe to extreme droughts were believed to be recurring after every four to five years. The perceptions of the smallholder cereal farmers in Makueni County mirror SPI results which established occurrence of 20 near-normal droughts, 5 episodes of mild droughts and 3 severe droughts, totaling to 28 drought episodes between 1990 and 2020. This study is in concurrence with results of a study done in Asia by Ullah *et al*. (2022) which found an increasing frequency of severe droughts in central and southern parts of the region since 1990s. The studies also linked the frequent drought events to changing climatic conditions which result in terrestrial and atmospheric warming.

5.2.6 Annual Drought Projection in Makueni County using ARIMA Models

This study projected an upward annual drought trend in Makueni County from 2024 to 2054. This implies frequent recurrence of droughts in Makueni County from 2024 to 2054. The projected increase in frequency of droughts is an indication of impending drought risk in the three decades spanning 2024 to 2054.

The results of the study are consistent with the results of a drought projection study conducted in central Asia and Africa by Jiang and Zhou (2023) and Ayugi *et al*. (2022). These studies projected increase in drought conditions in the regions due to the variability in atmospheric and oceanic circulations in the Indian Ocean. In addition, the results of this study mirror those a study conducted in South Asia by Ullah e*t al*. (2022) which projected an increase in frequency and magnitude of droughts in the region by mid-21st Century.

5.2.7 Seasonal Drought Projection in Makueni County using ARIMA Models

This study projected reduction in MAM seasonal rainfall amounts in Makueni County between 2024 and 2054. This implies a projected frequent recurrence of droughts in MAM season.

Therefore, the projected frequent droughts portent projected drought risk in MAM season in Makueni County. On the other hand, this study projected increase OND seasonal rainfall amount between 2024 and 2054. This implies a reduction in drought occurrence in Makueni County during the seasons. Therefore, projected reduced drought risk in Makueni County signifies the reliability of the short rainfall season in Makueni County. This makes the season a reliable cropping season. Therefore, intensive production of food crops is advisable for OND season in Makueni County.

Even though seasonal drought projection indicates an upward trend in MAM season and a downward trend in OND season from 2024 to 2054, climate forcing events including climate variability and change, atmospheric circulations and solar variability patterns may influence the actual trend of the projected seasonal drought events.

Results of the study are consistent with the results of a drought projection study conducted in Central Asia by Jiang and Zhou (2023) which projected significant reductions in seasonal rainfalls and increase in temperatures. This study revealed increasing drought trends in Central Asia where significant reduction in amount of soil moisture was also projected till the end of the 21st Century. The results of this study are consistent with those of studies conducted in Africa and the Indian Ocean region by Ayugi *et al*. (2022). Global Center on Adaptation (GCA) (2022) projected increase in frequency, duration and magnitude of droughts in Africa. The studies linked the droughts in Africa to varying precipitation patterns which are driven by atmospheric and oceanic circulations, and climate variability. Jiang and Zhou (2023) and Ullah e*t al*. (2022) projected increase in the frequency of droughts in Central and South Asia due to atmospheric circulations and circulations in the Indian Ocean.

5.3 Influence of Indian Ocean Dipole on Occurrence and Nature of Drought

This section covers the influence of IOD on occurrence of drought in Makueni County which includes multiple linear regression of EWIO IO SSTs and rainfall, SST trends in EWIO and EEIO, comparative SST trend in EWIO and EEIO and comparative influence of WIO and EEIO SSTs on occurrence of drought in Makueni County.

5.3.1 Multiple Linear Regression of EWIO IO SSTSs and Rainfall

The EWIO R^2 value of 0.580 is closer to 1, implying that 58% of the variance in the rainfall amount (dependent variable) is explained by IO SSTSs (predictor variables) in the linear regression. The IO SSTSs have a significant influence on occurrence of droughts in Makueni

County. The results indicate that a reduction in the value of SSTs in Block A and Block B in the Indian Ocean leads to a similar reduction in the amount of rainfall received in Makueni County. This study established positive coefficients in SSTs in EWIO both at 10^0S-50^0E and at 10^0N-70^0E which is an indication that as the value of SSTs (Predictor variables) increase, the amount of rainfall (drought indicators) which is the dependent variable, also increase. On the other hand, increase in the value of SSTs lead to a similar increase in amount of rainfall in Makueni County. Therefore, increasing SSTs in the Indian Ocean results in increase in amount of rainfall and events while a reduction in SSTs result deficit or low amount of rainfall which may be accompanied by drought events in Makueni County. High SSTs in the Indian Ocean resulted in higher-than-normal amounts of rainfalls in 1997 and 1998 which was marked as an El Nino event. Further, higher-than normal SSTs in the Indian Ocean resulted in higher rainfall amounts in 2010, 2015 and 2016. However, low SSTs resulted in droughts in 1996, 2000 and 2004.

The results of this study are supported by results of studies conducted in East Africa and WIO region by An *et al.* (2023), Funk *et al.* (2018), Liu *et al.* (2023), Palmer *et al.* (2023), Sagero *et al.* (2018) and Uhe *et al.* (2018) which established that IOD is the principal driver of precipitation hence droughts and climate variability over the Indian Ocean and the East African region. Liu *et al.* (2023) established IOD-related weak warming in WIO during positive IOD events. An *et al.* (2023) also found that a gradual development of IOD is caused by stochastic forcing such as weather noise, internal feedback processes and external drivers thereby resulting in warming conditions in East African region. Further, results of this study agree with those of a study which was conducted by Koesuma *et al.* (2021) which found that IOD influenced the frequency and trends of drought in the Indian Ocean and East Africa in the past few decades. In addition, it was established that 50% and 65% of MAM and OND seasonal rainfalls were linked to the variation in Indian Ocean SSTs (Omondi *et al*., 2013). Palmer *et al.* (2023) also argued that short rains in OND season are projected to experience more rainfall compared to the projected depressed rainfall conditions in MAM. The study also revealed that IOD significantly influences occurrence, magnitude and duration of rainfall hence droughts in East Africa.

5.3.2 SST Trend in EWIO

This study established a positive relationship between EWIO locations at 10^0S-50^0E and at 10^0N-70^0E. The positive relationship is indicated by a similarity in the fluctuating patterns of SSTs in the EWIO. The results indicate that a rise in SST at 10^0N-70^0E is accompanied by a similar rise in SST at 10^0N-70^0E in the EWIO. Higher SSTs were experienced at 10^0N-70^0E, compared to 10^0S-50^0E. The highest SST value at 10^0N-70^0E was 29.4^0C while the lowest SST value was 28.5^0C. However, 27.5^0C and 26.5^0C were the highest and lowest SSTs at 10^0S-50^0E, respectively. This study is in agreement with those of a study conducted in EWIO by Liao and Wang (2021) which found that warming in EWIO occurs in boreal autumn and decays fast in spring of the succeeding year. The study revealed that maximum warming in EWIO occurs in January. Sharma *et al*. (2023) pointed out that, even though EWIO is comparatively cooler than EEIO, warming conditions in EWIO are associated with an expanding eastern basin warm pool which enhances convection and hence a regional atmospheric flow including Walker and Hadley circulations. The study also revealed that warming in EWIO is also associated with advection warming of the Pacific Ocean. The study also associated warming in EWIO with ENSO teleconnection, deepening of the thermocline driven by Rossby waves and evaporating dumping driven by a reduction in speed of wind which is linked to anomalous easterlies operating in central Indian Ocean.

5.3.3 Multiple Linear Regression Modelling of SST in EEIO

The R^2 value of 0.674 is closer to 1, implying that 67.4% of the variance in the rainfall amount in Makueni County is explained by IO SSTSs in EEIO. The ANOVA indicates that the p-value is 0.000 which is less than 0.05. Therefore, the results are significant at 95% confidence interval (5% level of significance).

The SSTs at 0^0-110^0E p-value is 0.011 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 0^0-110^0E is a statistically significant variable. This implies that changes in SSTs are associated with changes in drought occurrence in Makueni County.

The SSTs at 10^0S-90^0E has a p-value of 0.000 which is less than the significance level of 0.05. This indicates a non-zero correlation between the variables, therefore, worthwhile to be included in the regression model. This indicates that SST at 10^0S-90^0E, is a statistically significant variable. This implies that changes in SSTs are associated with changes in drought occurrence in Makueni County.

Positive coefficients in both SST at 0^0-110^0E and 10^0S-90^0E are indications that as the value of SSTs (Predictor variables) increases, the means of rainfall (drought indicators) which is the dependent variable, also increases.

This study corroborates results of a study conducted in Indian Ocean by Khan *et al.* (2021), Ng *et al*. (2018) and Goswami (2023) which established that EEIO experiences warming conditions whose effects are significant in surrounding regions. Mohapatra *et al*. (2020) also established a warming trend in EEIO after 1950s. In addition, Effy *et al.* (2020), Khan *et al.* (2021) and Mohapatra *et al*. (2020) indicated that EEIO experiences comparatively higher temperatures hence warmer conditions than WIO.

5.3.4 SST Trend in EEIO

This study revealed existence of a positive relationship between EEIO locations at 0^0-110^0E and at 10^0S-90^0E. The positive relationship is shown by nearly similar fluctuating patterns of SSTs at 0-110^0C latitude-longitude and at 10^0S-90^0E in the EEIO. The results indicate that a rise in SST at 0^0-110^0E is accompanied by a similar rise in SST at 10^0S-90^0E in the EEIO. However, the magnitude of the temperatures at the two locations varied. This study found a rise in SST at 0^0-110^0E in 1997 which peaked in 1998 at 29.9^0C. The results show that 0^0-110^0E experienced comparatively higher SSTs which peaked at 29.9^0C while the lowest SST was 28.6^0C. On the other hand, comparatively lower SSTs were experienced at 10^0S-90^0E whereby the highest value in SSTs was 28.4^0C while the lowest SST was 27.5^0C. However, the results indicate that the highest SSTs were experienced in 1997 and 1998. However, the results revealed that the lowest SSTs which reached a low of 27.5^0C were experienced at 10^0S-90^0E in 1993, 1994, 2017 and 2018.

This study corroborates results of a study conducted in Indian Ocean by Goswami (2023) which established that EEIO is one of the warmest regions within the Indian Ocean known for monotonous warming. The study associated the warming trend in EEIO to easterly winds and nocturnal winds in the western coast of Sumatra. Ng *et al.* (2018) established that EEIO experiences IOD-like warming trend in the tropical Indian Ocean. The study associated warming in the region to weakened Walker circulations.

5.3.5 Comparative SST Trend in EWIO and EEIO

This study established that EEIO experienced comparatively higher SSTs than EWIO. The highest and lowest SSTs at 0^0-110^0E in the EEIO were 29.9^0C and 28.6^0C, respectively. However, the highest and lowest SSTs at 10^0N-70^0E in the EWIO were 29.4^0C and 28.5^0C, respectively. Even though this study undertook a comparative analysis of the SSTs in the EWIO and EEIO, the cause of the variation in SSTs between the two points has not been explained.

Results of this study concur with those of a study conducted in WIO by Effy *et al.* (2020) which established that the WIO is comparatively cooler than EEIO. The study linked the warmer conditions in EEIO to the higher SST conditions which are mostly above 27.5^{0}C warming threshold for deep convection in the tropical Oceans. It also linked the warm EEIO conditions to existence of a warm pool in the Indian Ocean. These results are also in agreement with those of a study conducted in EEIO by Mohapatra *et al.* (2020) which established a warming trend in EEIO after 1950s. The study associated the warming conditions in EEIO to multidecadal variability and wind forcing. Khan *et al.* (2021) associated warming conditions in EEIO to a strong convection in the EEIO which were accompanied by SSTs anomaly from east to west thereby driving a series of Kelvin waves which deepened the thermocline in EEIO, hence the warming conditions in 2016 and 2017 in the region.

5.3.6 Comparative Influence of EWIO and EEIO SSTs on Occurrence of Drought

This study established that the relationship between IO SSTSs in EWIO and rainfall in Makueni County returned R^2 value of 0.580, which is closer to 1. This implies that 58% of the variance in the rainfall amount (dependent variable), hence drought in Makueni County is explained by IO SSTSs in EWIO in the linear regression. This study also found that the relationship between IO SSTSs indicated R^2 value of 0.674, which is closer to 1. This implies that 67.4% of the variance in the rainfall amount (dependent variable), hence drought in Makueni County is explained by IO SSTSs in EEIO in the linear regression. Therefore, IO SSTSs in EEIO have a more significant effect on occurrence of drought in Makueni County compared to IO SSTSs in EWIO. The lower influence of IO SSTSs in the EWIO is linked to the lower temperatures experienced in EWIO compared to EEIO.

Results of this study are supported by those of studies conducted in WIO and EEIO by Effy *et al.* (2020), Khan *et al.* (2021) and Mohapatra *et al.* (2020) which revealed that WIO is comparatively cooler than EEIO whereby the latter experiences a warming trend. The warming trend in EEIO influences rainfall patterns and occurrence of drought around the East Coast of Africa and the surrounding regions.

5.4 Effects of Drought on Cereal Yields in Makueni County

This section covers the annual cereal yields, cereal production trends, correlation of drought and cereal yields, effect of drought on cereal yields and effect of drought on livelihoods of smallholder cereal farmers in Makueni County.

5.4.1 Annual Cereal Yields

Most of the smallholder farmers produced 1 to 10 bags of sorghum and finger millet in Makueni County. However, majority of the smallholder farmers produced 1 to 10 bags of maize annually. These results are consistent with results of a study conducted by Fiwa *et al.* (2015) on crop production in Malawi which revealed that annual sorghum, millet and maize yields were low at 0.716 tha^{-1}, 0.809 tha^{-1} and 1.593 tha^{-1}, respectively.

5.4.2 Cereal Production Trends

A significant fluctuation in sorghum, finger millet and maize yields was recorded in Makueni County between 1990 and 2020. These fluctuations in cereal yields were associated with frequent droughts in Makueni County. Results of this study corroborate those of as study conducted by Odeph *et al.* (2020) which revealed that approximately 30.73 MMT of finger millet is produced annually globally where fluctuation in acreage was recorded. The results of this study also corroborate those of as study conducted by Abraha *et al*. (2015) and Njagi *et al.* (2019) which revealed that ASALs have the potential to produce between 1.5 and 5.0 tha^{-1}. However, Muui *et al*. (2013) reported low sorghum yields at 0.85 tha-^{1,} in Africa. USDA (2016) reported fluctuations whereby annual production was approximately 24.3 MMT. The results of this study also corroborate those of as study conducted in Ethiopia by Belete (2020) who established that Ethiopia yielded 3.06 tha^{-1} of maize despite a high potential ranging from 7.0 to 12.0 $tha^{-1,}$ annually.

5.4.3 Correlation of Drought and Cereal Yields

There is a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, $r(29) = .699$, $p<0.01$. Existence of a strong positive correlation between rainfall and sorghum yields is an indication that reduction in amount of rainfall, leads to reduction in sorghum yields in Makueni County and vice versa. There is a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, $r(29) = .359$, $p<0.01$. The weak positive correlation between rainfall and finger millet yields shows that a reduction in amount of rainfall which depicts drought, leads to a reduction in finger millet yields in Makueni County. On the other hand, an increase in amount of rainfall leads to an increase in finger millet yields in Makueni County. There is a significant, weak, positive correlation between rainfall and maize yields in Makueni County, $r(29) = .346$, $p<0.01$. Existence of a weak positive correlation between rainfall and maize yields shows that increase in amount of rainfall leads to an increase in maize yields in Makueni County and vice versa.

The positive correlation between rainfall and cereal yields in Makueni County shows that drought events which are indicated by deficit in rainfall, usually below the statistical means received in a given geographical area in a season or a year, significantly affect cereal yields. Fluctuations in cereal yields are consistent with the episodes of near-normal droughts which occurred in 1992 to 1996, 1999 to 2002, 2007, 2008 and 2011 to 2016. Fluctuations in rainfall amounts are also consistent with the occurrence of mild droughts in 2000, 2009 and 2017 and severe droughts which were experienced in Makueni County in 2004 and 2005. The fluctuations in rainfall amounts were associated with fluctuations in sorghum, finger millet and maize yields in Makueni County over the same period. Even though 1998 had significantly high rainfall from the El Niño event, cereal yields were low.

Results of this study corroborate the results of a study conducted in United States of America (USA) by Ortiz-Bobea *et al*. (2019) who established that drought determines cereal yields. The study revealed a 12% decline in cereal yields at a 20% drop in soil moisture in USA. Msongaleli *et al*. (2013) also associated the low cereal yields with frequent and severe droughts in Africa. Omoyo *et al*. (2015) established that maize growing season is also affected by onset and period of droughts and cessation of the phenomenon thereby influencing fluctuations in yields. Results of this study corroborate those of a study which was conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly impacted socioeconomic activities from 1991 to 1992. The study established that up-to 20 million people were affected due to drought-related food shortage.

5.4.4 Effect of Drought on Cereal Yields

Majority of the smallholder cereal farmers recorded a reduction in cereal yields during drought periods. The high frequency of droughts in Makueni County indicated by 20 near-normal drought episodes from 1990 to 2020, affected cereal production and yields significantly. The effect of drought on cereal yields in Makueni County is shown by low cereal yields whereby majority of the cereal farmers produced between 1 to 10 bags of sorghum. In addition, effect of drought is also shown by the small farm sizes ranging from 0.1 to 0.5 ha used for cereal production by majority of the smallholder cereal farmers. The use of small hectarage for cereal production in Makueni County is a precursor to low yields; a situation magnified by frequent droughts in the region. Even though the agroecological conditions in Makueni County favour DT cereal production, majority of the cereal farmers reported low cereal produce ranging between 1 and 10 bags of maize annually in Makueni County, hence a key challenge to food security in the region. A high frequency of near-normal droughts results in adverse soil conditions and limited soil moisture thereby limiting cereal production. The results of this study support the point that frequent mild droughts exacerbate the effects of the phenomenon on cereal production in ASALs (Hadebe *et al*., 2017; Mundia *et al*., 2019; NEMA, 2019).

Results of this study corroborate the results of a study conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly affect crop production and yields in the region where food insecurity and malnutrition were recorded. Further, Ayugi *et al*. (2022) established widespread drought episodes in East Africa where the events were experienced in 1998, 2000, 2005/2006, 2007, 2008, 2011 and 2016. The study established occurrence of multi-year droughts in 2005/2006 which affected the rainfed agricultural activities of majority of the population hence food security in East Africa. Ayugi *et al*. (2022) revealed that droughts significantly affect maize production due to reduced soil water. The low yields are also corroborated by Mbinda *et al*. (2021) who decried the low yields of finger millet in ASALs in Kenya which is approximately 0.5 tha^{-1} despite the high yield potential of 2.5 tha^{-1}. The low finger millet yields were associated with the frequent droughts in ASALs in Kenya.

5.4.5 Effect of Drought on Livelihoods of Smallholder Cereal Farmers

This study established a high frequency of droughts in Makueni County, which indicated 20 near-normal droughts, 5 mild drought episodes and 3 severe droughts between 1990 and 2020. Consequently, the frequent droughts affected cereal production and yields significantly in the region. The negative effect of drought on cereal yields in Makueni County is indicated by low cereal yields. Majority, (43%) of the cereal farmers produced between 1 to 10 bags of sorghum. In addition, the negative effect of drought is signified by small farm sizes ranging from 0.1 to 0.5 ha of land that was recorded by majority, 32.9%, 30.2% and 24.4% of the smallholder sorghum, finger millet and maize farmers, respectively. Low cereal yields that were associated with frequent droughts were recorded by smallholder cereal farmers. This affected livelihoods and income levels thereby increasing the vulnerability of the farmers in Makueni County. Further, low cereal yield levels recorded from the small farm sizes which were adopted as a drought adaptation strategy, affected production levels and income for the farmers, thereby increasing the level of vulnerability in Makueni County.

Results of this study corroborate those of a study conducted in Central America by Harvey *et al.* (2018) who found that drought results in reduction in crop production consequently resulting in food insecurity. Food insecurity affects the livelihoods of crop farmers whereby limited food leads to malnutrition and loss of investments in agriculture. Results of this study mirror those of studies conducted in South Africa by Zenda (2024) which established that drought significantly affects livelihoods of cereal farmers due to reduction in water for rain-fed agriculture whereby 60% is used in agriculture. The study established that reduction in water limits crop production thereby resulting in loss of investment and business opportunity.

5.5 Socioeconomic Characteristics of the Smallholder Cereal Farmers in Makueni County

This section covers socioeconomic characteristics of the smallholder cereal farmers in Makueni County which include gender, age, level of education and occupation of the smallholder cereal farmers in Makueni County. This section also covers sizes of the farms used by smallholder cereal farmers for cereal production in Makueni County.

5.5.1 Questionnaire Response Rate

A total of two hundred and twenty-five (225) smallholder cereal farmers participated in this study, though only two hundred and twelve (212) which is 94.2%, returned the questionnaires. This implies a high questionnaire return rate in Makueni County.

5.5.2 Gender of the Smallholder Cereal Farmers

Majority, (53%) of the household heads were males while 47% were females. The study found that smallholder cereal farming in Makueni County is dominated by males. The large number of males in the smallholder farming was attributed to the land tenure systems and traditional practices that favour males as the traditional land owners in the area of study and economic conditions. These results are consistent with results of studies conducted among smallholder crop farmers in Malawi (Fiwa *et al.*, 2015), Cape Province and Limpopo Province in South Africa (Koshe, 2022) which found that majority (92%) and (69.1%), respectively, were males. These results are also consistent with results of studies conducted among smallholder crop farmers in Madagascar, Mozambique and Kenya by Fitawek (2022) which found that majority, (86.5%) of the farmers who invested in large-scale agriculture were males.

5.5.3 Age of the Smallholder Cereal Farmers

Most, (40%) of the household heads were between 36 and 53 years old, 8% were 18 to 35 years old, 24% were 55 to 71 years old while 8% were above 71 years old. This implies that cereal farming is more popular among the advanced members of the society compared to the youthful cereal farmers. These results are consistent with results of a study on crop production in Malawi by Fiwa *et al.* (2015) which established that majority, (75%) of the smallholder farmers were in the age group 30-55 years. Fitawek (2022) also found that majority, (58.5%) of the farmers in Madagascar, Mozambique and Kenya who invested in large-scale agriculture were aged between 30 and 49 years. However, the results of the study contrast those of studies conducted in Cape and Limpopo Provinces of South Africa by Koshe (2022) which revealed that majority, (36.1%) of the farmers were above 65 years old. However, Murugani (2016) revealed that majority, (62.5%) males and (42.9%) females of the farmers in Limpopo Province in South Africa were above 60 years old.

5.5.4 Level of Education of the Smallholder Cereal Farmers

Most, (37.3%) of the smallholder cereal farmers had primary education while 34.9% had secondary education. This implies that primary and secondary education undertaken by a high population of smallholder farmers may have significantly contributed to the adoption of drought-resilient cereals such as sorghum, millet and maize. These results are consistent with results of a study on crop production in Malawi, Mqanduli, Eastern Cape Province and Limpopo Provinces of South Africa by Fiwa *et al.* (2015 and Mhambi (2022) which found that majority of the smallholder farmers, had primary education. Fitawek (2022) also revealed that majority, (56.8%) of the farmers in Madagascar, Mozambique and Kenya who invested in large-scale agriculture had primary education.

5.5.5 Occupation of the Smallholder Cereal Farmers

Majority, (66%) of the respondents are smallholder cereal farmers, 15% are employed in the private sector, 11% are traders and 8% are agro-pastoralists. This implies that smallholder cereal production is a very popular economic activity in the study area. These results are consistent with results of a study on crop production in Malawi by Fiwa *et al.* (2015) and in Mpumalanga region and Limpopo Province in South Africa by Hlatshwayo *et al.* (2023) which established that most of the farmers were crop producers.

5.5.6 Farm Size in Hectares

Most of the smallholder cereal farmers in Makueni County used small farm sizes (0.1 to 0.5 ha) for sorghum, finger millet and maize production. This implies that a large number of smallholder cereal farmers own small farms or that the production of the crop experiences significant challenges that discourage its production in the ASAL area. The small farm sizes for the production of sorghum, millet and maize significantly affect production of the cereals hence food security in the study area. These results are consistent with results of a study on crop production in Malawi by Fiwa *et al.* (2015) which argued that the most common size of smallholder farm sizes was 1.88 ha. Fitawek (2022) also found that majority (66.7%) of the farmers in Madagascar, Mozambique and Kenya who invested in large-scale agriculture had less than 1 ha of farmland while 25.2% had between 1 to 3 ha of farmland.

5.6 CBA and IK Drought Adaptations Practiced by Cereal Farmers

This section contains the CBA and IK drought adaptations practiced by the smallholder cereal farners in Makueni County based on their gender, age and level of education

5.6.1 CBA and IK Drought Adaptations by Gender of the Smallholder Farmers

More females than men in Makueni County adapted to droughts through IK drought prediction and monitoring, late planting of cereal seeds, IK-based seed preservation, IK-based seed storage, supplementary irrigation and early planting of seeds. More males than females in Makueni County adapted to droughts through planting early maturing seeds, planting drought resistant cereal seeds and use of improved seeds. Results of the study were consistent with the results of a study conducted in Vhembe District in South Africa and rural areas of Eswatini by Phoobane and Masinde (2023) and Tfwala *et al*. (2023), respectively, which established that use of IK was very popular whereby majority of the farmers use IK techniques in drought prediction and early drought warning systems in the region. In addition, Habakubaho *et al.* (2023) found that adoption of IK weather projection and drought prediction techniques such as observing the colour of the sky and clouds, day-time variation in temperatures, occurrence of lightning and thunderstorm and monitoring the patterns, strength and direction of winds in drought-prone area of Nyagatare and

Gatsibo Districts of Rwanda were also practiced. IK-based drought prediction and monitoring influenced the time of land preparation and planting in Limpopo Province, South Africa (Rankoana, 2021). The techniques such as mulching were used in soil conservation in drought-prone area of Nyagatare and Gatsibo Districts of Rwanda and Uganda (Habakubaho *et al.*, 2023; Mfitumukiza *et al.*, 2020).

5.6.2 CBA and IK Drought Adaptations by Age of the Smallholder Farmers

Majority of the smallholder cereal farmers who adapted to droughts were below 53 years old. The study also revealed that the most popular drought adaptation strategies included increasing farm size, use of farm manure, IK-based bio-control of weeds, use of improved seeds and planting early maturing cereal seeds. It is not clear why majority of the heads of households in 36 to 53 years age bracket practiced more drought adaptation strategies compared to the other age brackets.

Results of the study are consistent with the results of a study in Africa by Ripoll *et al*. (2017) which revealed that young people are using modern techniques in rural development whereby cereal production, agri-business and agricultural research play a key role despite the financial and systems-based challenges. Asravor *et al*. (2023) established that youth farm operators were more efficient in agricultural production and decision making compared to middle-aged and aged farmers in Ghana. The results of the study are also consistent with the results of a study in Guji Zone in Ethiopia by Ayele *et al*. (2021) which established that cereal commercialization was influenced by the age of the smallholder farmers.

5.6.3 CBA and IK Drought Adaptations by Level of Education of the Smallhoder Farmers

Most of the cereal farmers who practiced drought adaptations in Makueni County had primary education. The results also revealed that late planting of seeds and IK-based drought prediction and monitoring were practiced by majority of the cereal farmers with primary education. Results of the study are also supported by results of a study conducted in Madagascar, Mozambique and Kenya by Fitawek (2022) which found that majority, (56.8%) of the farmers who invested in large-scale agriculture had primary education. These results are also consistent with results of a study on crop production in Malawi by Fiwa *et al.* (2015) which found that most of the stallholder farmers had primary education (lower and upper primary). Murugani (2016) also found that most of the farmers in Limpopo Province in South Africa had primary education.

5.6.4 Most Popular Drought Adaptation Strategies

This study revealed that IK-based drought prediction and monitoring, late planting of cereal seeds and supplementary irrigation are popular drought strategies among agro-pastoralists in Makueni County. These results are consistent with results of a study on crop production in Malawi (Fiwa *et al.*, 2015) and Limpopo Province in South Africa (Hlatshwayo *et al.*, 2023) which established that most of the farmers were crop producers.

The following agronomic adaptations were the most popular among the female cereal farmers as indicated: mono-cropping, timely weeding and intercropping with cereals. The results also show that intercropping with legumes, improvement in land tillage, improving seed spacing and practicing agro-forestry were the most popular agronomic adaptations among male cereal farmers in the study area. These results are consistent with results of a study on crop production in Mpumalanga in Malawi by National Statistics Office (NSO) (2012) which established that majority, (75%) of the households practicing small-scale farming were males. Fitawek (2022) also found that majority, (86.5%) of the farmers in Madagascar, Mozambique and Kenya who invested in large-scale agriculture were males. This indicates that agro-practices by the farming households were influenced, to a large extent, by the male household heads. This is an indication that traditional practices that favour male dominance on households and land ownership still influence crop production in SSA.

The most popular drought adaptation agronomic practices among cereal farmers in 36 to 53 years age bracket include intercropping with cereals, timely application of organic manure, timely weeding and improving cereal seed spacing. The results of this study concur with those of a study done in Uganda by Mfitumukiza *et al.* (2020) which pointed out that agronomic drought adaptations such as mulching, indigenous agroforestry, change of planting time, crop rotation, digging of trenches, application of organic manure and construction of granaries were common and were practiced by 26%, 22%, 20%, 15%, 10%, 4% and 3% of the smallholder farmers, respectively. Further, the results of this study concur with those of a study done in Kenya by Gebre *et al.* (2023) which established that most of the farmers adopted the following popular drought adaptation strategies: DT varieties of crops (55%), crops diversification (34%) and adoption of early maturing crops (22%).

Mono-cropping, improving land tillage and improving seed spacing were the most common agronomic adaptations to drought among cereal farmers with primary education. The results also indicate that timely application of organic manure, improving seed spacing and timely weeding were the most popular agronomic drought adaptation practices among cereal farmers with secondary education. Results of the study were consistent with the results of a study conducted in central Vietnam by Van Huynh (2020) which found that appropriate time for land preparation and planting were influenced by IK-weather forecasting techniques which were practiced by the Xo Dang people. In addition, Rankoana (2021) found that small-scale farmers in Limpopo Province, South Africa adopted IK techniques in preparation of farmlands, varying crop planting periods and changing of crops to ensure timely and suitability in agricultural production. Mfitumukiza *et al.* (2020) also established that IK techniques of application of organic manure were used to improve soil nutrient level hence crop yields in Uganda.

5.7 Agronomic and Technical Drought Adaptation Strategies

This section contains agronomic, technical and indigenous drought adaptation strategies practiced by the smallholder cereal farmers in Makueni County.

5.7.1 Agronomic Adaptations

Intercropping cereals, timely application of organic manure, timely weeding and intercropping cereals with legumes were the most common agronomic practices undertaken by the cereal farmers in the following percentages 73%, 70%, 69% and 69%, respectively. The results also show that majority of the cereal farmers (68%) and (65%) practice agro-forestry and improving seed spacing, respectively.

The results of a survey conducted on smallholder cereal farmers in Makueni County indicated that majority, (64%) of the smallholder cereal farmers adopted timely weeding as a measure of adapting to droughts and to limit the competition for soil moisture, minerals and space between the cereal crops and weeds during drought in Makueni County. Meanwhile, 60% and 52% of the smallholder cereal farmers improved seed spacing and timely application of organic manure and cow-dung, respectively. In addition, the study established that 36% of the farmers intercropped cereals with pulses. The study also established that 26% of the smallholder cereal farmers adopted agro-forestry to adapt to droughts and to improve yields. Use of traditional drought prediction and monitoring techniques, variation in farm size, variation in planting time and adoption of drought resilient cereal seeds are important measures in adapting to drought in the study area.

Results of this study are consistent with the results of a study conducted in Uganda by Mfitumukiza *et al.* (2020) which found that IK techniques including application of organic manure were used to improve soil nutrient level hence crop yields. Results of this study are also consistent with the results of studies conducted in ASALs in West Africa and South Africa by Carr *et al* (2022) and Hawkins *et al*. (2022) who argued that adoption of DT cereal cultivars improves drought adaptation and cereal yields. Carr *et al*. (2022) also detailed that adoption of short season cereal cultivars, adoption of local cereal landraces and matching cereal seeds with the relevant AEZs improved drought adaptations and cereal yields. Carr's study also determined that varying cereal sowing dates, effective farm tillage practices, crop management and improving water use resulted in improved cereal yields in drought-prone regions in West Africa. Further, Kahinda *et al*. (2021) found that adoption of soil management practices is a commendable drought adaptation strategy in Sub-Saharan Africa. Furthermore, Pili and Ncube (2022) revealed that improved adoption of farm inputs, seeds and implements resulted in improved drought adaptation in Overberg and West Coast Districts, Western Cape, South Africa.

5.7.2 Technical Adaptations to Drought

This study established that 66% of the farmers planted early while 16% planted late based on drought prediction whereas 44% of the farmers adopted supplementary irrigation. Besides, the study revealed that irrigation farming was practiced due to the unreliability of the MAM seasonal rainfall while the OND seasonal rainfall is the major rainfall season with reliable rainfall. In addition, the study established that irrigation farming is undertaken along perennial rivers such as River Thange and River Kaiti.

This study established that irrigation farming is encouraged in the study area due to availability of spring water from Kiboko Springs, Simba Springs, Makindu Springs, Kibwezi Springs and Thange Springs near Mtito Andei. In addition, the study established that 48%, 40% and 36% of the farmers planted drought resistant cereal seeds, planted early maturing cereal seeds and used improved cereal seed varieties, respectively. Further, the study revealed that capacity building and provision of timely climate information was done by KMD.

Results of this study are consistent with the results of studies conducted in ASALs in the HoA and in South Africa by FAO (2022) and Hawkins *et al*. (2022) which revealed that adoption of modern techniques in land and water use in irrigation efficiency resulted in improvement in food security in the regions. In addition, Szaboova (2023) established that smallholder rural farmers adapted to droughts in the Near-East and North Africa through diversification of the farming systems which include diversifying crops and livestock. Kahinda *et al*. (2021) found that improvement and adoption of drought early warning systems are commendable drought adaptation strategies in Sub-Saharan Africa.

5.7.3 Indigenous Drought Adaptation Practices

This study revealed that 55%, 41%, 37%, 36% and 32% of the cereal farmers used farm manure to improve soil quality and to conserve soil, adopted traditional methods in bio-control of pests and diseases, used traditional seed storage methods, used traditional seed preservation methods and adopted traditional drought prediction and monitoring methods, respectively.

The results of this study are supported by a study done in China by Xu *et al.* (2017) which pointed out that bio-technological drought adaptation measures ensured bio-control of pests and diseases hence increase in cereal yields. Results of this study are also supported by a study conducted in Africa by Rurinda *et al*. (2020) which revealed that application of farm manure resulted in improvement in cereal yields.

5.7.4 Indigenous Drought Prediction Techniques

This study revealed that 32% of the cereal farmers adopted traditional drought prediction and monitoring methods which influenced cereal seed planting time whereby 66% of the smallholder farmers planted early while 16% planted late. The results of key informant interview conducted in the study area also revealed that the farmers adapted to droughts by predicting the weather conditions through observing conditions of the sky, coloration, and number of tree leaves.

Results of this study are in agreement with the results of a study conducted in drought-prone area of Vhembe District in South Africa and Nyagatare and Gatsibo Districts of Rwanda by Phoobane and Masinde (2023) and Habakubaho *et al.* (2023) which found that adoption of IK weather projection and drought prediction techniques such as observing the colour of the sky and clouds, day-time variation in temperatures, occurrence of lightning and thunderstorm and monitoring patterns, strength and direction of winds resulted in timely land preparation and planting of cereal seeds. In addition, Van Huynh (2020) found that the Xo Dang people of central Vietnam used IK weather projection techniques by monitoring behavioral patterns of animals such as birds whereby the movement of the “Hoang Yến” birds (*Serinus canaria*) from the sea to the mountains signify impending windstorms while croaking of frogs signify impending rainfall. In addition, the Dragonflies flight patterns also indicate impending rainfall. Further, the disappearance of earthworms from the ground signifies impending drought events.

5.7.5 Indigenous Land Preparation Methods

This study established that 43.1%, 12.4%, 5.3% and 0.9% of the smallholder cereal farmers practice hand tilling, ox ploughing, bush clearing and seed broadcasting, respectively. Timely weeding and mulching were also identified as key drought adaptation measures in the study area. The CBA agricultural practices in Makueni County are adopted by the farmers due to existence of IK sources, communal agricultural approaches and minimal agricultural investment in the region.

Results of this study are in concurrence with the results of a study conducted in Limpopo Province, South Africa by Rankoana (2021) which found that small-scale farmers adopted IK techniques in preparation of farmlands. Zougmoré *et al.* (2023) also found that soil and water management using the Zaï Pit technique was used for drought adaptation in the Sahel. Further, Habakubaho *et al.* (2023) and Mfitumukiza *et al.* (2020) found that IK soil conservation techniques such as mulching; were were used to conserve soil moisture and to improve soil management practices hence improvement in crop yields in drought-prone area of Nyagatare and Gatsibo Districts of Rwanda and Uganda.

5.7.6 Pest Control Strategies

This study found that intercropping is practiced by 62.7% while use of dogs to control pests and diseases is practiced by 30.7% of the smallholder cereal farmers in Makueni County. Meanwhile, agroforestry is practiced by 1.3%. It was also established that mixed farming was practiced by 0.9% of the farmers. Mixed farming was practiced to diversify agro-production and to limit yield loss besides bio-control of pests.

Results of this study concur with the results of a study conducted in Vhembe District in South Africa by Phoobane and Masinde (2023) which found that use of IK is a very popular drought adaptation strategy whereby 63.1% of the smallholder farmers use the technique in prediction of crop pests and diseases. In addition, Habakubaho *et al.* (2023) and Mfitumukiza *et al.* (2020) established that IK-based crop pest and disease control techniques were employed whereby the pesticides were locally manufactured in drought-prone area of Nyagatare and Gatsibo Districts of Rwanda and Uganda. Further, Mfitumukiza *et al.* (2020) revealed that IK-based pest control methods also include digging of trenches in Uganda.

This study found that agro-forestry involved planting Melia volkensii (*Mukau*) which is a fast-growing multi-purpose tree that produces high value timber and neem tree (*Mwarobaini*) which has traditional medicinal value, was also planted. The two species of trees are popular for agro-forestry and they are used for bio-control of pests in the study area. The trees are also popular due to their use of little water, shedding of leaves to reduce water intake and loss, deep roots for tapping water from the depths of soil and rocks and hard nature for production of valuable hard timber.

Results of this study corroborate the results of a study conducted in South Africa and Zimbabwe, Ghana and Kenya by Zvobgo *et al.* (2022) which established that farmers practiced agroforestry as a soil conservation and pest control technique. Zougmoré *et al.* (2023) found that practicing IK-based agroforestry and tailored shrub-based conservation agricultural techniques improve soil moisture conservation and management. The study also established that foliage nutrient establishment in the Sahel was also observed under the practices. In addition, Kalele *et al*. (2021) found that practicing agroforestry is a suitable bio-control and drought adaptation mechanism.

5.7.7 Mixed Cropping

This study established that smallholder cereal famers practiced mixed cropping of cereals with leguminous crops such as pigeon peas (*mbaazi*), green grams, and cow peas. The study also found that most farmers practiced intercropping whereby maize (*mbemba*) is intercropped with peas (*nzouu*), beans (*mboso*), cowpeas (*nthooko*) and chicken peas (*ndengu*). Some farmers also intercropped millet (*muvya*) or sorghum (*mwee*) with oranges (*masungwa*), mangoes (*maembe*) and paw paws (*mavavai*). The farmers observed that intercropping cereals with leguminous crops resulted in improvement in productivity.

Results of this study are consistent with those of a study conducted in central Vietnam by Van Huynh (2020) which found that intercropping was practiced as a key IK-based technique for drought adaptation by Xo Dang people. Further, Rankoana (2021) found that small-scale farmers in Limpopo Province in South Africa adopted crop diversification to minimize yield loss while improving adaptation to droughts in the region. Rankoana's study also found that the farmers changed crops to ensure suitable timing and agricultural production. In addition, ATLAS (2019) established that maize, sorghum and millet were key staple cereals which accounted for 30% of all foods in ASALs in Kenya.

5.7.8 CBA and IK Drought Adaptations

This study found that CBA and IK drought adaptations were popular strategies in Makueni County. It was found that majority (50.2%) of the smallholder cereal farmers who adopted CBA and IK adaptations to drought recorded an in increase in cereal yields while 11.1% of the farmers recorded reduction in yields. However, 38.7% of the cereal farmers recorded no change in cereal yields in the study area. The high percentage of farmers who practice CBA and IK cereal production with positive results is an indication of the significant role of CBA and IK techniques in managing food insecurity in the study area.

Results of this study are in concurrence with those of a study done by Qomariah *et al.* (2021) which established that a number of communities in Indonesia adopted CBA which is a community-led process in resolving the challenges of the community based on priority needs. Further, Mfitumukiza *et al.* (2020) found that adoption of CBA to droughts in Africa were suitable due to application of local knowledge, location specific solutions and prioritization of the challenges of the community. The study also pointed out that CBAs have significant environmental benefits and customary or communal representation resulting in successful implementation of the projects in the community.

5.8 Seed Preservation Methods

This study found that 19.1%, 17.3% and 15.6% of the farmers used smoking, granary and ash, respectively for seed preservation. The study also found that 2.2% and 0.4% of the farmers used gourds and honey, respectively to preserve seeds. The study established that smearing seeds with cow dung and hanging above fire places were useful measures in preservation of cereal seeds.

Results of this study agree with a study conducted in SSA by Nwaigwe (2019) which found that majority of the cereal farmers in the rural areas produced their own maize seeds. The study also established that underground pits, open pit methods and metal silos are used to preserve and store seeds. However, the rate of insect damage and destruction was noted to be high. Some seeds were treated with ash and stored in plastic containers or air-tight containers. Waithaka (2011) established that the following cereal seed preservation techniques were popular in Kenya: solar drying of maize, use of granaries and cribs, use of woven baskets and large gourds, and storage in earthen pots and lofts.

5.9 Types of Cereal Seeds

This section contains the various seeds of sorghum, finger millet and maize that are produced in Makueni County.

5.9.1 Sorghum Varieties

Local varieties of sorghum were more adaptable to droughts hence more popular in Makueni County. Gadam, Saredo and Serena were also produced in the study area. However, a large number, (51.1%) of the sorghum farmers were not aware of the sorghum varieties that they planted. Popularity of local sorghum landraces is linked to their autonomous adaptability to the ASAL conditions in Makueni County. Adoption of Gadam, Saredo and Serena was influenced by availability of the seeds and the ASAL conditions which favour production of DT cereals in Makueni County.

Results of this study corroborate those of studies conducted in Tigrayan regions of Northern Ethiopia by Wendmu *et al.* (2022) which established that farmers selected sorghum seeds in the pre-harvesting stage. The study also established that seed selection during harvesting stage was practiced by almost half of the sorghum farmers in Kunama and Tigrayan regions. The study established that farmers paid attention to seed size whereby a large seed size, large and long panicles, and early maturing seeds were preferred by sorghum farmers in Kunama and Tigrayan regions of northern Ethiopia.

Results of this study are also supported by those of a study conducted in Limpopo province in South Africa by Dunjana *et al.* (2022) which found that most of the farmers used traditional sorghum seeds which were stored for future planting due to low access to new seed varieties. The study also revealed that even though traditional and home stored sorghum seeds were popular, successive harvests tended to experience reduced seed quality and low yields. Andiku *et al.* (2022) established that a number of sorghum genotypes such as GBK 000955, GBK 034699, GBK 043040, GBK-051589, GBK 000445, GBK-051521 GBK 044111, GE/30/1/2013A, Sila and Epuripur were cultivated in East Africa. In addition, WFP (2018) revealed that a number of sorghum varieties such as the KARI MTAMA-1, Gadam, Serena, Seredo and Goose sorghum, were suitable for agroecologically stressed conditions such as ASALS in Kenya. Further, Okeyo *et al*. (2020) found that Serena, Seredo and Gadam sorghum seed varieties were very popular in Siaya County in Kenya. The study also established that local sorghum landraces such as Ochuti and Nyakabar seed varieties were common in the county thereby scoring the significant role of autonomous adaptability of local sorghum landraces to varied and adverse pedo-climatic conditions in the country.

5.9.2 Finger Millet Varieties

Majority of the finger millet farmers planted local varieties. Finger millet varieties including U15, KAT FM1 and PM1 were also planted in Makueni County. However, the study found that 59.1% of the farmers were not aware of the finger millet varieties that they planted making choice of successful seeds a challenge. The study also found that finger millet and pearl millet perform very well in the higher altitudes such as Emali and Mulala areas of Kibwezi sub-county; though bird attack is a major menace to their production.

Results of this study were consistent with the results of a study conducted in ASALs in Kenya by Onyango (2016) which determined that adoption of DT millet hybrid seeds leads to increase in yields. In addition, the study revealed that local landraces which are adaptable to local AEZs were useful in improving food security in ASALs in Kenya. The ASAL conditions in Kenya can support the production of many finger millet varieties including KAT/FM-1 (Oduori & Nungo, 2019) and U-15 (Onyango, 2016; Wafula *et al*., 2017). Adoption of these finger millet varieties increased popularity of the cereal in ASALs in Kenya where the crop is sometimes intercropped with drought-resilient legumes.

5.9.3 Maize Varieties

Majority of smallholder maize farmers produced DK 8031 and DUMA 43 varieties. Pioneer, Katumani and local maize landraces were also planted in the study area. Local landraces of maize that are planted in the study area included Sungura, Kishindo, Kikamba maize, Haraka, Panuah and Kinyanya. However, this study found that 26.7% of the maize farmers were not aware of the maize varieties that they planted making choice of successful seeds a challenge. Even though maize is produced all over the county, a large percentage of maize is produced in the higher altitude regions such as Emali and Mulala areas of Kibwezi West sub-County. The study also established that the farmers consistently plant maize annually with the hope of harvesting despite the fact that drought is frequent in the area. However, the produce is often harvested early while still green therefore limiting recording of yields and improvement in food security.

Results of this study agree with the results of a study conducted in ASALs in Kenya by WFP (2018) which found that Katumani composites and Makueni composites were suitable maize varieties for ASALs in Kenya. The results of the study are also in agreement with those of a study conducted by Obunyali *et al*. (2019) which found that adoption of drought tolerant varieties of maize such as TEGO hybrids for ASALs resulted in increase in yields which were recorded as higher than those of commercial hybrids and were ranging from 4.1 to 4.3 $Mgha^{-1}$ in ASALs in Kenya.

5.10 Source of Cereal Seeds

This section contains information on the sources of sorghum, finger millet and maize seeds.

5.10.1 Source of Sorghum Seeds.

Majority, (31.6%) of the smallholder cereal farmers source sorghum seeds from the local market while the family seed store accounts for 11.1% whereas MoA accounts for only 7.1% of sorghum seeds. This study also established that only 4.4% and 2.2% of the smallholder cereal farmers source seeds from KALRO and NGO/CBOs, respectively. However, only a small percentage of 0.4% of the farmers sources their seeds from EABL/KBL. The high percentage of cereal farmers sourcing cereal seeds from the local markets indicate the significant role played by local markets and family seed banks in the production of cereals in the study area.

Results of this study agree with those of studies conducted by Kiambi and Mugo (2016) who established that developing countries such as Kenya adopt informal and traditional seed system which is majorly dependent on seasonal harvests and availability of seeds in local markets. However, Chepng'etich (2013) revealed a significant rate of improvement of cereal seed varieties by KALRO where 40 sorghum cultivars have been developed. Kalele *et al.* (2021) also established that a number of the smallholder farmers adopted certified cereal seed varieties thereby improving access to DT and fast yielding cereal seeds which result in improvement in yields in ASALs in Kenya.

5.10.2 Source of Finger Millet Seeds.

This study found that 32.4% of the smallholder farmers source finger millet seeds from the local market while 7.1% source seeds from MoA. This study also established that KALRO, NGOSs/CBOs and EABL/KBL account for 4.9%, 3.6% and 0.9% of finger millet seeds, respectively. The high count of smallholder cereal farmers that access finger millet seeds from the local markets indicate the importance of availability of cereal seeds. In addition, traditionally preserved finger millet seeds also find their way into the local market thereby explaining the popularity of the local landraces in the region.

Results of this study concur with those of a study conducted in Oromia and Southern Nation Nationalities People Region in Ethiopia by Gebreyohannes *et al.* (2021) which found that the sources of finger millet included Bureau of Agriculture, exchange between farmers, local seed sources, research institutions, local markets and cooperatives. Mbinda *et al.* (2021) found that most smallholder farmers in Kisii and Western regions of Kenya were able to distinguish between traditional and hybrid seeds of finger millets though most farmers were unaware about the names of the seed varieties. The study also established that 61% of the farmers adopted local landraces of finger millet due to early maturity and their taste while an average of 59% of all the finger millet farmers in the regions adopting hybrid varieties. The study also found that most farmers in the two regions sourced their finger millet seeds from home stores comprising seeds from previous harvests.

5.10.3 Source of Maize Seeds.

This study established that local markets, MoA and family seed store account for 52.9%, 15.6% and 15.1% of sources of maize seeds, respectively. This study also found that KALRO, NGOs/CBOs and EABL/KBL account for 6.2%, 1.3% and 0.4% of sources of maize seeds, respectively.

The results of this study are consistent with the results of a study conducted in Mali and Ethiopia by Sissoko *et al.* (2019) and Wendmu *et al.* (2022), respectively, which found that drought adaptation included adoption of new sorghum seed varieties whose yields were significantly higher compared to traditional seeds. Results of this study agree with those of a study conducted in Kenya by Rutsaert *et al.* (2021) which established that a large number of maize farmers in Kenya accessed hybrid seeds from KALRO, NGOs and private seed companies. The study also found that local varieties were purchased from the local markets. Further, the study revealed that local varieties were planted in ASALs due to low awareness of the new varieties in the country and muted enthusiasm in their distribution to markets and to the farmers. Moreover, USAID-KAVES (2015) revealed that family seed stores and local markets played a significant role in provision of local landraces which are highly adaptable to drought conditions in ASAL regions.

5.11 Outcomes of Drought Adaptations

This section covers outcomes of the CBA and IK drought adaptations practiced in Makueni County.

5.11.1 Technical Adaptations and Sorghum Yields

Planting cereal seeds early (66.7%), application of farm manure (57.0%) and planting drought-resilient cereal seeds (44.7%) led to the highest sorghum produce between 1 to 10 bags in Makueni County. Planting seeds early (1.8%), planting short period seeds (1.8%), increasing farm size (1.8%) and using IK-based weed and pest control strategies (1.8%) resulted in above 31 bags of sorghum in Makueni County. The identified drought adaptation strategies are commendable in order to increase food production in Makueni County.

Results of this study agree with those of a study conducted in Nigeria by Onyeneke *et al*. (2019) which found that planting cereal seeds early, adopting new cereal varieties, adopting ecological pest management and adopting traditional and conservation land tillage practices result in improvement in yields. The study also indicated that organic carbon improvement result in improvement in cereal yields. Results of this study corroborate those of studies conducted in Ghana and ASALs in East Africa by Dumba *et al*. (2021) Julia (2015), Madege *et al*. (2017) and Radeny *et al*. (2019) which found that adopting early maturing and drought-resilient cereal varieties resulted in improvement in cereal yields. In addition, Rurinda *et al*. (2020) revealed that application of farm manure resulted in improvement in cereal yields.

5.11.2 Agronomic Drought Adaptations and Sorghum Yields

Timely weeding (61.4%), improving land tillage (56.1%), seed spacing (55.3%) and timely application of organic manure (54.4%); were the most popular drought adaptations which resulted in sorghum yields between 1 to 10 bags in Makueni County. Embracing the mentioned drought adaptation strategies by all sorghum farmers in Makueni County will result in improvement in yields and food security in the county.

Results of this study corroborate those of a study conducted in Nigeria by Onyeneke *et al*. (2019) which revealed that ecological pest management, traditional and conservation land tillage practices and organic carbon improvement result in improvement in cereal yields. FAO (2018) recommended sorghum seed spacing to be 30 to 45 centimetres (cm) in order to improve cereal production in Southern Africa. Madege *et al*. (2017) found that improvement in land tillage practices resulted in improvement in cereal yields in ASALs in East Africa. WFP (2018) also found that improving land tillage and spacing for seeds improved cereal yields in ASALs.

5.11.3 Technical Drought Adaptations and Finger Millet Yields

Majority of the smallholder farmers adopted planting seeds early (59.6%), application of farm manure (46.5%) and planting drought-resilient seeds (39.5%) which resulted in production of finger millet ranging between 1 to 10 bags.

Results of this study agree with those of a study conducted in South Asia by Aryal *et al.* (2021) which established that farmers in India, Nepal and Bangladesh adopted use of organic fertilizer in cereal production hence improvement in yields. Results of this study agree with those of studies conducted in ASALs in Pakistan (Khan *et al*., 2022), Western Nepal (Adhikari, 2018) and West Africa (Ogundeji & Okolie, 2022), respectively, which found that supplementary irrigation, adoption of early maturing cereal seeds and early drought warning improved drought-resilience and cereal yields. Use of farm manure also resulted in improvement in cereal yields in Africa (Rurinda *et al*., 2020).

5.11.4 Agronomic Drought Adaptations and Finger Millet Yields

Majority of the farmers practiced timely weeding (54.4%) and improving seed spacing (50.0%) which resulted in production of finger millet ranging from 1 to 10 bags in Makueni County.

Results of this study corroborate those of a study conducted in Malawi by FAO (2018) which revealed that pest and weed control results in control of diseases therefore improvement in cereal yields. A study in ASALs in Kenya by WFP (2018) found that improving land tillage and spacing for seeds improved cereal yields in ASALs. WFP recommended improvement in spacing for sorghum seeds in drylands to improve yields.

5.11.5 Technical Drought Adaptations and Maize Yields

Planting maize seeds early (48.5%), application of farm manure (39.2%), planting drought-resilient seeds (35.3%) and planting early maturing cereal seeds (30.4%) resulted in maize yields ranging from 1 to 10 bags in Makueni County. The results also indicated that application of farm manure (5.4%), planting seeds early (4.9), supplementary irrigation (3.9%) and IK-based bio-control of weeds (3.9%) resulted in production of above 31 bags of cereals.

Results in this study concur with those of a study conducted in Nigeria by Yakubu *et al*. (2021) which established that adoption of early maturing sorghum varieties resulted in improved yields. Dumba *et al.* (2021) established that planting early maturing cereal seeds and varying planting dates resulted improvement in cereal yields. Kool *et al.* (2014) found that irrigation farming improved cereal yields in Sudan. Radeny *et al*. (2019) found that adoption of IK drought adaptations such as integrating weed and pest bio-control with cereal production resulted in improvement in yields in Tanzania.

5.11.6 Agronomic Drought Adaptations and Maize Yields

Timely weeding (41.7%) and improving seed spacing (40.7%) resulted in maize production in Makueni County ranging between 1 and 10 bags. On the other hand, timely weeding (5.9%) and improving seed spacing (4.9%) resulted in production of above 31 bags of maize in Makueni County. Agronomic drought adaptation strategies mentioned above can be used to improve maize production when adopted by most of the farmers in Makueni County.

Results of this study corroborate those of a study conducted in ASALs in Kenya by WFP (2018) which established that improvement in seed spacing resulted in increase in cereal yields in poorly drained soils in drylands. Phoobane and Masinde (2023) found that use of IK is very popular in Vhembe District in South Africa where 76.1% of the farmers confirmed using the traditional techniques in farming. The farmers acknowledged adoption of IK due to their relevance, effectiveness and accessibility, therefore, IK improved adaptation to droughts and agricultural production. Further, use of IK such as drought prediction techniques which determined planting dates and adoption of DT cereals (Rankoana, 2021), improved cereal yields in Limpopo Province, South Africa.

5.12 Comparison of Drought Adaptations

Majority, (50.2%) of the smallholder cereal farmers who adopted CBA and IK adaptations to drought in Makueni County reported an increase in cereal yields. This implies that CBA and IK have a significant effect on cereal production and yields in Makueni County. Therefore, CBA and IK techniques can be reliably used in managing food insecurity in the study area.

Even though the study established an increase in yields as indicated by majority of the smallholder cereal farmers in Makueni County, 11.1% of the smallholder cereal farmers reported reduction in yields. The reported reduction in yields may be attributed to other factors.

A comparatively large percentage, (38.7%) of the smallholder cereal farmers recorded no change in cereal yields in Makueni County. The high percentage of farmers who practice CBA and IK cereal production yet report no change in cereal yields may be attributed to poor recording, loss of data and elongated duration that may have contributed to limited recollection of the cereal yield levels in Makueni County.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the summary of the study, key findings and conclusions made from it. This chapter also presents recommendations for practice and further research. The summary, conclusions and recommendations for practice have been done based on the order of the study objectives.

6.2 Summary of the Findings

This section covers summary of the findings, conclusions and recommendations which follow the order of the study objectives.

6.2.1 Drought Trend and Projection in Makueni County

The first objective of this study sought to establish the trend and to project drought in Makueni County between 2024 and 2054. The study established 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts between 1990 and 2020. Mild droughts occurred in 1992, 1996, 2000, 2005 and 2012. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008 and 2011 to 2016. Furthermore, multi-year droughts occurred from 2003 to 2005 and from 2007 to 2009. Majority of the smallholder farmers in Makueni County believe that near-normal droughts recur yearly while mild drought recurs every year and after every two years. Severe to extreme droughts were believed to be recurring after every four to five years. This study projected an upward annual drought trend in Makueni County from 2024 to 2054. This implies frequent recurrence of droughts in Makueni County between 2024 and 2054. The projected increase in frequency of droughts is an indication of impending drought risk in the three decades spanning 2024 to 2054.

6.2.2 Influence of IOD on occurrence of Drought in Makueni County

The second objective of this study sought to determine the influence of Indian Ocean Dipole on the occurrence and nature of droughts in Makueni County between 1990 and 2020. This study established that the relationship between IO SSTs in EWIO and EEIO and amount of rainfall in Makueni County returned R^2 values of 0.580 and 0.674, respectively. This implies that 58% and 67.4% of the variance in rainfall amount hence drought in Makueni County is explained by IO SSTs in EWIO and EEIO, respectively. The IO SSTSs in EEIO have a more significant effect on occurrence of drought in Makueni County compared to IO SSTSs in EWIO. This means that Indian Ocean Dipole has a significant influence on occurrence of droughts in Makueni County. The study established a reduction in the value of SSTs in Block A and Block B in the Indian Ocean which leads to a similar reduction in the amount of rainfall resulting to drought episodes in Makueni County. On the other hand, an increase in the value of SSTs lead to a similar increase in amount of rainfall in Makueni County.

6.2.3 Effects of Drought on Cereal Yields

The third objective sought to examine the effect of drought on cereal yields in Makueni County from 1990 to 2020. This study found that there was a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, $r(29) = .699$, $p<0.01$. The existence of a strong positive correlation between rainfall and sorghum yields is an indication that a reduction in amount of rainfall, marking the occurrence of droughts, leads to a reduction in sorghum yields in Makueni County and vice versa. The high frequency of droughts in Makueni County indicated by 20 near-normal drought episodes and 5 mild droughts between 1990 to 2020, significantly affected cereal production and yields whereby majority of the cereal farmers produced between 1 to 10 bags of sorghum. Low sorghum yields were produced by most of the sorghum farmers from small pieces of farmlands ranging between 0.1 and 0.5 ha.

The study established a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, $r(29) = .359$, $p<0.01$. The weak positive correlation between rainfall and finger millet yields shows that a reduction in amount of rainfall which marks the occurrence of droughts leads to a reduction in finger millet yields in Makueni County and vice versa. The study also found that majority of the finger millet farmers produced low amounts of finger millet ranging between 1 and 10 bags annually. The effect of drought is also indicated by low finger millet yields and small sizes of farmlands ranging from 0.1 to 0.5 ha which were used to produce finger millet by majority of the stallholder farmers.

The study found existence of a significant, weak, positive correlation between rainfall and maize yields in Makueni County, $r(29) = .346$, $p<0.01$. The existence of a weak positive correlation between rainfall and maize yields shows that reduction in amount of rainfall hence occurrence of droughts leads to a reduction in maize yields in Makueni County and vice versa. The negative effect of drought on maize yields was indicated by low maize yields and small sizes of farmlands ranging between 0.1 and 0.5 ha which were used by majority of the smallholder farmers to produce maize. The negative effect of drought on maize yields was indicated by low yields ranging from 1 to 10 bags being produced by majority of the maize farmers annually.

6.2.4 CBA and IK Drought Adaptations Practiced by Cereal Farmers

The fourth objective sought to find out the community-based drought adaptations practiced in Makueni County. This study found that more females than males in Makueni County adapted to droughts through IK drought prediction and monitoring (61%), late planting of cereal seeds (57%), IK based seed preservation (55%) and IK based seed storage (55%), supplementary irrigation (51%) and early planting of seeds (51%). In addition, more females adapted to droughts through bio-control of weeds (57%) and use of farm manure (54%). On the other hand, this study found that more males than females in Makueni County adapted to droughts through planting early maturing seeds (58%), planting drought resistant cereal seeds (54%) and use of improved seeds (53%). This study also revealed that the most popular drought adaptation strategies included increasing farm size, use of farm manure, IK-based bio-control of weeds, use of improved seeds and planting early maturing cereal seeds which were practiced by 55%, 50%, 49%, 48% and 46% of the households in 36 to 53 years age bracket.

The study also revealed that late planting of seeds and IK based drought prediction and monitoring were practiced by majority of the cereal farmers with primary education at 59% and 50%, respectively. The results also show that decreasing farm size (40%), IK-based seed preservation (38%), early planting of seeds (36%) and IK-based seed storage (33%) were the most popular drought adaptation strategies among cereal farming households with secondary education. Further, it was revealed that increasing farm size (72%), use of improved cereal seeds (71%) and IK-based cereal seed storage (70%), were the most popular drought adaptation strategies among the cereal farmers. This study also found that mono-cropping (60%), timely weeding (56%) and intercropping with cereals (56%), were the most popular agronomic adaptation practices among male cereal farmers. The results also show that intercropping with legumes (50%), improvement in land tillage (46%), improving seed spacing (46%) and practicing agro-forestry (46%) were the most popular agronomic adaptations among male cereal farmers in the study area.

This study revealed that intercropping cereals, timely application of organic manure, timely weeding and intercropping cereals with legumes were the most common agronomic practices undertaken by the cereal farmers in the following percentages 73%, 70%, 69% and 69%, respectively. The results also show that majority of the cereal farmers (68%) and (65%) practice agro-forestry and improving seed spacing, respectively. The study also found that majority (64%) of the smallholder cereal farmers adopted timely weeding as a measure of adapting to droughts. Appropriate seed spacing limits the competition for soil moisture, minerals and space between the cereal crops and weeds during drought in Makueni County. Further, 60% and 52% of the smallholder cereal farmers improved seed spacing and timely application of organic manure and cow-dung, respectively. In addition, the study established that 36% of the farmers intercropped cereals with pulses. The study also established that 26% of the smallholder cereal farmers adopted agro-forestry to adapt to droughts and to improve yields. The study established that 66% of the farmers planted early while 16% planted late based on drought prediction whereas 44% of the farmers adopted supplementary irrigation. In addition, the study established that 48%, 40% and 36% of the farmers planted drought resistant cereal seeds, early maturing cereal seeds resulted in improvement of cereal seed varieties, respectively.

The study revealed that 55%, 41% and 37%, 36% and 32% of the cereal farmers adopted farm manure to improve soil quality and to conserve the soil, traditional methods in bio-control of pests and diseases and traditional seed storage methods, respectively. The study also found that 36% and 32% of the smallholder cereal farmers used traditional seed preservation methods and traditional drought prediction and monitoring methods, respectively. The study revealed that 66% of the smallholder farmers planted early while only 16% planted late. The study also established that 43.1%, 12.4%, 5.3% and 0.9% of the smallholder cereal farmers practiced hand tilling, ox ploughing, bush clearing and seed broadcasting, respectively. Timely weeding and mulching were also identified as key drought adaptation measures in the study area. This study found that intercropping was practiced by 62.7% while use of dogs to control pests and diseases is practiced by 30.7% of the farmers. Agroforestry was practiced by 1.3% while mixed farming was practiced by 0.9% of the farmers. The study also found that agro-forestry involved planting Melia volkensii (*Mukau*) and Neem tree (*Mwarobaini*).

6.2.5 Outcomes of Drought Adaptations in Makueni County

The fifth objective sought to evaluate the outcomes of drought adaptation strategies among smallholder cereal farmers in Makueni County. This study revealed that farmers used different farm sizes for sorghum, finger millet and maize. It was found that 32.9% of the smallholder sorghum farmers cultivate the crop on farm sizes ranging from 0.1 to 0.5 ha while only 1.8% cultivate the crop on farm sizes above 3.1 ha. The study also established that 30.2% of the smallholder millet farmers cultivate the crop on land sizes ranging from 0.1 to 0.5 ha while only 0.9% cultivate the crop on farm sizes above 3.1 ha. This study also found that 24.4% of the smallholder maize farmers cultivate the crop on farm sizes ranging from 0.1 to 0.5 ha while only 12% cultivate the crop on farm sizes above 3.1 ha. This implies that a large number of smallholder cereal farmers own small farms or that the production of the crop experiences significant challenges that discourage its production in the ASAL area. The small farm sizes for the production of sorghum, millet and maize significantly affect production of the cereals hence food security in the study area.

This study found that most (43%), of the smallholder farmers produced 1 to 10 bags, while only 3% produced 11 to 20 bags of sorghum annually. Another 42% of the smallholder farmers produced 1 to 10 bags while only 4% produced 11 to 20 bags of finger millet annually. However, the study found that a comparatively larger population, 60% of the smallholder farmers produced 1 to 10 bags while 16% produced 11 to 20 bags of maize annually. The study established that drought adaptations in Makueni resulted in increase in cereal yields.

6.3 Conclusions

Makueni County experiences a high frequency of droughts indicated by 20 episodes of near-normal droughts, 5 mild droughts and 3 severe droughts which occurred between 1990 and 2020. There is a higher frequency of seasonal droughts in Makueni County during MAM season compared to OND season. There is a high frequency of near-normal, mild, severe droughts in Makueni County. Rainfall received in Makueni County in OND season is higher than in MAM season. An upward trend in OND seasonal rainfall in Makueni County was projected between 2024 and 2054. A declining trend of MAM seasonal rainfall was projected in Makueni County between 2024 and 2054. Increasing MAM seasonal droughts were projected in Makueni County between 2024 and 2054. An upward annual drought trend was projected in Makueni County between 2024 and 2054.

Indian Ocean Dipole has a significant influence on occurrence of droughts in Makueni County. Sea Surface Temperatures in Equatorial Western Indian Ocean are responsible for 58% of the variance in rainfall amount, hence occurrence of droughts in Makueni County. Sea Surface Temperatures in the Equatorial Eastern Indian Ocean are responsible for 67.4% of the variance in rainfall amount hence drought in Makueni County. Sea Surface Temperatures in Equatorial

Eastern Indian Ocean have a more significant effect on occurrence of drought in Makueni County compared to Sea Surface Temperatures experienced in Equatorial Western Indian Ocean.

There is a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, $r(29) = .699$, $p<0.01$. There is a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, $r(29) = .359$, $p<0.01$. There is a significant, weak, positive correlation between rainfall and maize yields in Makueni County, $r(29) = .346$, $p<0.01$. Majority of the cereal farmers recorded low yields between 1 to 10 bags of sorghum, finger millet and maize.

Most of the smallholder farmers' households in Makueni County are headed by males. Most of the respondents are in the age bracket between 36 and 53 years old. Majority of the smallholder cereal farmers in Makueni County have primary education. Majority of the respondents are primarily smallholder cereal farmers. Majority of the smallholder cereal farmers cultivate the crops on small farm sizes ranging from 0.1 to 0.5 hectares. Increasing farm size, use of improved cereal seeds and IK-based cereal seed storage, were the most popular drought adaptation strategies among the cereal farmers. The most popular agronomic drought adaptation practices among cereal farmers in 36 to 53 years age bracket include intercropping, timely application of organic manure, timely weeding and improving cereal seed spacing. The IK-based drought prediction and monitoring, late planting of cereal seeds and supplementary irrigation were popular drought adaptation strategies among agro-pastoralists.

Adoption of drought adaptation strategies in Makueni resulted in increase in cereal yields. Smallholder farmers who have adopted drought adaptations reported improvement of yields. Cereal yields from smallholder cereal farmers who have adapted to droughts were higher compared to cereal yields from those who have not adapted to droughts.

6.4 Recommendations for Practice

i. The Government of Kenya and the County Government of Makueni in partnership with other stakeholders should establish and equip meteorological stations and train personnel to improve monitoring of weather conditions, data collection and recording in Makueni County.

ii. The Government of Kenya and County Government of Makueni should use the drought projection results in this thesis to develop drought risk adaptation policy for Makueni County and other ASALs in Southeastern region of Kenya.

iii. The Ministry of Agriculture should establish a consistent cereal data base for cereal yields in Makueni County to improve access and research on agro-systems to improve cereal production.

iv. The Government of Kenya and County Government of Makueni should encourage the adoption of the following popular drought adaptation strategies: Increasing farm size, use of improved cereal seeds, agro-forestry, improving seed spacing, timely weeding, intercropping cereals with pulses and irrigation farming.

v. The Government of Kenya, County Government of Makueni and other stakeholders should upscale adoption of drought-tolerant sorghum, finger millet and maize varieties to improve cereal production and food security in Makueni County and other Arid and Semi-Arid Lands in Kenya.

6.5 Recommendations for Further Research

i. A study on flash droughts in Kenya is recommended.

ii. A study on the influence of anthropogenic forcing on drought occurrence in Kenya is recommended.

iii. A study on other sustainable drought management practices such as aquaculture, large-scale irrigation farming and apiculture in Arid and Semi-Arid Lands in Kenya is recommended.

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APPENDICES

Appendix A: Questionnaire for Smallholder Cereal Farmers

This research is being conducted by Jackob Ondiko Jack Haywood, a PhD Geography student at Egerton University. The purpose of this research is to assess the effects of drought on cereal yields and farmers adaptation strategies in Makueni County, Kenya.

Disclaimer! The information obtained in this feedback was treated with confidence.
(As the head of the household, you have been selected among the smallholder sorghum, millet and maize farmers to assist in providing information for the study).
The total number of respondents is 225 distributed as follows: Kathonzweni ward (Makueni sub-County) (78), Mukaa ward (Kilome sub-County) (37), Makindu ward (Kibwezi West sub-County) (63) and Ivingoni / Nzambani (Kibwezi East sub-County) (47).

Questionnaire code: …………………...Name of enumerator……………………………………

Date of Interview………………………Name of sub-County…………………………………..

Name of Ward ………………………………………….

Section A: Socio-economic Characteristics of the Household

1. General Information

1. Gender of respondent Male……………………..Female………………………….
2. Marital status Married…………………Single…………………………...
3. Farmers' group membership YES……………………...NO…………………………….
4. Age of Respondent (years)

No.	**Range in Age (years)**	**Tick**
a	18-35	
b	36-53	
c	54-71	
d	Above 72	

5. Level of Education of Smallholder cereal farmers

No.	Level of education	Tick
a	None	
b	Primary	
c	O level (Secondary)	
d	A level (Higher)	
e	Diploma	
f	Degree	
g	No response	

6. Occupation of Smallholder cereal farmers

No.	Occupation	Tick
a	Cereal farmer	
b	Agro-pastoralist	
c	Teacher	
d	Civil servant	
e	Trader	
f	Employee: private sector	
g	No response	

7. What is the size of your farm in hectares that is used for the following crops? (1 ha=2.4 acres). (**Tick**)

No.	Farm size in hectares	Sorghum	Millet	Maize
a	0.0 - 0.5			
b	0.6 - 1.0			
c	1.1 - 2.0			
d	2.1 - 3.0			
e	>3.1			

8. How many bags of the following cereals do you produce per year? (90 kg bags) (**Tick**)

No.	**Number of 90 kg bags per year**	**Sorghum**	**Millet**	**Maize**
a	0-10			
b	11-20			
c	21-30			
d	31-40			
e	41-50			
f	51-60			
g	61-70			
h	>71			
i	No response			

9. How many bags of the following cereals did you produce during the most recent drought period? (90 kg bags) (**Tick**) (Write the drought year…………………………………).

No.	**Number of 90 kg bags per year**	**Sorghum**	**Millet**	**Maize**
a	0-10			
b	11-20			
c	21-30			
d	31-40			
e	41-50			
f	51-60			
g	61-70			
h	>71			
i	No response			

Section B: Drought Adaptation Strategies

i. Soil Management and Adaptations to Drought

10. Which adaptations are you practicing?

No.	CBA and IK Drought adaptations practiced	Tick
a	Adoption of traditional drought prediction and monitoring	
b	Rain water harvesting and supplementary irrigation	
c	Planting seeds early	
d	Planting seeds late	
e	Adoption of farm manure	
f	Increasing farm size	
g	Decreasing farm size	
h	Adoption of traditional methods in bio-control of weeds/ pests	
i	Adoption of improved cereal seeds	
j	Adoption of farm mechanization	
k	Adoption of traditional seed preservation	
l	Adoption of traditional seed storage	
m	Planting early maturing/ short period sorghum cereals	
n	Planting drought resistant cereal varieties	
o	None	

ii. Agronomic Adaptations (Farming Practices)

11. Which adaptations are you practicing?

No.	Adaptation options practiced	Tick
a	Improving land tillage/ cultivation practices	
b	Improving seed spacing	
c	Practicing timely weeding	
d	Practicing timely organic manure application	
e	Practicing mono-cropping (single crop)	
f	Practicing intercropping cereals with legumes	
g	Practicing intercropping sorghum with finger millet or maize	
h	Practicing agro-forestry	
i	None	

12. Which sorghum varieties do you plant in your farm?

No.	Sorghum Variety	Tick
a	Gadam	
b	Saredo	
c	Serena	
d	Local Varieties	
e	No Idea	

13. Which finger millet varieties do you plant in your farm?

No.	Finger Millet Variety	Tick
a	U15	
b	KAT FM	
c	PM I	
d	Local Varieties	
e	No Idea	

14. Which maize varieties do you plant in your farm?

No.	Maize Variety	Tick
a	Duma 43	
b	Katumani	
c	Pioneer	
d	DK 8031	
e	Local Varieties	

15. What is the source of the seeds that you plant on your farm? **(Tick)**

No.	Source of sorghum seed	Sorghum	Millet	Maize
a	KALRO			
b	NGO/CBO			
c	Ministry of Agriculture			
d	Market			
e	Family Seed Store			
f	EABL/ KBL			
g	Other (Specify)			

16. i) Do you practice CBA adaptations to droughts? YES……………..NO………………

ii. If yes, which CBA adaptations do you practice?

a) Traditional land preparation methods

No.	Traditional Land Preparation	Tick
a	Ox ploughing	
b	Hand Tilling	
c	Bush clearing	
d	Broad casting	
e	Planting early	

b) Traditional cereal production practices

No.	Traditional Production Practices	Tick
a	Use of manure	
b	Mulching	
c	Timely planting	
d	Timely weeding	
e	No Idea	

c) Traditional biological pest and disease control strategies

No.	Traditional Biological Pest Control	Tick
a	Agro-forestry	
b	Intercropping	
c	Use of dogs	
d	Mixed farming	
e	No Idea	

d) Traditional seed preservation methods

No.	Traditional Seed Preservation	Tick
a	Smoking	
b	Use of ash	
c	Use of guards	
d	Use of granary	
e	Use of honey	

17. i) Do you practice Indigenous Knowledge (IK) in drought adaptation? YES…….NO……..

ii) If yes, give examples of the Indigenous Knowledge (IK) you use in drought adaptation?

a) Traditional land preparation methods

No.	Traditional Land Preparation	Tick
a	Ox ploughing	
b	Hand Tilling	
c	Bush clearing	
d	Broad casting	
e	Planting early	

b) Indigenous cereal production practices

No.	Traditional Production Practices	Tick
a	Use of manure	
b	Mulching	
c	Timely planting	
d	Timely weeding	
e	No Idea	

c) Indigenous biological pest and disease control strategies

No.	Traditional Biological Pest Control	Tick
a	Agro-forestry	
b	Intercropping	
c	Use of dogs	
d	Mixed farming	
e	No Idea	

d) Indigenous seed preservation methods

No.	Traditional Seed Preservation	Tick
a	Smoking	
b	Use of ash	
c	Use of guards	
d	Use of granary	
e	Use of honey	

18. What is the outcome of CBA and IK drought adaptations that you practiced?

No.	Outcome of CBA and IK Adaptations
a	Increased yields
b	No change
c	Reduction in yields

19. How has the seasonal rainfall amount changed during the period that you have been practicing cereal production?

No.	Amount of rainfall	Tick
a	Increased	
b	Decreased	
c	No change	

20. How often do you experience drought? (Tick)

No.	Near-normal Drought	Mild Drought	Severe Drought	Extreme Drought	Drought Frequency
a					Yearly
b					After every two years
c					After every three years
d					After every four years
e					After every five years
f					After every ten years

21. What is the effect of the drought on cereal yields?

No.	Effect of Drought on Cereal Yields	Tick
a	Increase in yields	
b	No change	
c	Reduction in yields	

Appendix B: Key Informants Interview Schedule

Key Informants Interview Guide

This research is being conducted by Jackob Ondiko Jack Haywood, a PhD Geography student at Egerton University. The purpose of this research is to assess the effects of drought on cereal yields and farmers adaptation strategies in Makueni County, Kenya.

Disclaimer! The information obtained in this feedback was treated with confidence.
(As a key informant, you have been selected to assist in providing information for the study).
The key informants were chiefs, village elders, agricultural extension officers and NGO officials with informants 4 per ward totalling 16.

Key informant code: …………………...Name of enumerator………………………………..
Date of Interview………………………Name of sub-County…………………………………

Name of Ward ………………………………………….

1. What is the approximate size of the smallholder farms in hectares that is used for the following crops? (1 ha=2.4 acres). (**Tick**)

No.	**Farm size in hectares**	**Sorghum**	**Finger millet**	**Maize**
A	0.0 - 0.5			
B	0.6 - 1.0			
C	1.1 - 2.0			
D	2.1 - 3.0			
E	>3.1			

2. How many bags of the following cereals are produced per year? (90 kg bags) (**Tick**)

No.	**Number of 90 kg bags per year**	**Sorghum**	**Finger Millet**	**Maize**
a	0-10			
b	11-20			
c	21-30			
d	>31			

3. How many bags of the following cereals were produced during the most recent drought period? (90 kg bags) (**Tick**) (Write the drought year…………………………………).

No.	**Number of 90 kg bags per year**	**Sorghum**	**Finger Millet**	**Maize**
a	0-10			
b	11-20			
c	21-30			
d	31-40			
e	41-50			
f	51-60			
g	61-70			
h	>71			
i	No response			

4. What is the effect of the drought on cereal yields?

No.	**Effect of Drought on Cereal Yields**	**Tick**
a	Increase in yields	
b	No change	
c	Reduction in yields	

5. Which are the most common IK and CBA adaptations to drought in Makueni County? ……………………………………………………………………………………………..…………
…………………………………………….……………………………………………………….
………………………………..……………………………………………………………………

6. Which varieties of sorghum are planted in Makueni County?

……………………………………………………………………………………………………

7. Which varieties of finger millet are planted in Makueni County?

…………………………………………………………………………………………………..

8. Which varieties of maize are planted in Makueni County?

……………………………………………………………………………………………………

9. What is the outcome of CBA and IK drought adaptations that you practiced?

No.	Outcome of CBA and IK Adaptations
a	Increased yields
b	No change
c	Reduction in yields

10. How has the seasonal rainfall amount changed in the last few years?

No.	Amount of rainfall	Tick
a	Increased	
b	Decreased	
c	No change	

11. How regularly do you experience drought?

……………………………………………………………………………………………………

12. How regularly is drought experienced in the sub-County? (Tick)

No.	Near-normal Drought	Mild Drought	Severe Drought	Extreme Drought	Drought Frequency
a					Yearly
b					After every two years
c					After every three years
d					After every four years
e					After every five years
f					After every ten years

13. Which of these sub-Counties is most affected by droughts?

No.	Sub-County	Tick
a	Kilome	
b	Makueni	
c	Kibwezi West	
d	Kibwezi East	

Appendix C: Egerton University Introduction Letter

EGERTON UNIVERSITY

Tel: Pilot: 254-51-2217620
254-51-2217877
254-51-2217631
Dir.line/Fax: 254-51-2217847
Cell Phone

P.O. Box 536 - 20115
Egerton, Njoro, Kenya
Email: bpgs@egerton.ac.ke
www.egerton.ac.ke

OFFICE OF THE DIRECTOR GRADUATE SCHOOL

Ref: ND13/15540/19

Date: 16th February, 2023

The Director General
National Commission for Science Technology and Innovation,
P. O. Box 30623-00100
NAIROBI.

Dear Sir,

RE: REQUEST FOR RESEARCH PERMIT – MR. JACKOB ONDIKO HAYWOOD

This is to introduce and confirm to you that the above named student is in the Department of Natural Resources, Faculty of Environment & Resource Development, Egerton University.

He is a bona-fide registered Ph.D. student in this University. His research topic is **"Assessment of Effects of Drought on Cereal Yields and Farmers Adaptation Strategies in Makueni County, Kenya."**

He is at the stage of collecting field data. Please issue him with a research permit to enable him undertake the studies.

Your kind assistance to him will be highly appreciated.

Yours faithfully,

BOARD OF POST GRADUATE STUDIES
22 FEB 2023

Prof. George M. Ogendi, PhD
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

GMO/mg

"Transforming Lives Through Quality Education"

Appendix D: Nacosti Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 117221

Date of Issue: 24/March/2023

RESEARCH LICENSE

This is to Certify that Mr.. JACKOB ONDIKO HAYWOOD of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Makueni on the topic: ASSESSMENT OF EFFECTS OF DROUGHT ON CEREAL YIELDS AND FARMERS ADAPTATION STRATEGIES IN MAKUENI COUNTY, KENYA for the period ending : 24/March/2024.

License No: **NACOSTI/P/23/24352**

117221

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix E: Ministry of Education Research Authorization

REPUBLIC OF KENYA
MINISTRY OF EDUCATION
STATE DEPARTMENT FOR BASIC EDUCATION

Email:cdemakueni@gmail.com
When replying please quote

County Director of Education Office
P.O. Box 41-90300
MAKUENI

MKN/C/ED/5/33/ VOLII/157

6th April, 2023

Jackob Ondiko Haywood
EGERTON UNIVERSITY

RE: RESEARCH AUTHORISATION

Reference is hereby made to the letter from National Commission for Science Technology and Innovation (**NACOSTI**) dated 24th March, 2023 authorizing you to carry out research on **"Assessment of effects of Drought on cereal yields and farmers adaptation strategies in Makueni County"** for the period ending 24th March, 2024.

Following this authorization, you are allowed to proceed with your research as requested.

COUNTY DIRECTOR OF EDUCATION
DATE: 6/4/2023
P.O. BOX 41-90300
MAKUENI

Dr. Arodi Samson
For County Director of Education
MAKUENI

SGS

Appendix F: Makueni County Commissioner Research Authorization

OFFICE OF THE PRESIDENT
MINISTRY OF INTERIOR AND NATIONAL ADMINISTRATION

Telegram:
Telephone:
Fax:
Email: *cc.makueni@interior.go.ke*

COUNTY COMMISSIONER
MAKUENI COUNTY
P.O. Box 1-90300
MAKUENI

Ref: MKN/CC/ADM.6/1 VOL.V/69

6th April, 2023

Jackob Ondiko Haywood
EGERTON UNIVERSITY

RE: RESEARCH AUTHORIZATION

Reference is made to Director General National Commission for Science Technology and Innovation Research License Ref. No. NACOSTI/P/23/24352 dated 24th March, 2023 on the above subject.

You are hereby authorized to undertake research on **"Assessment of Effects of Drought on Cereal Yields and Farmers Adaption strategies in Makueni County"** for the period ending 24th March, 2024.

By a copy of this letter the Deputy County Commissioners are requested to give you the necessary assistance.

COUNTY COMMISSIONER MAKUENI COUNTY 06 APR 2023 P.O. Box 1-90300, MAKUENI

N. J. KIMUTAI
FOR: COUNTY COMMISSIONER
MAKUENI

c.c.
County Director of Education
MAKUENI

Deputy County Commissioners
MAKUENI COUNTY

Appendix G: Publications

Open Access Library Journal
2024, Volume 11, e11819
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Influence of Indian Ocean Dipole on Drought Occurrence in Makueni County, Kenya

Jackob H. Ondiko, Amon M. Karanja, Humphreys W. Obulinji, Kennedy N. Ondimu

Department of Geography, Egerton University, Nakuru, Kenya
Email: ondikojackob2018@gmail.com

How to cite this paper: Ondiko, J.H., Karanja, A.M., Obulinji, H.W. and Ondimu, K.N. (2024) Influence of Indian Ocean Dipole on Drought Occurrence in Makueni County, Kenya. *Open Access Library Journal*, 11: e11819.
https://doi.org/10.4236/oalib.1111819

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Published: July 31, 2024

Abstract

Increasing frequency, severity and duration of droughts in Arid and Semi-Arid Lands in Kenya in the past three decades is a major challenge to survival of agrarian livelihoods and food security in Makueni County. Increasing frequency and severity of droughts in the region are influenced by a number of factors. The Indian Ocean Dipole is the principal factor driving droughts in the lower Eastern region. The influence of the Indian Ocean Sea Surface Temperatures on occurrence of droughts in Makueni is exacerbated by a long coastal contact zone between East African coast and the Indian Ocean coastline. 80% of the Kenya landmass is under Arid and Semi-Arid zones. The study determined the influence of Indian Ocean Dipole on occurrence and nature of droughts in Makueni County, Kenya. The study adopted explanatory sequential mixed methods research design. Indian Ocean Sea Surface Temperature data and rainfall data were collected from the National Oceanic Atmospheric Administration website and Kenya Meteorological Department respectively. Linear regression model was used in data analysis. The study found that Indian Ocean Dipole has a significant influence on the occurrence of droughts in Makueni County. The study established that a reduction in the value of Indian Ocean Sea Surface Temperatures in Western Indian Ocean (10˚S - 10˚N, 50˚ - 70˚E) and Eastern (tropical) Indian Ocean (10˚S - 0˚, 90˚ - 110˚E) leads to a similar reduction in the amount of rainfall hence drought episodes in Makueni County. On the other hand, an increase in the value of Indian Ocean Sea Surface Temperatures leads to a similar increase in amount of rainfall in Makueni County. Variation in Indian Ocean Sea Surface Temperature resulted in erratic, unpredictable and fluctuating rainfall patterns accompanied by 5 mild and 20 near-normal drought episodes with multi-year droughts between 2003 and 2009. Increasing trend of seasonal droughts was also established due to declining March-April-May seasonal rainfall. An upward trend in October-November-December seasonal rainfall was also established. This study recommends studies on the influence

IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)

e-lSSN: 2319-2402, p- ISSN: 2319-2399.Volume 18, Issue JO Ser. 2 (October 2024), PP 42-48

www.iosr:journals.org

Drought Adaptation Strategies Among Smallholder Cereal Farmers In Makueni County, Kenya

Jackob Haywood Ondiko
Amon Mwangi Karanja
Humphreys Were Obulinji
Kennedy Nyabuti Ondimu

The Department Of Geography, Egerton University P. 0. Box 536--20115 Nakuro, Kenya.

Abstract

Increasing frequency and severity of drought increase vulnerability of smallholder cereal fanners globally. Arid and Semi-Arid Lands cover 80% of Kenya and location around the equator are major factors in drought development in the country. Frequent droughts result in fluctuations in cereal yields hence food insecurity in Makueni County. This study evaluated community-based and indigenous knowledge drought adaptations practiced by smallholder cereal fanners in Makueni County, Kenya. This study adopted explanatory sequential mixed methods research design. Household surveys (N=225) and key infonnant interviews (N=l6) were used. Descriptive techniques were used in data analysis. The study found that frequent droughts in Makueni County resulted in adoption of small Jann sizes for production of maize, sorghum and finger millet. Majority of the fanners produced between 1 and 10 bags of cereals. Majority (50.2%) of the smallholder cerealfanners who adopted community-based adaptations and indigenous knowledge-based drought adaptations strategies recorded an in increase in cereal yields in Makueni County. Early planting (66.7%), timely weeding (61.4%), manure application (57.0%), improving land tillage (56.1%), seed spacing (55.3%) and planting drought- resilient seeds (44.7%) led to the high annual cereal yields ranging between 1 and JO bags in Makueni County. The drought adaptation strategies are commendable for upscaling in agro-ecological zones with similar climatic conditions in order to improve food production in the country. lnfonnation and data generated by this study is expected to result in improvement in drought adaptation policy fonnu/ation and adaptive capacity of smallholder cereal fanners hence, improvement in food production and security.

Keywords: *Adaptation, Community-Based Adaptations, Drought, Indigenous Knowledge*

Date of Submission: 16-10-2024 Date of Acceptance: 26-10-2024