PAN AFRICAN UNIVERSITY INSTITUTE FOR WATER AND ENERGY SCIENCES INCLUDING CLIMATE CHANGE

SPATIAL TEMPORAL ANALYSIS OF THE IMPACTS OF CLIMATE VARIABILITY AND LAND USE LAND COVER CHANGE ON MAIZE YIELD IN KENYA

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ABBREVIATIONS AND ACRONYMS

MAM – March April May

OND – October November December

USGS- United States Geological Survey

CRU TS- Climate Research Unit gridded Time Series

GDP -Gross Domestic Product

LUC- Land Use Change

LULCC- Land Use and Land Cover Change

Tmax- Maximum Temperature

Tmin- Minimum Temperature

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DEDICATION

I dedicate this work to my daughter, Maria Ivanna.

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ABSTRACT.

The Agricultural sector is most susceptible to climate variability and change, especially in Africa because it primarily depends on rainfall, and the adaptive capacity is low. Increase in population and urbanization as well as unsustainable farming practices have influenced land use changes leading to diminishing croplands. These two factors; climate variability and land use land cover change have intensified food insecurity in Kenya which depends on only 20% of its land area for agricultural production. It is therefore crucial to enhance the understanding of land use and land cover change impacts coupled with climate variability dynamics on agricultural productivity. This study examined the spatial temporal impacts of climate variability and land use land cover change on maize yield in Kenya for the period of 2012-2020. The maize yield data used was obtained from the Kenya maize yield Database while Precipitation, Maximum temperature and Minimum Temperature data was obtained from the Climatic Research Unit gridded Time Series (CRU TS) which has a spatial resolution of 5° latitude by 0.5° longitude. Land Cover Type Product (MCD12Q1) offered by MODIS was obtained from the USGS website. ArcGIS 10.8 and Microsoft excel were used in the analysis. The non-parametric Man-Kendell and Sens slope tests showed no trend in the data with a p value > 0.05 for T-max, T-min and Precipitation. Spearman rank correlation test showed that a strong positive correlation between maize yield and the climatic parameters for the, Lake Victoria Basin, Highlands East of Rift Valley, Coastal Strip and North Western Regions. In all the four regions, except T-max for the Coastal Strip, the R^2 is 0.5 and above while the p value is <0.05. The results of the Land use land cover classification showed that open shrublands increased significantly in area by 11,229km2, closed shrublands by 4365km2 and Barren land by 4145 km2. On the other hand, grasslands recorded the highest decrease in area of about 7235 km2 followed by croplands, 4414km2 and Savannah 4116km2. The findings suggest that climate variability in the study area has a significant impact on maize yield for four out of six climatological zones as evidenced by decline in precipitation trends for the MAM season which is the long rainy season. Land use and land cover changes also have a negative impact on maize yield through decline in croplands by 4414km2 from 2011 to 2020.

Key Words: climate variability, maize yield, land use land cover, Kenya

CHAPTER ONE: INTRODUCTION.

1.1 Background.

The objective of Sustainable Development Goal 2, which aims to eradicate hunger, achieve food security, and improve nutrition, is to promote food security through sustainable agricultural practices (FAO, 2015a). This is because agriculture forms the foundation of our diets and nutrition, and economic growth, environmental sustainability, equity, and inclusion can be enhanced by food production and proper nutrition. By doing so, the burden on already overburdened healthcare systems can be alleviated by promoting good health for all (Ngure et al., 2021). Climate change exacerbates food security risks in vulnerable nations and communities, and its impacts are multidimensional, affecting various sectors and regions across the world due to its transdisciplinary nature (Kogo et al., 2022). The Food and Agricultural Organization's report highlights that climate change exacerbates food security risks for the most vulnerable countries and populations (FAO, 2015b). The Intergovernmental Panel on Climate Change (IPCC) also indicates that global agriculture in the 21st century has been significantly impacted by climate change, with most countries likely to experience increased average temperatures, stressed water resources, more frequent and intense heat waves, changes in precipitation patterns, and desertification (IPCC, 2022).

Despite considerable progress in recent years towards combating hunger, an estimated 800 million people were still experiencing chronic malnutrition, and 161 million children under the age of five were stunted in 2015. Moreover, 500 million individuals were suffering from obesity. Additionally, two billion people lacked essential micronutrients necessary for a healthy life. These statistics, as reported by the Food and Agriculture Organization (FAO, 2015a), underscore the ongoing challenges in achieving global food security. In Africa, 80 meteorological, hydrological, and climate-related hazards were reported in 2022, with 56% being flood-related events. These natural hazard events resulted in approximately 5,000 fatalities, with 48% attributed to drought and 43% to flooding. In total, more than 110 million people were directly affected by these disaster events, causing over US$8.5 billion in economic damages. Although drought was the primary cause of death and affected people, flooding was the main cause of economic damages (WMO, 2022). It is estimated that 3.3 to 3.6 billion people reside in areas highly susceptible to the impacts of climate change, and the vulnerability of humans and ecosystems is interconnected. Regions and individuals with limited development opportunities are particularly exposed to climate-related hazards(WMO, 2016).

Climate change has led to an increase in severe weather and climate events, which has resulted in millions of people experiencing acute food insecurity and water scarcity. This poses a threat to the progress made in the fight against hunger and malnutrition (FAO, 2015b). The consequences are most pronounced in areas such as Africa, Asia, Central and South America, Least Developed Countries (LDCs), Small Islands, and the Arctic, as well as globally for Indigenous Peoples, small-scale food producers, and low-income households. According to data, between 2010 and 2020, human fatalities from floods, droughts, and storms were 15 times higher in highly vulnerable regions compared to areas with very low vulnerability (IPCC, 2023). Additionally, climate change, including the rising frequency and intensity of extreme events, has had a negative impact on food and water security, making it difficult to achieve the Sustainable Development Goals (IPCC, 2022). Currently, over eleven million people are facing acute food insecurity in nine Southern African countries, including Angola, Eswatini, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Zambia, and Zimbabwe, due to the deepening drought and climate crisis (Godfrey & Tuhuma, 2020). Climate change also affects water availability, which is a significant source of uncertainty for many regions. It influences precipitation, runoff, and snow/ice melt, which in turn affects hydrological systems, water quality, water temperature, and groundwater recharge. In many parts of the world, increased water scarcity resulting from climate change presents a major challenge for climate adaptation. Furthermore, rising sea levels will affect the salinity of surface and groundwater in coastal areas (FAO, 2015a).

Land use and land cover change (LULC) is a significant trigger of global environmental change due to its effects on biogeochemical cycling and its role in global warming. LULC also directly impacts global climate change by emitting greenhouse gases, losing biodiversity, and depleting soil resources (Maina et al., 2020). Various drivers, such as population growth, urbanization, land scarcity, and the expansion of agricultural land, contribute to LULC. The indicators of LULC manifest in various ways, including increased concentrations of greenhouse gases, the conversion and fragmentation of natural vegetative areas, and biodiversity loss (Onyango et al., 2021). Proximate drivers, which directly transform the land cover, include human activities. Underlying drivers, such as government policies and technological advancements, indirectly trigger the proximate causes and are influenced by demographic, biophysical, social, cultural, technological, economic, political, and institutional factors. Therefore, most recent and current land cover changes are attributed to human actions(Balaka Opiyo et al., 2022; Fred Muchuma et al., 2021). The current exponential increase in population is likely to increase the intensities and extents of LULCC, which will strain Kenya's land resources. Approximately 75% of Kenya's population engages in agriculture, which is primarily rainfed, but only 20% of the land is arable, causing unprecedented changes in ecosystems and environmental processes in the country (Maina et al., 2020; Onyango et al., 2021).

Sub-Saharan Africa is particularly susceptible to the consequences of climate variability due to its heavy reliance on rain-fed agriculture and smallholder farmers to achieve food security. More than half of the countries in the region allocate over 50% of their cereal production to maize, which accounts for at least half of the proteins and calories consumed in the Southern and Eastern parts of Africa, as well as one-fifth of the calories and proteins consumed in West Africa (Tesfaye et al., 2015). As a result, climate change hinders Africa's ability to attain food security (Chepkoech et al., 2018). Food insecurity caused by climate change typically leads to shortages of food and agricultural inputs, resulting in higher food prices. In September 2022, coarse grain prices were exceptionally high in Somalia, South Sudan, and Sudan. In Somalia, the prices of maize and sorghum were up to 45% and 75% higher, respectively, compared to the previous year due to low production following four consecutive below-average harvests. Significant production declines were also observed in Zambia and Zimbabwe, due to unfavorable rainfall distribution, as reported by (WMO, 2022). The Sahel region of West Africa continues to be devastated by drought, food, and refugee crises resulting from a combination of erratic rainfall, failed harvests, soaring market prices, and insecurity. Vulnerable populations in Niger, Burkina Faso, Mali, Chad, Mauritania, Senegal, and The Gambia are at risk of severe hunger, as documented by (Godfrey & Tuhuma, 2020). According to the Food and Agriculture Organization (FAO), the projections indicate that SSA will witness changes in precipitation intensity and distribution, increases in temperature, and higher incidences of extreme events such as droughts, floods, and disease epidemics (FAO, 2015b).

The agricultural industry is a vital aspect of the economy of Kenya as well as food security. Unfortunately, it is considered highly susceptible to climate-related risks. This sector contributes about 28% of the country's GDP and over 65% of its exports, with crop, livestock, and fisheries sub-sectors contributing about 78%, 20%, and 2% to the agricultural GDP, respectively (WBG, 2021). In February 2017, the government declared a drought emergency. As the UN Environment ERISC Phase II report suggests, Kenya could experience a 4.4% reduction in GDP in the event that prices of food double due to drought events. The prices of maize and beans, which are commonly consumed together, are often indicative of any drought situation(UN, 2019).

Approximately, 56% of the Kenyan population experiences food insecurity at some point in the course of the year. About 2 million people out of this, rely on relief food due to their persistent food insecurity. During droughts, this number increases to 5 million. These individuals living in poverty have a high likelihood of being food insecure, with 53% of the rural population and about 49% of the people living in urban areas. This situation of food scarcity results in limited access to safe and nutritious food in sufficient quantities, impacting their physical and economic well-being (Wambugu PW & Muthamia ZK, 2009). Between April 2016 and April 2017, Kenya experienced a 21% increase in food prices, which can have significant consequences for vulnerable populations. During periods of drought, internal migration often increases, leading to additional social costs. Drought also plays a crucial role in exacerbating food insecurity and malnutrition, putting a strain on government finances. These issues are important to consider, as they can have far-reaching effects on society (UN, 2019). Thus, agriculture continues to be a vital sector in the Kenyan economy, with a remarkable impact on economic growth and poverty reduction through its benefactions to food and nutrition security, the provision of raw materials for agro-industry, employment creation, and foreign exchange earnings. The sector remains a cornerstone of the economy, supporting the Vision 2030 agenda (GoK, 2021). The sector contributes directly 26% of the country's GDP and adds another 27% indirectly through linkages with agro-based industries. It is estimated that a 1% increase in the agricultural sector's growth leads to a 1.6% increase in the overall economy. This highlights the importance of agriculture as the main driver of national economic growth in Kenya, with the sector also having a significant impact on the performance of nearly all other industries. However, despite its importance, food security remains a challenge in Kenya, with many people still struggling to access adequate and nutritious food (GoK, 2021; Miruka et al., 2012).

The nation heavily relies on agriculture, especially on imports of maize, wheat, and rice, which highlights the need for enhancing agricultural productivity through sustainable and resilient practices to ensure food security and economic growth (WBG, 2021). According to (IITA, 2007), maize has emerged as the most significant cereal crop in sub-Saharan Africa, as it serves as a staple food for nearly half of the region's population. With a high yield potential of 8.6 tons in developed countries and 1.3 tons in developing countries, maize is a versatile crop that can thrive in various agro-ecological zones. Additionally, every part of the crop has economic value, as the grain, leaves, stalk, tassel, and cob can all be utilized in the production of diverse food and non-food products. Maize is a vital staple food in Kenya, with approximately 90% of farms growing it. It is a crucial food security crop for both the urban and rural populations of the country, and inadequate yields can result in severe food shortages and famine. In 2001, maize accounted for roughly 28% of the gross farm output from small-scale farming in Kenya. However, between 2001 and 2007, maize production significantly decreased, and a considerable portion of the maize consumed in Kenya is now imported from Uganda (Wambugu PW & Muthamia ZK, 2009) Kenya, like many African countries, relies heavily on agriculture, with the majority of its population deriving their livelihood from small-scale farm enterprises. Trans Nzoia county located in the western part, is considered the food basket of the country as it leads in maize production. The people of Trans-Nzoia have traditionally engaged in the cultivation of maize, beans, and goats and have been leading in maize production in the country for decades (Gichuki Manana, 2014). Maize yield variability is primarily influenced by changes in air temperature and precipitation, followed by radiation (FAO, 2022; Xu et al., 2016).

The effects of climate variability on precipitation, soil moisture and production always constitute a threat to food security in the Republic of Kenya given that a large proportion of the Kenya people live in the rural regions and depend solely on rainfed agriculture for their livelihood (Ochieng et al., 2016). In the north-eastern agricultural lands of Kenya which are largely marginalized, an estimated 4.4 million people were reported to be food insecure between October and December 2022. This trend is worrying because it is almost 90% higher on yearly basis(WMO, 2022). The Agricultural Sector directly contributes approximately 25.4 % of the country’s gross domestic product as well as about 27% indirectly via agro-based industries (FAO, 2015b) which confirms that it is an important contributor to employment of rural households as well as food security. On the other hand, LULCC have led to shrinking of agricultural land as more developments and built-up areas sprout as a consequence of urbanization. Besides, conventional agricultural practices leading to land fragmentation have significantly affected arable land leading to reduced fertility and increased degradation. Besides, in Sub Saharan Africa, LULCC is among the major causal factors driving soil loss in upland watersheds. Consequently, this causes soil erosion eventually disrupting the hydrological balance of watersheds (Aneseyee et al., 2020). Additionally, apart from the anthropogenic emissions of greenhouse gases, LCC also has impacts on fluxes of energy, momentum as well as moisture to the atmosphere thereby influencing climate locally and regionally(Bagley et al., 2012). In a nut shell, LULCC can have multiple ecological effects including impacts on water quality. Subtle changes in farming practices in the rural areas can affect landscape features and functions this impacting the environment as a whole (Houet et al., 2010).

1.2 Problem Statement.

Climate change is expected to affect the frequency and intensity of extreme weather events, which will have significant consequences for agriculture. The impact of these events on the agricultural sector is already substantial. Data from the Food and Agriculture Organization (FAO) shows that 25% of all economic losses and damages caused by climate hazards such as droughts, floods, and storms in developing countries between 2003 and 2013 affected the agricultural sector. Agriculture-dependent communities and those reliant on natural resources are at the greatest risk, as their livelihoods are highly vulnerable to the impacts of climate change and they have limited capacity to respond. In regions with high levels of food insecurity and inequality, increased frequency of droughts could disproportionately affect poorer households, particularly women who are already vulnerable and have limited access to resources (FAO, 2015a).

Like many other countries in the Sub-Saharan Africa, Kenya has experienced variations, both seasonal and annual in temperature and rainfall over the last 50 years which is believed to be associated with climate change (Kogo et al., 2022). Considering the fact that Kenya depends solely on rainfed agriculture, the extreme events caused by climate variability are meant to disrupt the normal functioning of the rainfall seasons and patterns thus rendering the country vulnerable to climate induced food insecurity. This situation is exacerbated by the fact that about 75% of the Kenyan population engages in agriculture, but only 20% of the land is arable (Maina et al., 2020; Onyango et al., 2021). On the other hand, due to urbanization and the exponential growth of Kenya's population, land use changes have occurred that have seriously impacted the soils and water quality thus further impacting crop yield within the already encroached croplands. The effects of human induced disasters such as the severe drought in the north eastern part of Kenya, coupled with anthropogenic land use and land cover change therefore puts more pressure on the scarce land resource leading to food insecurity. With the rummaging effects of all these factors combined, it is therefore important to assess the effects of climate variability and land use land cover change on maize yield so as to understand the problem and proffer mitigation and adaptation strategies that can help build resilience and improve food security within the country.

Gap

Most of the studies previously conducted on climate variability and crop yield in Kenya focused on specific regions of the country, for instance, Ngure et al., (2021) worked on climate stressors and household food security in Murang'a county, Omoyo et al., (2015a) worked on climate variability and maize yield in the south eastern parts of Kenya that is, Machakos, Mwingi and Makueni. Other similar studies have been done in Nyeri (Maina et al., 2020), Kitui (Gladys, 2017), as well as in Busia, Siaya and Migori counties on land use land cover change and watershed urbanization (Onyango et al., 2021) Another study has also been conducted by (Kogo et al., 2022) on the climate change response in a rainfed production system in western Kenya and also Fred Muchuma et al., (2021) worked on land use land cover change in Bungoma county but did not link it to maize yield. On the regional level, (Fenta et al., 2017) conducted a study on the spatial and temporal distribution of trends of rainfall in Eastern Africa while (Adhikari et al., 2015) did a review of impacts of climate change on major crops. These studies focused on smaller regions of the country but no previous studies have been done on climate variability and maize yield in the entire country. Ochieng et al., (2016) worked on the whole country but focused on the effects of climate variability and change on revenue from maize and tea. Additionally, no previous studies in Kenya have linked climate variability, land use land cover change and maize yield. In view of previous studies done on the subject and in the study area, the interlinkages between climate variability, land use and land cover change and maize yield are scanty and unexplored in Kenya and most of the studies have only focused on some parts of the country. Therefore, study seeks to examine the spatial temporal impacts of climate variability and land use land cover change on maize yield in Kenya for the period of 2012-2020.

Main Objective

The main aim of this study is to assess the spatial and temporal impacts of climate variability and land use land cover change on maize yield in Kenya from 2012-2020.

1.3 Specific Objectives.

a) To assess climatic trends in Kenya for the period of 2012-2020
b) To assess the effects of rainfall and temperature variability on maze yield in Kenya for the period of 2012-2020.
c) To assess the possible impact of land use land cover change (for the years 2011 and 2020) on maize yield in Kenya

1.4 Research Questions

a) What are the climatic trends in Kenya from 2012-2020?
b) What are the effects of Rainfall and Temperature variability on maize yield in Kenya between 2012-2020?
c) What is the impact of land use land cover change for the years 2011 and 2020 on maize yield in Kenya?

CHAPTER 2: LITERATURE REVIEW

2.1 Climatic Trends

Human activities, such as the emission of greenhouse gases, have indisputably caused global warming, as evidenced by the 1.1°C increase in global surface temperature above the 1850-1900 level during 2011-2020. Despite ongoing efforts to reduce emissions, greenhouse gas emissions continue to increase due to unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, countries, and individuals (IPCC, 2022, 2023). According to the same report, there is a 50% likelihood that global warming in the near term, even under a low greenhouse gas emission scenario, will reach or exceed 1.5°C. Additionally, it is projected that there will be less summertime precipitation in northern Europe, the Mediterranean, and some parts of central and eastern Europe, with these regions also experiencing more frequent and intense droughts (Issahaku et al., 2016). The reason for the increased frequency and intensity of droughts in Asia is due to the rise in temperature, which leads to severe drying in regions and a decrease in the number of rainy days, but with a greater intensity of rainfall (IPCC, 2022). Climate variability has varying impacts on different communities or regions. The IPCC predicts that an increase of 2°C in temperature poses a threat to both plants and animals, as well as an increase in economic losses due to floods and droughts on an annual basis (IPCC, 2023).

Concerns have been raised about the serious impacts associated with the impacts of climate change, particularly on developing countries, which have limited capacity to cope with the adverse impacts of climate change (Adom, 2024). Climate-related disturbances in regions critical for global food supplies can lead to disruptions in supply flows and food price spikes, thereby increasing market volatility and altering trade patterns. The impact of climate change on food price fluctuations is expected to be compounded by trade, which plays a crucial role in adjusting to agricultural and food production changes driven by climate shifts. Recent events have shown that domestic policies, such as export restrictions, can contribute to price fluctuations. Unfortunately, poor countries and their populations with insufficient purchasing power may find it challenging to access global markets (FAO, 2015a). In 2022, the average near surface temperature in Africa was 0.16°C [0.06°C–0.28°C] above the 1991–2020 climatological standard normal, and 0.88°C [0.74°C–1.07°C] above the 1961–1990 average. Over the past 60 years, all six African sub-regions have experienced an increase in temperature trends compared to the period before 1960. North Africa has experienced the most rapid warming trend, with a temperature increase of around +0.4°C/decade between 1991 and 2022, compared to +0.2°C/decade between 1961 and 1990. Southern Africa, on the other hand, experienced the slowest warming trend among the sub-regions, with a temperature increase of around +0.2°C/decade between 1991 and 2022 (WMO, 2022). The Sahel region of West Africa has exhibited multidecadal rainfall fluctuations (Dai et al., 2004). This trend is expected to persist, with a shift towards more seasonal rainfall patterns and longer dry spells between events (Kundzewicz et al., 2007). Research by Holmes et al. [1997] has shown that the African Sahel region has been experiencing a prolonged drought since the late 1960s. The long-term changes in surface water availability are closely associated with rainfall patterns and increased evaporation (Issahaku et al., 2016).

According to the WMO, (2022) report, precipitation anomalies in 2022 were higher than the 1991-2020 average in several regions, including large parts of West Africa, Sudan, north-eastern Africa, the eastern Sahel region, and parts of Southern Africa. However, below-normal annual rainfall prevailed over much of North and north-western Africa, particularly in Morocco, Algeria, Tunisia, and western Libya. The high temperatures experienced in these regions resulted in a significant increase in the number of heatwave days. In a study conducted in Nigeria from 1980-2015, the overall findings indicated that there was significant variability in rainfall and temperature over space and time. However, the scholar reported that the spatial variation in temperature was more visible than that of rainfall. Conversely, temporal changes were more discernable in rainfall series as compared to temperature series (Umar et al., 2019). In Central Africa, significant amounts of precipitation above average (higher than 200 mm) were recorded in central and southern Chad, northern Cameroon, the Central African Republic, and parts of Congo as well as the Democratic Republic of the Congo. On the other hand, negative rainfall anomalies of over 350 mm were noted in Gabon, Equatorial Guinea, south-western Cameroon, and parts of the southern Democratic Republic of the Congo (WMO, 2022). Coastal cities in West Africa, including Niamey and Abidjan, regularly experience urban flooding, which exacerbates the socio-economic and physical vulnerability of these cities, particularly affecting the informal sector and livelihoods. Climate change is expected to lead to more extreme events, making early warning more challenging and necessitating enhanced adaptability (Godfrey &

Tuhuma, 2020). On the contrary, 2022 saw one of the chilliest years in Cameroon's recent history, registering a temperature drop of -0.24 °C compared to the average from 1991 to 2020. This led to extensive flooding in the Far North Region due to heavy rains, overflowing rivers, and breached dikes. By September 2022, the floods had affected more than 37,000 people, injuring over 95 individuals, demolishing over 9,000 houses, and inundating a dozen healthcare facilities and 88 schools, thereby disrupting the education of more than 26,600 children (WMO, 2022). Meanwhile, in eastern Africa, coastal regions and major inland lakes have experienced cooling trends (Issahaku et al., 2016). This area has suffered from increased drought occurrences for more than a decade, with the most severe event happening between 2010 and 2011, leading to a humanitarian crisis that necessitated a significant international response (Godfrey & Tuhuma, 2020). According to the WMO, (2022), northwestern Africa, notably Morocco and northern Algeria, reported the highest temperature anomalies. Moreover, North Africa as a whole exhibited the most substantial temperature rise compared to other African sub-regions, with temperatures surpassing the 1991–2020 average by 0.50 °C and the 1961–1990 average by 1.40 °C. In Southern Africa, central and western Angola saw above-average rainfall, with some areas experiencing rainfall totals within the top 10% of historical records. However, eastern Angola, Zambia, Zimbabwe, and certain parts of southern South Africa faced significant rainfall deficits exceeding 200 mm. Over in the West Indian Ocean, suppressed rainfall led to substantial negative anomalies in eastern Madagascar and Seychelles, while Comoros and specific regions in Madagascar received surplus rainfall.

Sub-Saharan Africa contains numerous regions where the severe impacts of climate change intersect with densely populated communities facing poverty and vulnerability. In recent times, this area has endured a series of calamitous climate-related events. These include the prolonged drought ongoing since 2012 in the Sahel region of West Africa, affecting nations like Niger, Burkina Faso, Mali, Chad, Mauritania, Senegal, and the Gambia; the 2017 drought in the Horn of Africa; and the devastating tropical storms, including Tropical Cyclone Idai and Tropical Cyclone Kenneth, which struck Southern Africa in 2019, with Kenneth being the strongest storm ever recorded on the continent. Additionally, East Africa faced its worst desert locust outbreak in decades in 2020, posing severe threats to food security and livelihoods (Godfrey & Tuhuma, 2020).. Early 2022 saw Southern Africa battered once more by tropical cyclones and storms, impacting over 2.8 million individuals and resulting in over 800 deaths. These included Tropical

Storm Ana in January affecting over 1.3 million people in Madagascar, Mozambique, Malawi, and Zimbabwe; Tropical Cyclones Batsirai and Emnati in February affecting over 423,800 individuals in Madagascar; and Tropical Storm Dumako in February affecting over 33,700 people in Madagascar and Mozambique. In March, Tropical Cyclone Gombe affected over 900,000 people in Mozambique and Malawi, while in April, Tropical Storm Jasmine affected nearly 5,000 people in southern Madagascar (WMO, 2022).. Furthermore, early 2019 saw Mozambique hit by two severe tropical cyclones within a short span, Tropical Cyclone Idai and Tropical Cyclone Kenneth, marking unprecedented occurrences in recorded history (Godfrey & Tuhuma, 2020). Sub-Saharan Africa is home to various climate change hotspots, where the severe physical and ecological consequences of climate change intersect with significant populations of impoverished and vulnerable communities. Over the past few years, the region has experienced a number of serious climate-related crises, such as the ongoing drought, refugee and food crisis in the Sahel region of West Africa that has affected individuals in Niger, Burkina Faso, Mali, Chad, Mauritania, Senegal, and the Gambia since 2012; the 2017 Horn of Africa drought; Tropical Cyclone Idai and Tropical Cyclone Kenneth (the most powerful storm to ever hit Africa) in 2019; and the worst outbreak in decades of swarms of desert locusts across East Africa in 2020, which posed a significant threat to food security and livelihoods (Godfrey & Tuhuma, 2020; IPCC, 2023).

During the initial months of 2022, Southern Africa experienced a barrage of tropical cyclones and storms, impacting over 2.8 million individuals and resulting in over 800 fatalities in the region. In January, Tropical Storm Ana affected more than 1.3 million people in Madagascar, Mozambique, Malawi, and Zimbabwe. In February, Tropical Cyclones Batsirai and Emnati affected over 423,800 people in Madagascar, while Tropical Storm Dumako affected more than 33,700 people in Madagascar and Mozambique. March saw Tropical Cyclone Gombe affecting over 900,000 people in Mozambique and Malawi, followed by Tropical Storm Jasmine in April, which impacted nearly 5,000 people in southern Madagascar (WMO, 2022). In early 2019, Southern Africa experienced two consecutive cyclones—Tropical Cyclone Idai and Tropical Cyclone Kenneth. Cyclone Kenneth stands as the most intense storm ever to strike Africa and marks the first instance in recorded history of two powerful tropical cyclones hitting Mozambique in a single season (Godfrey & Tuhuma, 2020). Kenya's extensive topography leads to notable temperature fluctuations. Highland areas exhibit considerably cooler temperatures compared to coastal and lowland regions. Seasonal temperature variations are minimal, with average temperatures ranging from 18°C at higher elevations to 26°C along the coast. Rainfall patterns across Kenya vary significantly, with arid zones in the north receiving less than 250 millimeters annually, while the west can experience over 2,000 mm per year. The highland regions, crucial for agriculture, receive approximately 1,000 mm of rainfall annually. Kenya observes four distinct seasons, dictated by the seasonal movement of the Inter-Tropical Convergence Zone (ITCZ), including the "warm dry season" from January to March, the "long wet season" from April to June, the "cool dry season" from July to September, and the "short wet season" from October to December (WBG, 2021). Since the beginning of 2020, East Africa has grappled with the most severe desert locust outbreak in decades, posing a significant threat to food security and livelihoods. Studies have linked this phenomenon to a warmer climate, which exacerbates the severity of locust swarms, disproportionately impacting Africa (Godfrey & Tuhuma, 2020).

Kenya has witnessed notable fluctuations in precipitation patterns, displaying considerable diversity across different regions. While the northern areas have seen increased rainfall, southern regions have experienced a trend towards drier conditions since the 1960s, although this pattern has shown significant variability. There has been a rise in both the frequency and intensity of extreme rainfall events, accompanied by an increase in aridity and occurrences of drought. Major droughts occur approximately every decade on average, with prolonged droughts becoming more frequent since 2000 (WBG, 2021). In 2022, the WMO reported a mixture of wetter and drier conditions across East Africa. Sudan and southern Tanzania saw rainfall surpassing the top 10% of historical records, while Ethiopia, northern Uganda, Somalia, and Kenya observed rainfall levels below the lowest 10% threshold. Drought persisted in the region, with southern Ethiopia, Kenya, and Somalia experiencing five consecutive seasons of below-average rainfall, marking the longest such period in 40 years. The scarcity of rainfall significantly impacted agriculture and food security, leading to disruptions in markets, challenges in supply chains, and increased food prices (WMO, 2022). Nationally, exposure to climate risks can result in shocks to agricultural output and food availability, affecting the accessibility and stability of food supplies for the entire population, especially in countries where a significant portion of income is spent on food (FAO, 2015a).

2.2 Climate Variability Impacts on Maize yield.

Climate change has significantly altered global agriculture in the 21st century, according to assessments by the Intergovernmental Panel on Climate Change (IPCC). The report indicates that most countries will witness rising average temperatures, more frequent heatwaves, heightened stress on water resources, desertification, and periods of intense precipitation. While agricultural productivity has generally increased worldwide, the growth has been slowed by climate change over the past five decades (IPCC, 2023; Ochieng et al., 2016). The variability in climate affects various socio-economic activities crucial to global food security, posing a significant risk to humanity. Extreme climate events like prolonged droughts, heatwaves, floods, and erratic rainfall patterns can cause severe disruptions to agricultural production, with far-reaching implications for human livelihoods and food security. Temperature and rainfall, key climate variables, play crucial roles in crop growth, with even minor changes impacting crop output (Guntukula & Goyari, 2020).

The impact of climate change on agricultural production systems is both direct and indirect. Direct effects include alterations in physical conditions such as temperature levels and rainfall patterns, directly affecting specific agricultural practices. Indirect effects manifest through changes in other organisms like pollinators, pests, disease vectors, and invasive species. These indirect impacts are significant but complex to assess and predict due to numerous interacting factors, many of which remain poorly understood (FAO, 2015a). In tropical regions, where temperature and rainfall are critical factors, crop yield maximization is often limited by these variables. Many crops in these regions grow close to their optimal temperature, making them susceptible to extreme weather events that can harm yield. As temperatures rise, highland areas may see increased yields while lowlands may face water scarcity, further reducing productivity. The timing of stress on crops is crucial, as variability in precipitation can lead to water stress, reducing leaf area and increasing pollen sterility, ultimately resulting in poor-quality yields. Conversely, regions experiencing excess heat and water due to climate change may see heightened infestation by pathogens, weeds, and insects, further damaging agricultural systems (Barnabás et al., 2008; Mumo et al., 2018a; Ziska et al., 2011).

There is a consensus that global food security will be negatively affected by climate change in various ways. According to Hadley scenarios, food imports are projected to increase significantly compared to scenarios with no climate change or variability. Globally, a 1°C increase in temperature is expected to lead to a 10% decline in cereal yield, except in high-latitude countries (Jones & Thornton, 2003; Lobell et al., 2011; Mumo et al., 2018a). The effects of past climate trends on crop production are evident in various regions worldwide, with negative impacts outweighing positive ones (Porter et al., 2014). This is reflected in the recurrent occurrence of price spikes following climate extremes in key producing areas. Climate change has already adversely affected wheat and maize yields globally and locally. Moreover, the increased frequency of unusually hot nights in most regions poses a threat to most crops, as evidenced by observed impacts on rice yields and quality (FAO, 2015a).

The literature is in consensus regarding the effects of increasing temperatures on crop yields and agricultural land value. These impacts are projected to be disproportionately higher in developing regions like Africa, particularly in the long term. Studies conducted in Africa, Central, and South America indicate a significant decline in agricultural productivity. In Africa, this decline is estimated to range from -2.9% in 2030 to -18% in 2050 (Adom, 2024). Less developed nations such as India and Africa are more susceptible to the adverse effects of climate sensitivity on agriculture, primarily due to their reliance on rainfed agricultural practices (Guntukula & Goyari, 2020). Climate change is anticipated to diminish cereal crop yields in Africa by shortening the growing season, intensifying water stress, and increasing the incidence of diseases, pests, and weed outbreaks (Adhikari et al., 2015). This is particularly concerning for Sub-Saharan Africa (SSA), where agriculture constitutes a significant economic sector, engaging over 65% of the workforce and contributing 32% to national gross domestic products. However, the sector grapples with low productivity and a dearth of modern farming technologies. Despite its substantial size, agricultural production systems in the region heavily rely on rainfall, rendering them vulnerable to climate variability. The burgeoning population in the region further strains food production systems (Adhikari et al., 2015). Maize is the predominant staple crop in SSA, primarily cultivated by smallholders. More than half of the countries in SSA allocate over 50% of their cereal area to maize production (FAO, 2022). About 77% of total maize production in SSA (excluding South Africa) is consumed as food. Maize is cultivated on approximately 25 million hectares in SSA, accounting for 27% of the total cereal area and 34% of cereal production between 2005 and 2008. Additionally, it serves as a crucial source of dietary protein and the second most important source of calories in eastern and southern Africa (Adhikari et al., 2015). A study on climate change and its impact on eastern Africa suggests that maize yields are likely to be moderately affected, with potential yield changes ranging from -45% to +18% by the 2080s. Reduced crop yields due to climate change could expose a significant number of individuals in Africa to severe hunger, malnutrition, and food insecurity, with over 200 million people estimated to face extreme hunger in the long term (Adom, 2024).

Kenya's natural resources are under escalating strain due to population growth, coastal erosion, deforestation, inadequate land management, and the ramifications of climate change, including seasonal fluctuations. These factors pose a substantial threat to Kenya's unique biodiversity, local livelihoods, and long-term food security for a significant portion of its population (WBG, 2021). Climatic variability and change continually jeopardize food security in Kenya by influencing rainfall patterns, soil moisture levels, and crop production. Since the early 1990s, Kenya has encountered several severe droughts, including those in 1991-1992, 1992-1993, 1995-1996, 1998-2000, and 2004, as well as flooding from El Niño rains in 1997-1998 and drought in 2008-2009. These climatic events directly impact agricultural production and food security, given that a majority of Kenya's population resides in rural areas and depends on agriculture for sustenance. Furthermore, the heavy reliance on rain-fed agriculture exacerbates the vulnerability (Ochieng et al., 2016). The agricultural sector is particularly vulnerable to climate change impacts due to its sensitivity and extensive exposure. Rising temperatures are expected to alter the distribution and abundance of pests affecting crops and livestock. Moreover, the frequency and severity of droughts in arid and semi-arid regions are projected to reduce crop yields for major staples such as maize, wheat, rice, livestock, and fisheries. Additionally, key cash crops like coffee and tea are likely to face significant challenges due to rising temperatures and increased pest and disease prevalence (WBG, 2021).

It is widely acknowledged that adaptation strategies can help alleviate the negative effects of global warming and climate change. These strategies encompass various measures such as cultivating alternative crops, practicing intercropping with different crop varieties, employing drought-tolerant seed varieties, implementing irrigation and water harvesting techniques, offering crop insurance, establishing early warning and monitoring systems, building dykes, facilitating human migration, adjusting planting schedules, diversifying both within and beyond agriculture, relying on safety nets and social networks, and selling assets (Ochieng et al., 2016).

Agriculture stands out as a significant economic activity greatly influenced by climate variability and change (Omoyo et al., 2015b). This impact occurs when the mean values of climate variables such as rainfall, maximum temperature, minimum temperature, and evapotranspiration, affected by extreme climatic events, influence crop yields under rain-fed conditions in many regions globally. Projections of climate change and variability suggest that they will contribute to increased occurrences of drought, food insecurity, irreversible declines in herd sizes, and poverty (Bergonci, 2001; Omoyo et al., 2015b). Aligned with the 2030 agenda for sustainable development, food security is anchored in Sustainable Development Goal 2: Zero Hunger (UN, 2018), a goal applicable to Kenya. Given that maize is a staple food and a primary component of the diet, its production is critical for ensuring food security (Musyimi et al., 2022). Temperature and precipitation significantly impact crop yield maximization, with high temperatures increasing soil water stress in lowlands, thus reducing crop yields, while rainfall variability limits optimal growth by contributing to water stress (Conway, 2009),. More than 80% of Kenya's land is arid and semi-arid, home to approximately 10 million people and about 70% of the national livestock herd (GOK, 2018; Omoyo et al., 2015a). Unfortunately, this region is highly vulnerable to climate variability and change, as it frequently experiences severe droughts and water scarcity

In Kenya, agriculture is predominantly small-scale, with around 4.5 million farmers cultivating 90% of agricultural land, and an estimated 3 million working in smallholdings, accounting for 75% of all farms (GOK, 2018). It serves as a major source of employment for young people and contributed approximately 52% of the country's GDP in 2017 and 35.1% in 2020 (Mumo et al., 2018b; Musyimi et al., 2022). Within the Eastern and Southern Africa region, Kenya is a major maize producer, a crop critical for food security in sub-Saharan Africa and serving as the primary food source for millions of Kenyans (FAO, 2022). However, the agricultural sector faces threats from weather and climate extremes (Musyimi et al., 2022). In Kenya, agricultural activities rely heavily on the long and intermediate rainy seasons, and with the increasing frequency and complexity of dry spells and flood hazards caused by climate change, the region has witnessed devastation and loss of livelihoods across key sectors of the county (GoK, 2018). Agriculture remains the backbone of Kenya's economy, and the sector's growth is vital for the country's overall economic and social development. Numerous studies have investigated climate variability and its impacts on food security in Africa, particularly in Kenya. For example, Ngure et al., (2021) found that changes in rainfall and temperature over time significantly affect household food security among smallholder farmers in Muranga County, Kenya. Their study, based on monthly rainfall and temperature data from Thika Meteorological station, along with household surveys, key informant interviews, and focus group discussions, revealed altered rainfall and temperature trends affecting crop yields, especially maize.

Chepkoech et al., (2018) conducted a study on the impact of climate change on African Indigenous vegetable production in Kenya, utilizing surveys and meteorological data. Their findings revealed that higher temperatures, reduced rainfall, delayed onset and early cessation of rains, erratic rainfall patterns, and frequent dry spells were contributing to increased occurrences of droughts and floods. Similarly, Ochieng et al., (2016) investigated the effect of climate variability and change on agricultural production among small-scale farmers in Kenya. Employing a household fixed effect estimator, they examined the influence of climate variability on revenue from various crops such as maize and tea. Their results indicated that the impact of climate variability on crop revenue varied across different crops, with temperature negatively affecting maize revenue but positively influencing tea revenue. In another study focusing on rain-fed crop production systems in western Kenya, farmers' perceptions highlighted reduced crop yields, increased fallow farms, and crop failure attributed to climate change. Adaptation strategies employed by farmers included adjusting planting times, utilizing drought-tolerant varieties, and diversifying crops (Kogo et al., 2022). A separate investigation into the effect of climate variability on maize yield in the arid and semi-arid lands of eastern Kenya revealed declining maize yields, particularly in Machakos County, followed by Kitui, Mwingi, and Makueni Counties for the period 1994-2008. The study also noted increasing seasonal and annual temperatures alongside declining rainfall trends across six weather stations (Omoyo et al., 2015c).

Maina et al., (2019). analyzed temperature and rainfall trends over 30 years (1981-2012) in Kieni, Central Kenya, indicating declining average annual rainfall and rising maximum temperatures. In Nyeri County, Maina et al., 2020). investigated land use and land cover changes from 1987 to 2017 using remote sensing and GIS techniques. Notably, previous studies often focused on specific regions of Kenya and lacked integration of climate variability dynamics and land use changes' impacts on maize yield. Furthermore, a study conducted in Kitui County, part of the South Eastern Lowlands, between 1981 and 2011, assessed the impacts of temperature and rainfall variability on food security and agricultural production. Significant variations in climatic parameters were observed, correlating with a decline in the region's economic sector (Gladys, 2017). Evaluating spatial and temporal trends of rainfall and erosivity in the Eastern African region from 1981 to 2016, Fenta et al., (2017) provided insights into climate patterns. Similarly, Gebrechorkos et al., (2019) investigated long-term trends in rainfall and temperature across the entire East African region, highlighting variations such as high average maximum rainfall in western Kenya and Ethiopia, as well as southeastern Tanzania.

2.3 Impact of Land use and Land Cover Change on maize yield.

Originally, land cover referred solely to the type and state of vegetation, such as forest or grass cover. However, it has since been expanded to include other elements like human structures, soil types, and various land cover categories, such as cropland, forest, wetland, pasture, roads, and urban areas, among many others (Bhandari et al., 2022). Land cover refers to the physical and biological cover of the land surface, including vegetation, bare soil, water, and artificial structures. On the other hand, land use refers to any physical and biological or chemical change to the physical and biological attributes of land that may be attributed to management (Maina et al., 2019). As a finite natural resource, land is essential for the economic growth and development of a country. Concerns about global environmental change have increasingly recognized the role of land use and land cover change (LULC) over time (Bhandari et al., 2022). With the global population expected to reach approximately 9 billion by 2050 and rising personal wealth and health, the demand for food and energy will continue to increase. Changes in land use and land cover (LULC) are increasingly acknowledged as a key contributor to global environmental transformations, encompassing greenhouse gas emissions, alterations in global climate patterns, biodiversity depletion, and soil resource degradation (Maina et al., 2019). Factors such as urbanization, population growth, land scarcity, and the expansion of agricultural land are driving LULCC worldwide. The indicators of LULCC include current global environmental concerns, such as the increasing concentrations of greenhouse gases in the atmosphere, the loss of biodiversity, and the conversion and fragmentation of natural vegetation areas. The concept of land cover originally referred to the kind and state of vegetation, such as forest or grass cover, but it has expanded in subsequent usage to include other elements, such as human structures and soil types. Land cover categories encompass cropland, forest, wetland, pasture, roads, and urban areas, among many others. As global environmental change concerns grow, some issues related to land use, land cover, and their changes over time are increasingly recognized (Bhandari et al., 2022). Human activities exacerbate this change, as they not only degrade the land but also contribute to the rise in greenhouse gas emissions in the atmosphere. Individuals most vulnerable to the consequences of human-induced climate change are those who heavily depend on agriculture and natural resources for their livelihoods, as they possess limited resources and ability to adapt to the rummaging effects of climate change. These populations are typically found in areas with high levels of food insecurity and inequality, where droughts disproportionately affect poor households, particularly women who are already vulnerable and have limited access to resources, as reported by the Food and Agriculture Organization (FAO, 2015a). Human activities such as socioeconomic, political, cultural, demographic, and environmental factors significantly influence land use and land cover changes, which are closely linked to the surging human population (Maina et al., 2019). Furthermore, land cover change (LCC) has an impact on the exchange of energy, momentum, and moisture between the atmosphere and the land surface, as well as on regional climate. Anthropogenic greenhouse gas emissions contribute to global warming and have a profound effect on local and regional climate. Additionally, land use and land cover changes can affect crop yields due to alterations in regional temperature (Bagley et al., 2012). Spatial and temporal changes in land use can impact the production of maize, particularly when farmland is repurposed for other uses.

The incessant increase in population size has resulted in a decrease in land size. The intensive use of land assets has brought about substantial transformations in land use and cover throughout history. The acceleration of land-use changes characteristics, driven by industrialization and rapid population growth, has had various environmental impacts (Balaka Opiyo et al., 2022). In Kenya, the agricultural sector faces the biggest risk from erratic rainfall and severe droughts, which have a significant impact on crop production, particularly maize, the staple food (Maina et al., 2019). In western Nepal, Bhandari et al., (2022). conducted a study analyzing the effects of land cover changes on crop yields and migration using Landsat data spanning two decades from 2000 to 2019. Similarly, (Onyango et al., 2021), focused on the Lake Victoria basin in Kenya, utilizing GIS and Remote Sensing techniques to assess changes in landscape environments over a forty-year period, particularly in counties surrounding the lake. However, this study was limited to land use and land cover changes within the basin and did not encompass the entirety of the country. Meanwhile, Fred Muchuma et al., (2021) examined land use and land cover changes in Chetambe Hills, Bungoma County, from 2000 to 2015, aiming to facilitate sustainable land use planning. Despite revealing a significant decrease in annual cropland, this study was confined to a specific region and did not consider climate variability. Similarly, a study in Kieni, Central Kenya, assessed changes in land use and land cover from 1987 to 2017, highlighting an increase in bare land by 9.36% (Maina et al., 2019). Additionally, Balaka Opiyo et al., (2022) investigated the trends and drivers of land use and land cover changes in the Migori River watershed, situated in western Kenya, based on remotely sensed data

2.4 Climate Datasets

C.R.U

The Climatic Research Unit gridded Time Series (CRU TS) is a widely utilized climate dataset that spans the entire landmass, excluding Antarctica, on a 0.5° latitude by 0.5° longitude grid. The dataset is based on an archive of monthly mean climate anomalies collected from more than 4000 weather stations distributed across the world (Harris et al., 2014). The CRU TS version 4.06 dataset covers the period between 1901 and 2021 and its trends are generally more extensive and robust (Bakke et al., 2023; Harris et al., 2020).

CHAPTER 3: MATERIALS AND METHODS

3.1. Study Area.

The study region Kenya, is located in East Africa, spans approximately 582,650 km2 and lies between latitudes 5°N and 5°S and longitudes 34° and 42°(B. O. Ayugi et al., 2016). It boasts a diverse geography, with complex geomorphological features shaping its local climate in different parts of the country. The country's bimodal rainfall and temperature patterns are determined by the Inter-Tropical Convergence Zone (ITCZ), with rainfall patterns varying due to seasonal variability and intensity caused by differences in altitude(Ngila et al., 2023). The two rainy seasons are; the "long rains" from March to May, and the "short rains" from October to December. The lengthy rainy season is of great importance to Kenya's agricultural production, which is a vital component of the country's economy. This sector contributes 26% of the Gross Domestic Product (GDP) directly and another 27% indirectly through connections with other industries(KMD, 2020). Additionally, the agricultural sector employs more than 40% of the total population and over 70% of Kenya's rural population. The climate ranges from arid and semi-arid in the lowlands to humid in the highlands, resulting in a wide range of landscapes and ecosystems in Kenya. The dry land mass is typically divided into six agroecological zones: agroalpine (0.1%), high potential (9.3%), medium potential (9.3%), semi-arid (8.5%), and dry (52.9%) (B. Ayugi et al., 2020; Parracciani et al., 2023).

The highlands are known for their relatively cool climate and fertile soil, which makes them ideal for agriculture. These areas are mostly dominated by commercial and small-scale farms that grow a wide variety of crops, including tea, coffee, flowers, vegetables, and pyrethrum. In addition to these cash crops, wheat and maize are also cultivated in the highlands, which lie at an altitude of 1,500 to 3,000 meters above sea level. Livestock production is also common in these regions (WBG, 2021). The dry and sparsely vegetated regions are in the north, the lowlands and humid rainforests along the eastern coast, the fertile lands in the central part, and around Lake Victoria. The central region of Kenya boasts the biodiverse mountain forests of Mount Kenya, which stands at an elevation of 5199 meters above sea level. Inlands comprise broad plains and numerous hills, while the northern and eastern parts of Kenya are home to shrublands located in the arid and semi-arid regions (Ngila et al., 2023).

Kenya is considered a lower middle-income country but boasts the largest economy in East Africa. It has a population of approximately 52.6 million people (2019) and an annual population growth rate of 2.3%.5 Approximately 27% of Kenya's population resides in urban areas, projected to increase to 33% and 46% by 2030 and 2050, respectively.6 The Gross Domestic Product (GDP) in 2018 was US$95.5 billion, with an annual growth rate of 5.4% (2019)(WBG, 2021). The study area was divided into six rainfall climatological zones as previously done by the Kenya Meteorological Department (KMD, 2020) as shown in **Figure 1.2**,

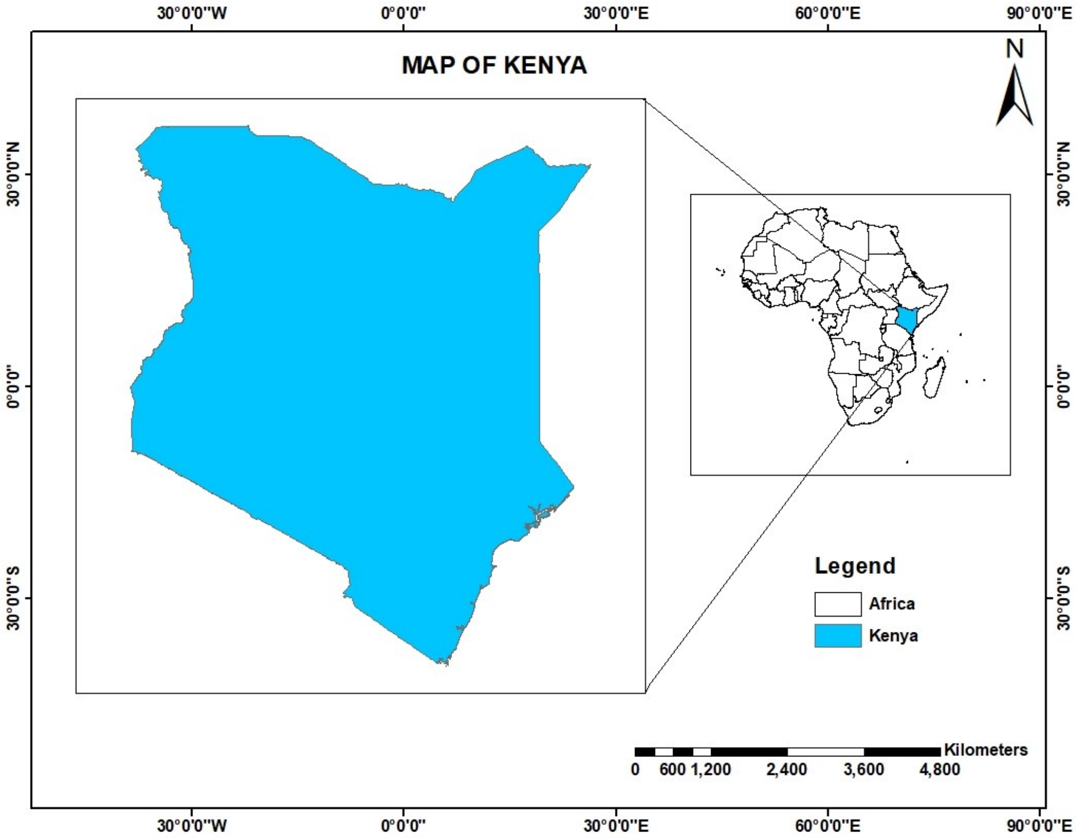

Fig 3.1: Map of Kenya

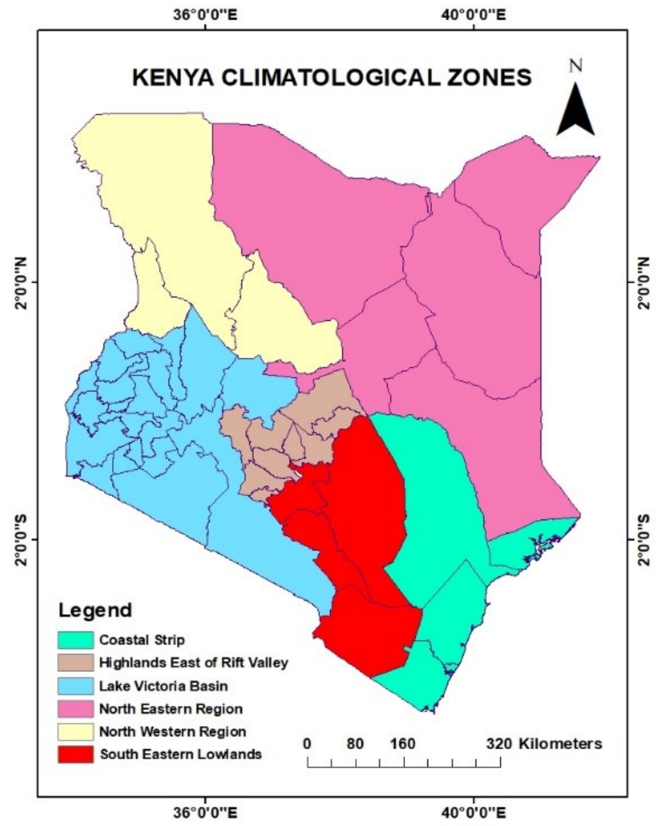

Fig 3.2: Climatological zones of Kenya

3.2 Data Sources.

The datasets used in this study were; Maize yield data for the period of study, that is 2012-2020 which was obtained from the Kenya Maize Yield Database https://nipfn.knbs.or.ke/download/maize-production-by-county-2012-2020/, Gridded monthly precipitation, maximum temperature and minimum temperature data from the CRU TS version 4.07 was obtained from the website https://crudata.uea.ac.uk/cru/data/hrg/ . CRU TS (Climatic Research Unit gridded Time Series) is a widely used climate dataset on a 0.5° latitude by 0.5° longitude grid over all land domains of the world excluding Antarctica. It is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observation (Harris et al., 2014, 2020). Typically, station anomalies are geographically interpolated using a 0.5×0.5-degree grid system that encompasses the global landmass, excluding Antarctica. By integrating this grid system with an existing climate model, researchers can obtain precise monthly values (Shi et al., 2017). This dataset was chosen because of its long period and finer resolution especially when working on a large study area. Land use and land cover maps of Kenya for the study period, 2011 and 2020 were obtained from the USGS Earth Explorer website https://earthexplorer.usgs.gov/ The Land Cover Type Product (MCD12Q1) offered by MODIS provides a comprehensive set of science data sets (SDSs) that map global land cover with a spatial resolution of 500 meters and an annual time step for six diverse land cover legends. These maps have been developed through the classification of Spectro-temporal features derived from data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS). Satellite data with lower spatial resolutions require less computation time, but they offer less detailed information and cannot detect any landscape changes that are smaller than the satellite sensor's spatial resolution. In contrast, satellite data with higher spatial resolutions provide more detailed information on land use and land cover (LULC). However, these data require more processing time and are limited to smaller study areas due to the lack of historical time-series data and the higher cost of image acquisition. To overcome these challenges, researchers commonly use Moderate Resolution Imaging Spectroradiometer (MODIS)(Afrin et al., 2019; Aredehey et al., 2018; Lunetta et al., 2022; Usman et al., 2015; Yin et al., 2014). While both MODIS data archives provide open access to high-quality multispectral band information that has been spectrally and geometrically corrected, researchers should use it data with caution in local-level LULC studies because of its relatively lower spatial resolution (Afrin et al., 2019). This study however focused on the whole of Kenya this Modis data was found most suitable.

3.3 Data Analysis

The Mann-Kendall (MK) test (Gilbert, 1987; Kendall, 1948; Mann, 1945) was used to evaluate the trend (either a monotonic upward or downward trend) of the climatic data, i.e., rainfall and temperature. The MK test is essentially a non-parametric form of the monotonic trend resulting from linear regression analysis. The MK test was used because of the fact that it is robust and allows for the effective treatment of outliers (Atta-ur-Rahman & Dawood, 2017; Hamed, 2008). The MK test is frequently used as a statistical procedure to analyze trends in environment, hydrologic data and climatology to determine whether or not monotonic patterns or statistically significant trends are present as well as to perceive a statistically significant decreasing or increasing trend in long- term temporal data (Mumo et al., 2018a). Apart from the robustness of the MK test, its non-parametric nature also means that it does not depend on regularly distributed data (Alhaji et al., 2018). Kendall's Tau varies between -1 and 1; it is positive when the trend increases and negative when the trend decreases. Additionally, since the MK test statistics are invariant to transformations such as logs, the MK test was highly applicable.

MK test was used to rest whether to reject or not to reject the null hypothesis, where:

H_0: No monotonic trend in the series
H_a: A monotonic trend is present in the series

The MK test was used to analyze the sign of the difference between data measurements in the later period and those measured earlier in the study. Each value measured in the later period was compared to the earlier measurements, resulting in $\frac{n(n-1)}{2}$ possible data pairs, where, n was the total number of observations. Missing values were allowed and the data did not need to follow any particular distribution. To calculate the MK test, differences between values measured in the later and earlier periods were computed, $(y_j - y_i)$, where $j > i$. The differences were assigned an integer value of 0, 1, or -1 corresponding to either no differences, positive, or negative differences respectively. The test statistic, S, was then computed as sum of the integers:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (y_j - y_i) \tag{1}$$

Where $sign\ (y_j - y_i)$ represents either 0, 1, or -1 as indicated above.

An upward trend was indicated when S was a large positive number, and no trend was indicated if the absolute value of S was small. The test statistic, τ was computed as: $\tau = \frac{S}{n(1-1)/2}$ and this had a range of -1 to +1, which is similar to the regression analysis correlation coefficient. The null hypothesis of no monotonic trend in the series was rejected when S and τ were statistically different from zero and if a significant trend was found, the rate of change was calculated using the Sen slope estimator (Helsel & Hirsch, 1992).

The Sen slope estimator was gotten by computing the median of the slopes for all pairs of data measurements that were used to compute S as follows:

$\beta_1 = median\left(\frac{y_j - y_i}{x_j - x_i}\right)$ for all $i < j$ and $i = 1,2,\ldots,n-1$ and $j = 2,3,\ldots,n$ (2)

Hence, the Sen slope estimates the overall slope of the time series. The trend is statistically significant when the p-value is less than 0.05.

Time series analysis, a method appropriate for longitudinal research design was adopted to determine the trend in mean annual and seasonal rainfall and annual maximum as well as minimum temperature for the period 2012-2020 and basic statistical techniques including the mean, sum and other frequencies were used in calculating the seasonal precipitation and annual maximum and minimum temperature data from the C.R.U monthly data.

ArcGIS 10.8 was used in the analysis of the spatial temporal trends of the climatic variables as well as to generate spatial maps for the study period while Microsoft excel was used to develop curves and graphs in a bid to visualize the results obtained. In establishing the degree of the monotonic relationship between maize yield and the climatic parameters which in this case are; minimum temperature, maximum temperature and precipitation, the Spearman Rank Correlation test was employed whereby maize yield was considered the dependent variable and the climate parameters the independent variables.

The formula for Spearman's correlation that was used was as follows:

$$\rho = 1 - \frac{6\Sigma\, d_i^2}{n(n^2-1)} \qquad (3)$$

Where d_i was the differences in paired ranks, that is $d_i = R_{x_i} - R_{y_i}$ and n was the total number of observations, that is 9 observations for each climatic region. The value of ρ lies between -1 and 1 and direct associations were indicated by positive values whereas inverse associations were indicated by negative values.

The statistical analysis was performed by Microsoft Excel and the results were considered significant at 0.05 probability level. The land use land cover maps were developed using ArcGIS 10.8 which was also used to estimate the difference in area of the land uses between 2011 and 2020. According to the IPCC, (2023), during 2010-2019, annual average greenhouse gas emissions were higher than in any previous decade. Thus, this period of study was chosen to assess if this higher-than-normal rate of GHG emission may have impacted agricultural productivity in Kenya, Maize was chosen because it is the staple food of the country and thus an index for measuring food security.

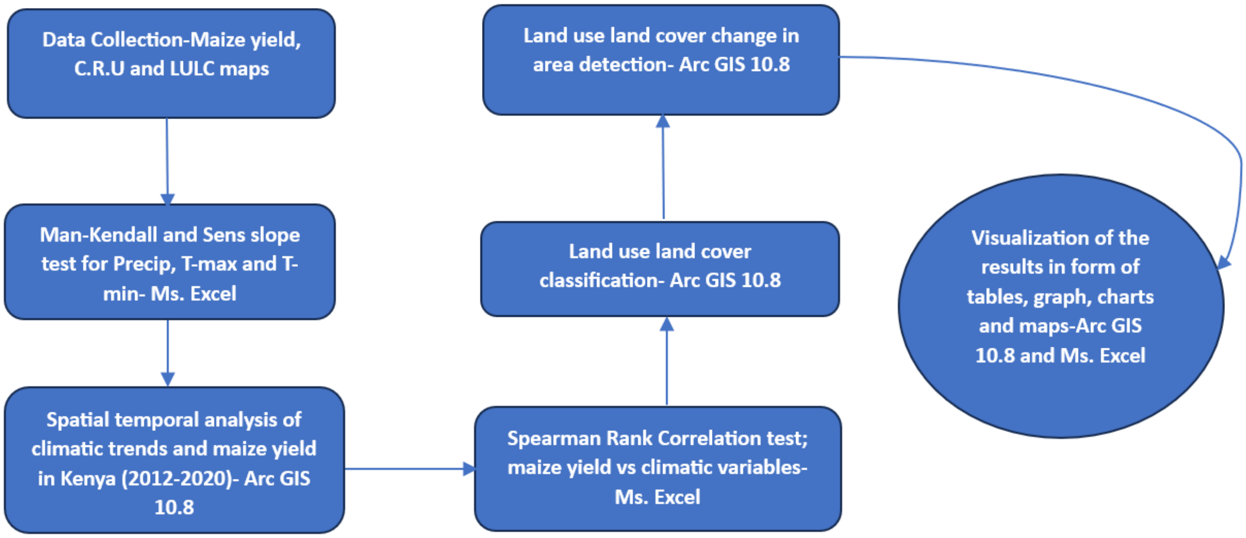

Figure 3.3: Flowchart showing the methodology used.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Climatic Trends in Kenya.

4.1.1 Precipitation

Man- Kendel test results showed that the p-value = **1.00** which means there is no trend in the series. A study conducted by Gladys, (2017) in Kitui County for the period of 1981-2011 established that there was an increasing trend in precipitation, nonetheless, it was not statistically significant. Opiyo, (2014) also reported no trend in the rainfall in Turkana region for the study period of 1950 to 2012. A study conducted by Maina et al., (2020) in Nyeri county for the period of 1981-2012 however contradicted our findings by indicating that rainfall had been decreasing during this period. This disparity in the results could be due to the difference in the study period and area, also bearing in mind that Nyeri county is relatively wet. According to the IPCC, most countries will experience more stressed water resources due to unreliable rainfall (IPCC, 2022). A study done in Borana area, Ethiopia between 1981-2018 reported an annual increasing trend in precipitation that was statistically significant. The spatial distribution pattern also showed variability that is consistent with the actual rainy seasons (Worku et al., 2022).

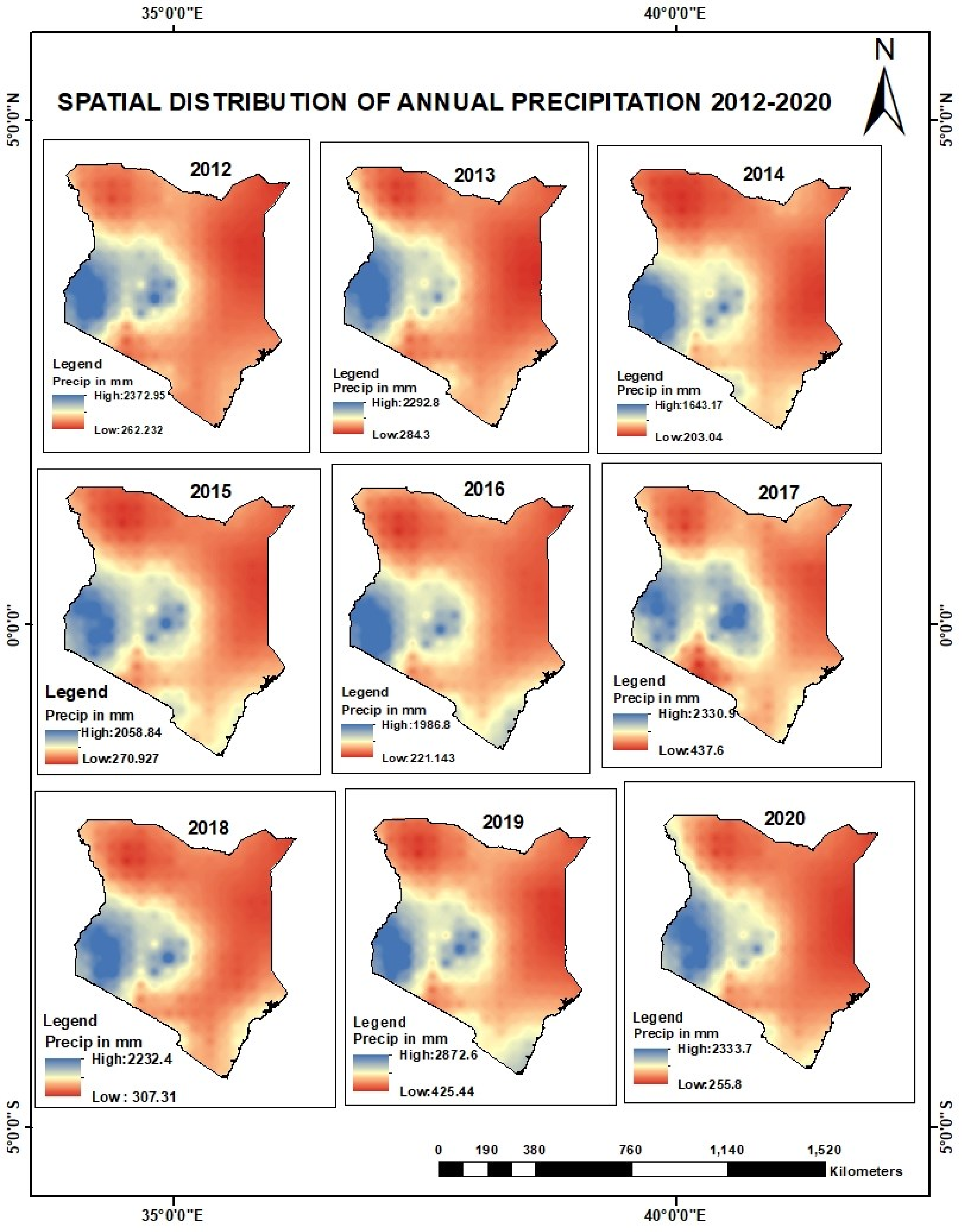

Figure 4.1: Spatial distribution of annual precipitation.

The spatial rainfall patterns highlight the prevalence of wetter areas in the Lake Victoria basin and Highlands East of Rift valley as compared to the North Eastern and North Western Regions. Additionally, there is a decreasing trend in the spatial distribution of rainfall in wetter areas.

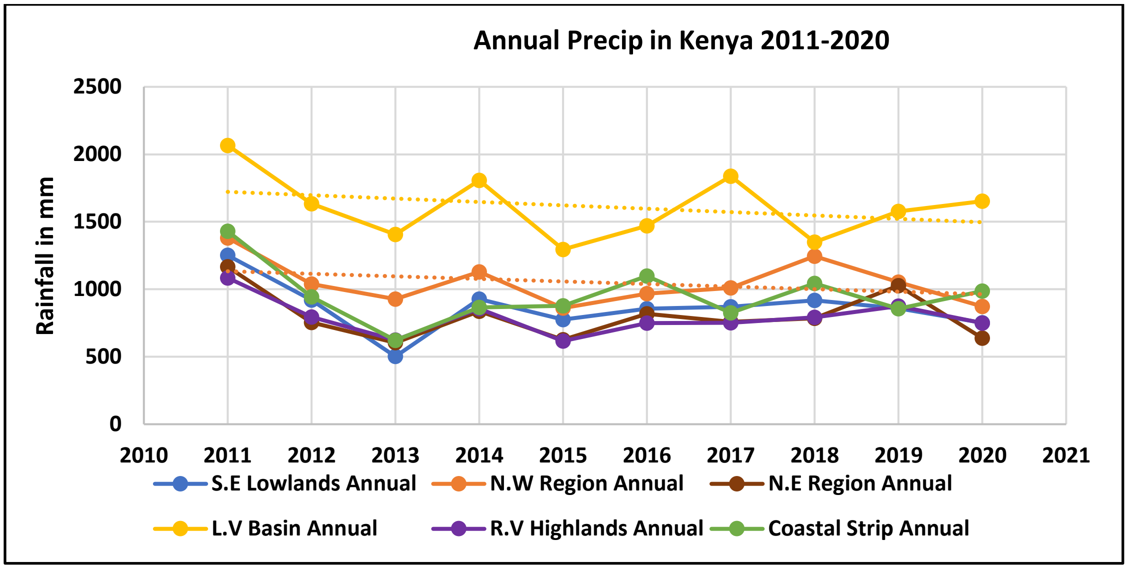

Figure 4.2: Temporal variation of annual precipitation

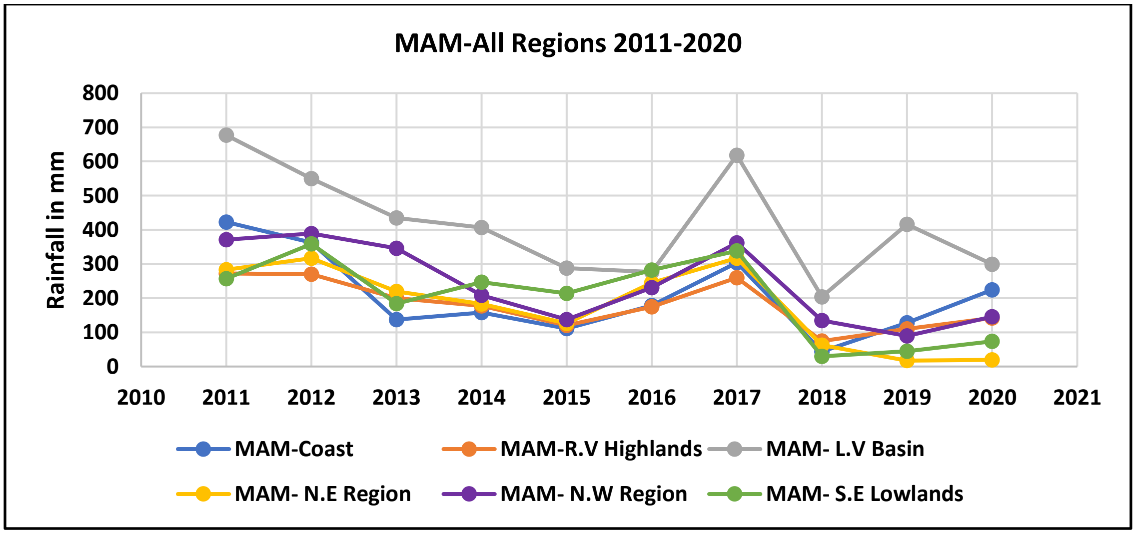

Figure 4.3: Temporal variation of seasonal precipitation MAM

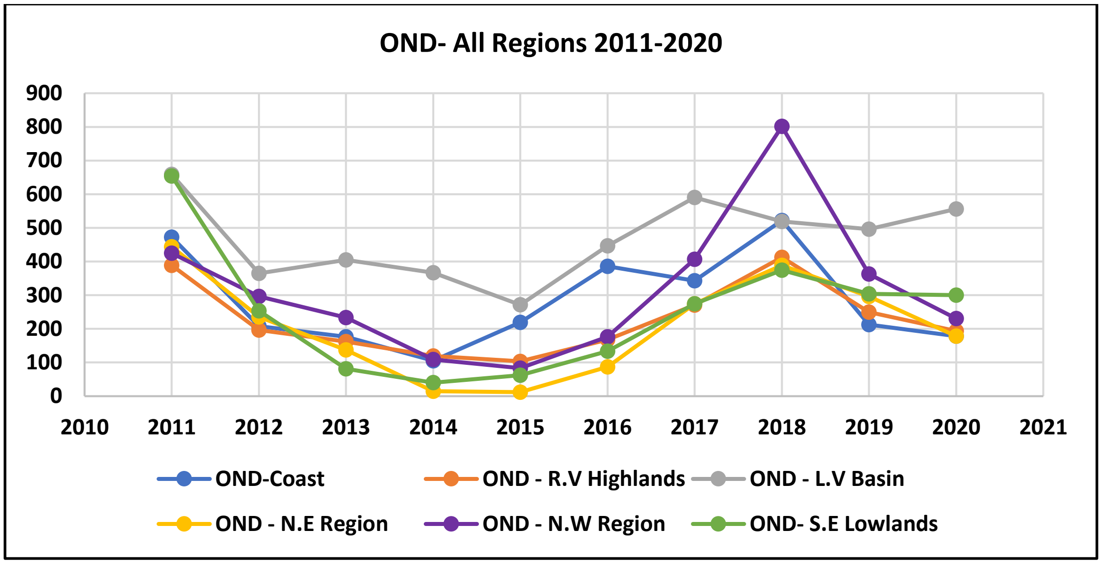

Figure 4.4: Temporal variation of seasonal precipitation OND

For the Mean Annual Precipitation, Lake Victoria Basin had the highest rainfall followed by North Western Region. Lowest annual rainfall patterns were recorded by the Highlands east of Rift Valley and the North Eastern Region. Generally, there is a decreasing trend of annual rainfall by all the regions, nonetheless, it is not statistically significant. Liebmann et al., (2014) also reported the same results while working on rainfall variability and change in the horn of Africa between 1979 to 2012. Our results however contradicts the results of a study conducted in Nigeria between 1980-2015 whereby the overall annual rainfall trend was increasing, but not statistically significant (Umar et al., 2019). This disparity in the results can be attributed to the differences in study period and geographical locations. The MAM seasonal rainfall patterns show show an overall decreasing trend with Lake Victoria basin still recording the highest rainfall. This is in agreement with past studies (Liebmann et al., 2014; Lyon & Dewitt, 2012; Maidment et al., 2015; Ongoma et al., 2018; Ongoma & Chen, 2017; Tierney et al., 2015). A study conducted by Sagero et al. (2018) on rainfall variability in Kenya also established a decreasing trend of MAM seasonal rainfall between 2010 and 2014. There is an overall increase in rainfall between 2016 and 2018 after which it drops again and the North Eastern region records the lowest rainfall in 2019 and 2020. This can be attributed to the prolonged drought that affected the semi-arid northern parts of Kenya. Decline in precipitation for the MAM can be linked to climate variability and has negative impacts on food maize yield given that it is the long rainy season. In the OND seasonal rainfall results, Lake Victoria basin still records the highest rainfall while North Eastern Region records the lowest for most parts of the study period. The North Western region recorded the highest rainfall of about 800mm in 2018 and then drastically dropped to less than 300mm by the year 2020. Generally, the OND short rain season shows greater rainfall variability as compared to the MAM long rain season. This greater variability can be attributed to the influence of El Nino Southern Oscillation Index (ENSO) and Indian Ocean Dipole (IOD) which causes more inter annual variability. The two systems are known to influence the OND rainfall more than MAM rainfall (Liebmann et al., 2014; Ogallo, 1988, 1989; Ongoma et al., 2018; Sagero et al., 2018). A study conducted by Opiyo, (2014) between 1950 to 2012 also confirmed our results by indicating a downward trend for the MAM seasonal rainfall and an upward trend for the OND seasonal rainfall. Gebrechorkos et al., (2019) discovered a notable downward trend in rainfall during the MAM season in central-eastern Ethiopia and Kenya. Furthermore, a significant upward trend in rainfall during the OND season was recorded in many areas of the region.

4.1.2 Maximum Temperature

The man Kendel test results for average maximum temperature showed a p-value of **0.592** which means there is no trend in the series. A study conducted by Opiyo, (2014) on the Tmax and Tmin temperature trends in Turkana County 1979-2012 confirms our results that the slight positive and negative trends observed were not statistically significant.

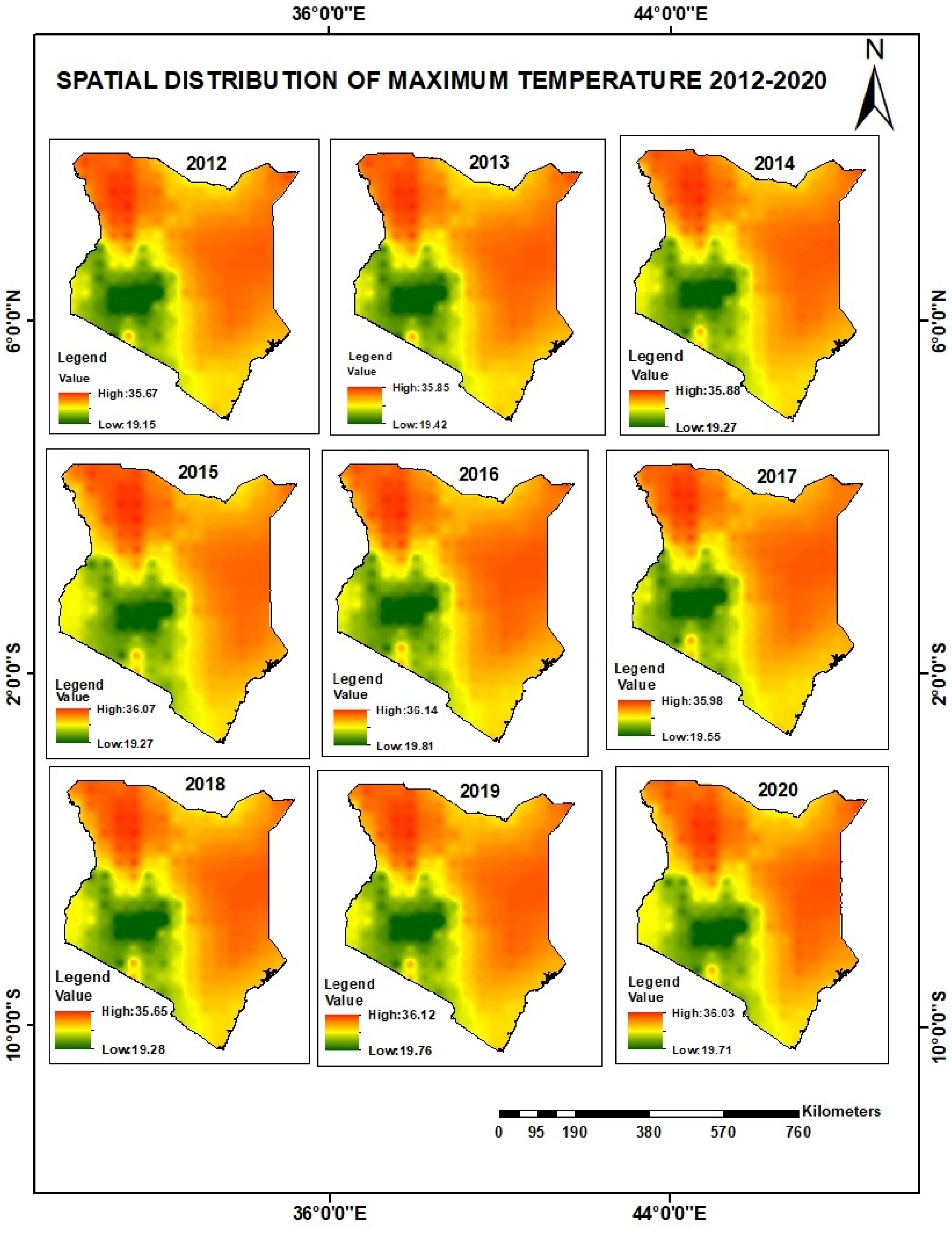

Figure 4.5: Spatial distribution of maximum temperature 2012-2020

The Saptial distribution of maximum temperature **(Figure 4.5)** shows that the Lake Victoria Basin and Highlands east of Rift Valley experience lower maximum temperatures throughout the study period as compared to the northern, eastern and the coastal parts. According to a report by the WBG, (2021) there is a significant variation in temperatures across Kenya, with the highlands experiencing much cooler temperatures than the lowland and coastal zones.

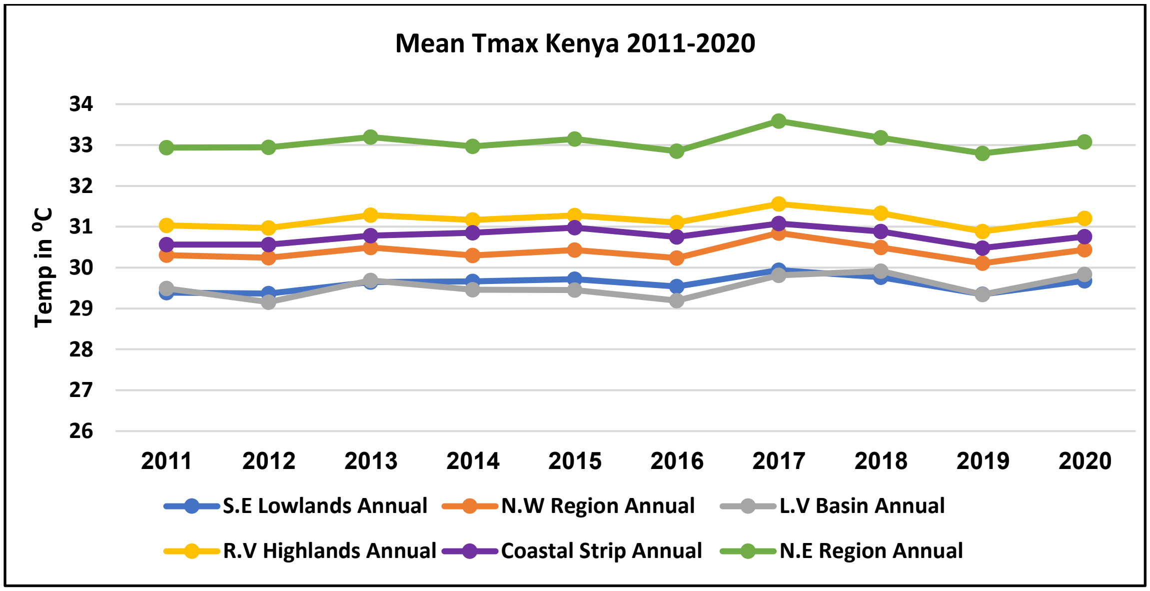

Figure 4.6: Temporal variation of mean annual maximum temperature 2011-2020

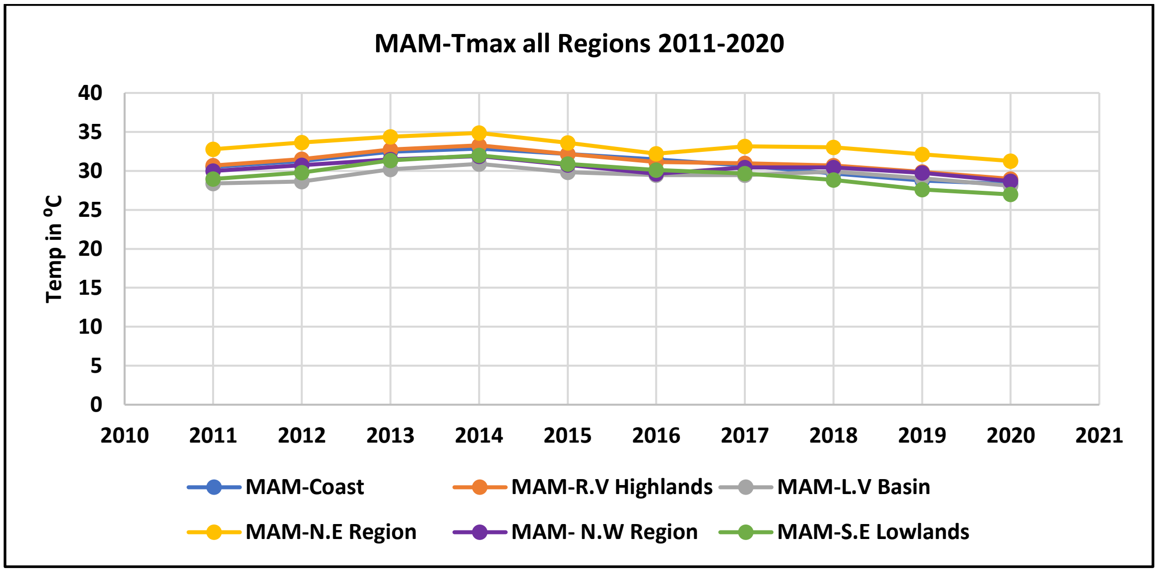

Figure 4.7: Temporal variation of seasonal Tmax-MAM

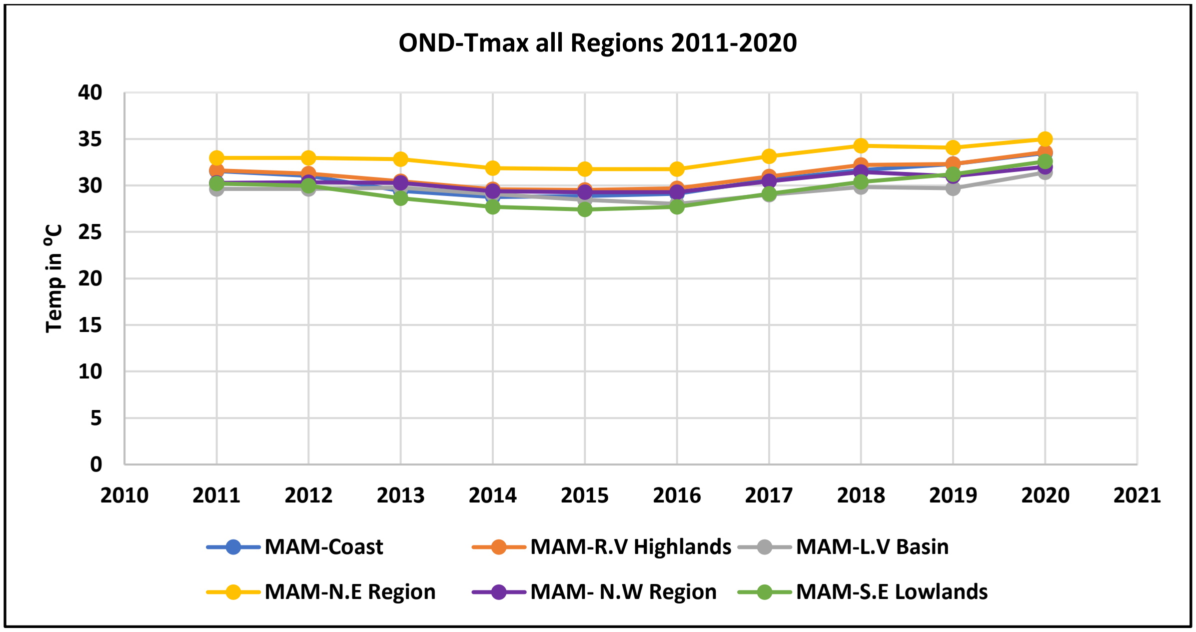

Figure 4.8: Temporal Variation of seasonal Tmax-OND

Generally, there is an increasing trend in Annual maximum temperature across all regions but it is not statistically significant (**Figure 4.6**). This confirms the results of a study conducted in Kitui County which is part of the South Eastern Region for the period of 1981-2011 (Gladys, 2017). Although temperature variations exist throughout Kenya, there is a noticeable warming trend, especially since the 1960s, with inland regions experiencing greater increases in both minimum and maximum temperatures, as reported by the (WBG, 2021). Another study was done in Nigeria between 1980-2015 which indicated that the trend statistics of annual maximum temperature was increasing generally for all stations, nevertheless not statistically significant (Umar et al., 2019). The North Eastern Region records the highest Mean Maximum Temperature ranging from 32.79°C-33.58°C throughout the study period followed by the Highlands East of Rift Valley 30.88°C-31.55°C. South Eastern Lowlands and Lake Victoria basin show lowest mean maximum temperature ranging from 29.34-29.93°C and 29.15-29.91°C respectively. The **MAM** seasonal Tmax in **Figure 4.7** shows a slight general increase from 2011-2014 after which the trend decreases for other regions except the North Eastern region which remains fairly constant. The North Eastern region also records the highest Tmax ranging from 31.27°C to 34.86°C while the Lake Victoria basin and South Eastern Lowlands record the lowest. On the other hand, the **OND** seasonal Tmax as shown in **Figure 4.8** shows a slightly increasing trend with the North Eastern Region recording the highest Tmax ranging from 31.75°C to 34.98°C and the South Eastern Lowlands recording the lowest. According to a study done on the East African region, noticeable rise in seasonal T-max of up to +3 °C was observed in many areas of the region, particularly during the MAM season. During the OND season, only a few regions in the area, such as eastern Kenya and southern and south-western Tanzania, showed a non-significant increase in T-max from 1979 to 2010. (Gebrechorkos et al., 2019). Another study done on the trends of surface air temperature over Kenya for the period of 1971-2010 indicated that there was generally an increasing trend for both Tmin and Tmax (B. O. Ayugi & Tan, 2019).

4.1.3 Minimum Temperature

The man Kendel test results for average minimum temperature the p-value was **0.592** indicating no trend in the series.

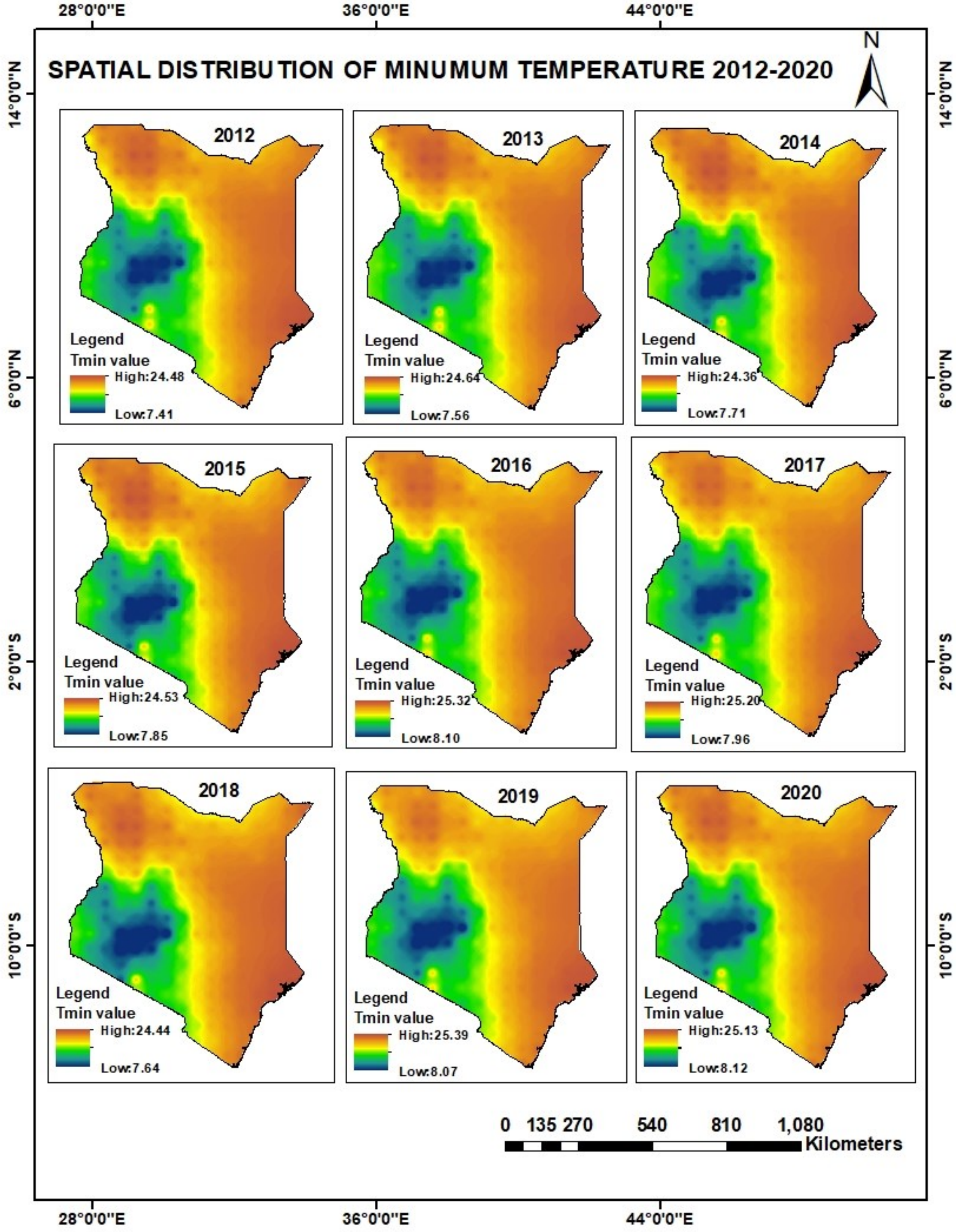

Figure 4.9: Spatial distribution of mean minimum temperature 2012-2020

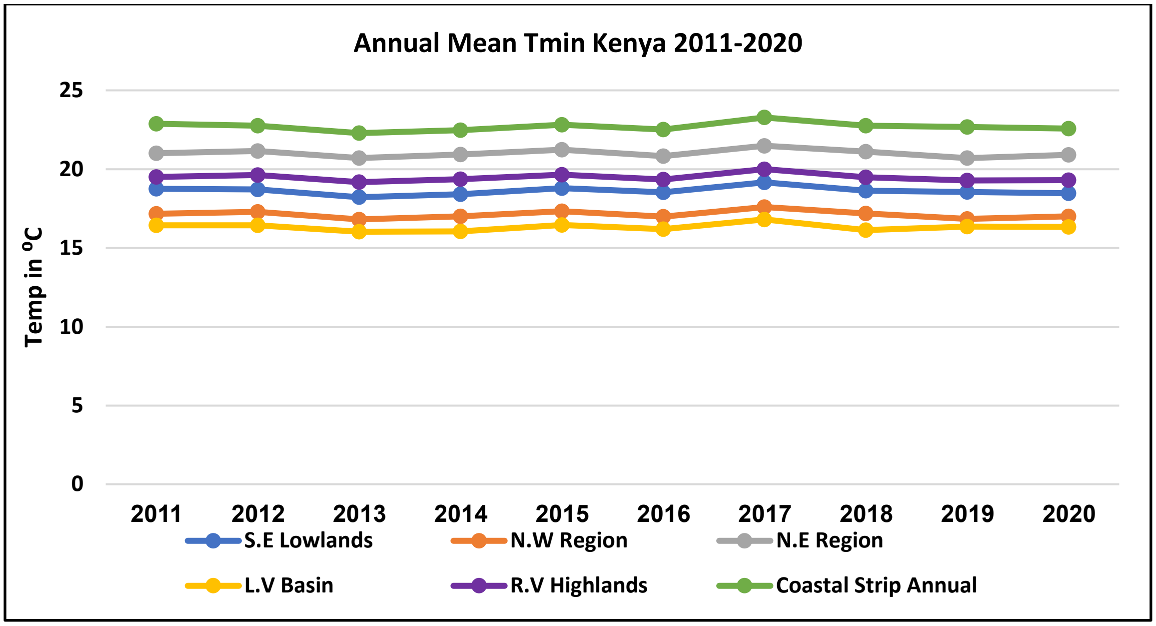

Figure 4.10: Temporal Variation of Annual Mean Minimum Temperature 2012-2020

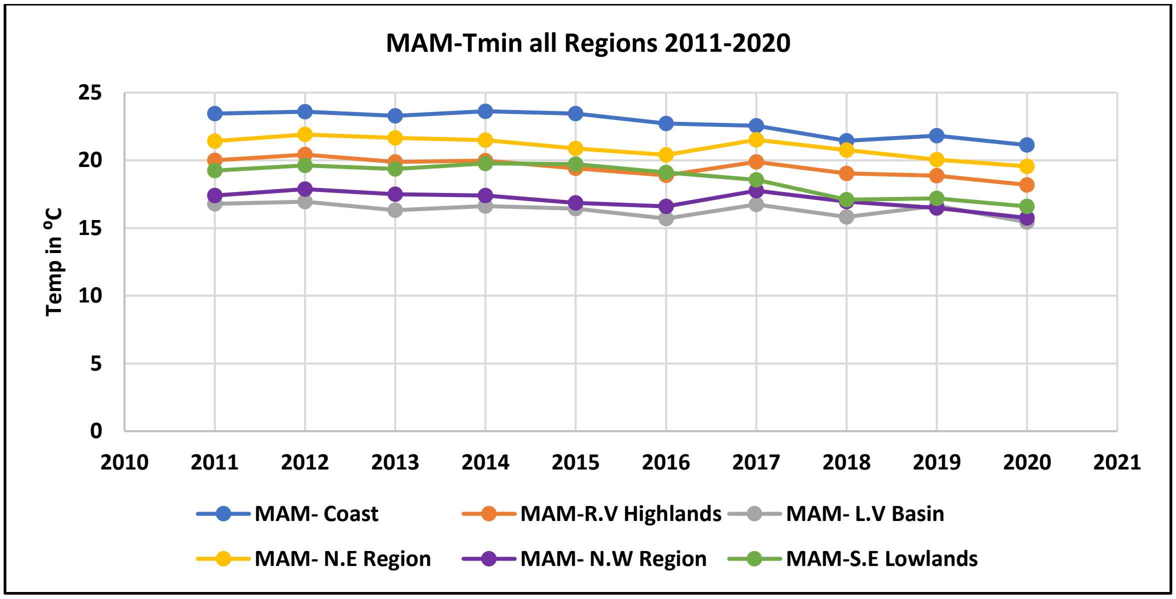

Figure 4.11: Temporal Variation of Seasonal Tmin -MAM

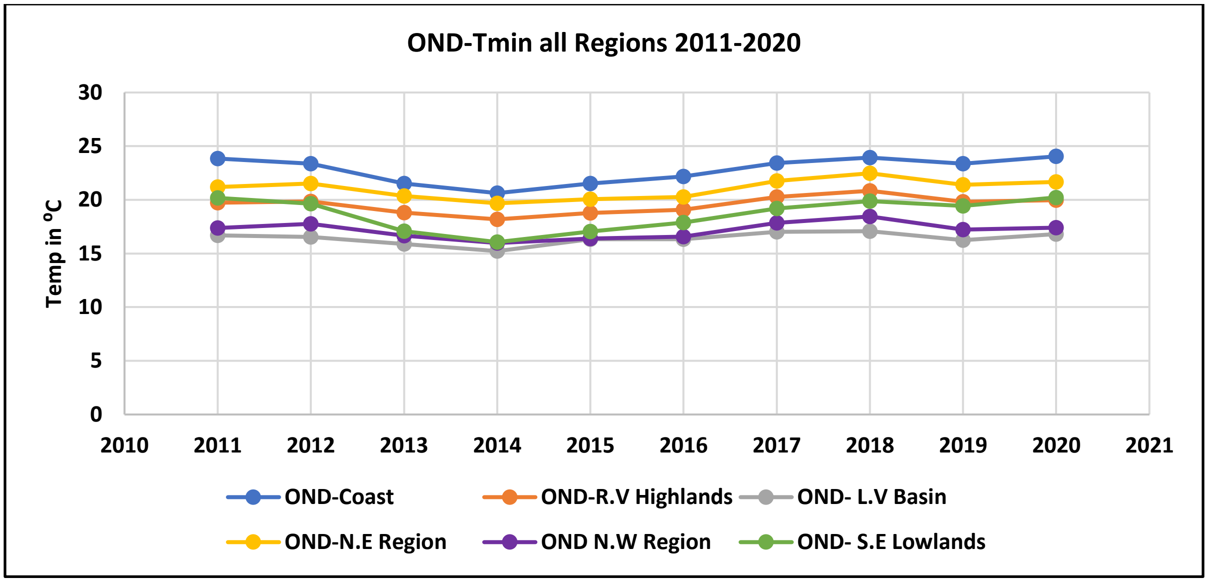

Figure 4.12: Temporal Variation of Seasonal Tmin-OND

The spatial maps of minimum temperature as shown in **Figure 4.9** depict a fairly constant distribution throughout the study period with the eastern and northern region experiencing higher temperatures while the central and western side experiences low temperatures. A study conducted by B. O. Ayugi & Tan, (2019) over Kenya from 1971 to 2010 confirmed that the highlands located in the western and central parts of the country exhibit low temperatures as compared to the arid and semi-arid lands of northern and eastern Kenya. He also noted a similar variation in spatial distribution. Annual Tmin in **Figure 4.10** shows no significant trend over time. The Coastal Strip records the highest Annual Mean Tmin ranging from 22.28°C-23.27°C as followed by the North Eastern Region 20.69°C-21.48°C. North Western Region and Lake Victoria basin record the lowest Annual Tmin ranging from 16.81°C-17.59°C and 16.02°C-16.80°C respectively. As shown in **Figure 4.11**, the **MAM** seasonal Tmin shows a decreasing trend with the coastal region recording the highest mean Tmin ranging from 22.28°C to 23.27°C followed by the North Eastern Region, 20.70°C to 21.48°C while the North western region and the Lake Victoria basin recorded the lowest mean seasonal Tmin. For the **OND** seasonal Tmin, the trend is fairly constant in **Figure 4.12** with the Coastal region again recording the highest Tmin, followed by the North Eastern Region. The North western region and Lake Victoria basin once again records the lowest mean seasonal Tmin. A study done on the East African region between 1981-2016 depicted significant increasing trend in Tmin in MAM (up to +2°C), particularly in Kenya and Tanzania. Statistically significant increasing trends in Tmin were also observed in southern part of Ethiopia of up to +1.2ºC during the MAM. For the OND however, the observed increasing trend was not statistically significant (Gebrechorkos et al., 2019). Another study conducted in the same region between 1986-2020 reported a positive trend in most of the meteorological stations both for the seasonal as well as annual timescales (Gashaw et al., 2023).

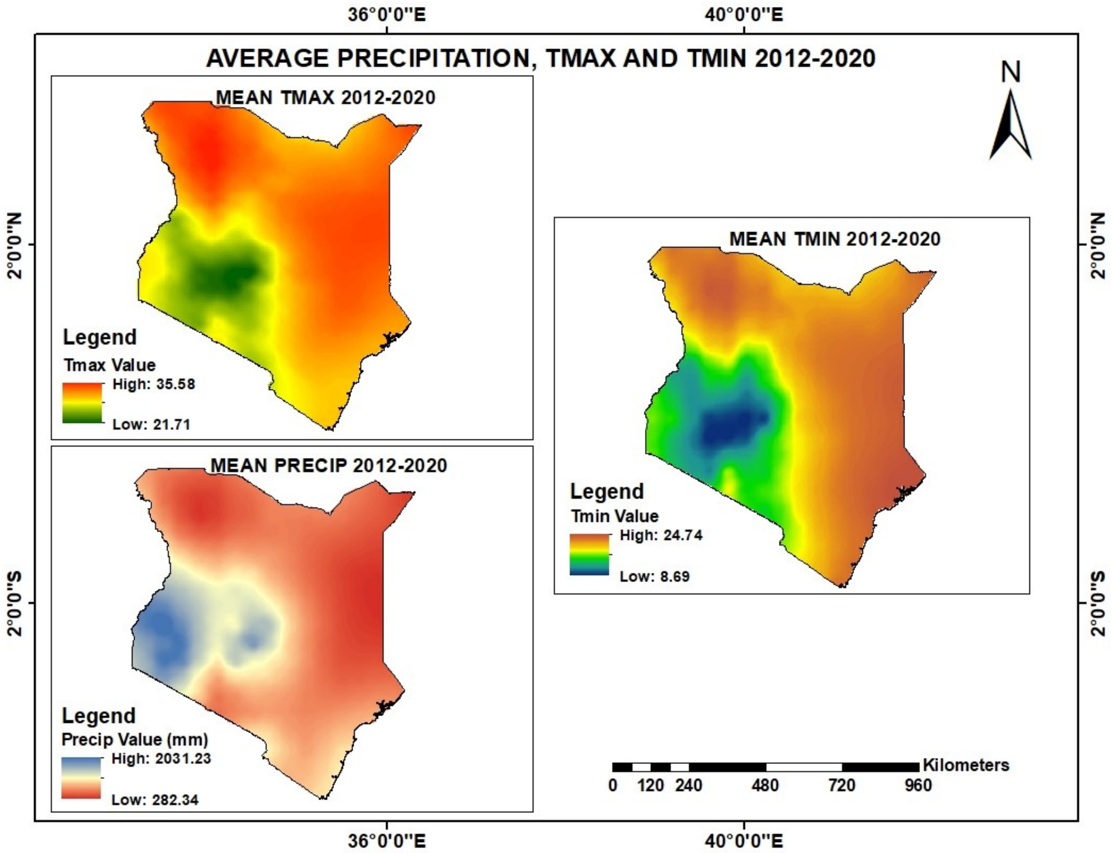

Figure 4.13: Average Precipitation, T-max and T-min 2012-2020.

Average precipitation ranges from 282.34mm to 2031.23mm as shown in **Figure 4.13**. The Lake Victoria basin located in the western part of the country receives more rainfall throughout the year as compared to other climatological zones and is thus considered wetter. Additionally, the mean annual rainfall over Kenya for the 2011-2020 period was found to be about 1010 mm. This confirms a study conducted by Fenta et al., (2017) over the east African region whereby he established that the mean annual rainfall is between 300 and 1200mm, much higher over the highlands and much lower over the lowlands. A study conducted by (Gebrechorkos et al., 2019) also showed long-term average maximum rainfall up to 2000mm in western parts of Kenya and Ethiopia, and south eastern parts of Tanzania. The mean maximum temperature for the study period, as shown in **Figure 4.13** ranges from 21.71ºC to 35.58ºC with an overall mean of 28.65ºC while the mean minimum temperature ranges from 8.69ºC to 24.74ºC with an overall mean of 16.72ºC. These results are similar to a study conducted in Borana area, Ethiopia whereby from 1981-2018, the mean annual Tmax was 29.66ºC while the mean annual T min was 16.31ºC (Worku et al., 2022). In another study, Maina et al., (2019) reported that the between 1981-2012, the maximum temperature of Kieni Constituency located in Nyeri County, had been rising as a result of climate change being experienced in the area. This confirms a report by the IPCC which states that most countries would experience increased average temperature due to climate change (IPCC, 2022). A study conducted by Gebrechorkos et al., (2019) over the east African region reported that the area with lower rainfall record exhibited higher T-max (up to 35 °C) and T-min (up to 25 °C) records, particularly in the eastern segment of the region, during the period of 1979–2010 (based on Observational Reanalysis Hybrid; OR). The observed T-min was low (<5 °C) in the central part of Ethiopia and south-western Tanzania and high (up to 25 °C) in the eastern part of Ethiopia and Kenya. In general, the eastern region of the study area displayed lower rainfall and higher temperature (T-max and T-min) records during 1981–2016 and 1979–2010, respectively (Gebrechorkos et al., 2019). This is consistent with the spatial distribution of the average Tmax, Tmin and precipitation as they show the eastern part of the country to be experiencing higher temperatures as compared to the western and central parts.

4.2: Effects of Rainfall and Temperature variability on Maize yield.

4.2.1 Maize Yield Distribution 2012-2020

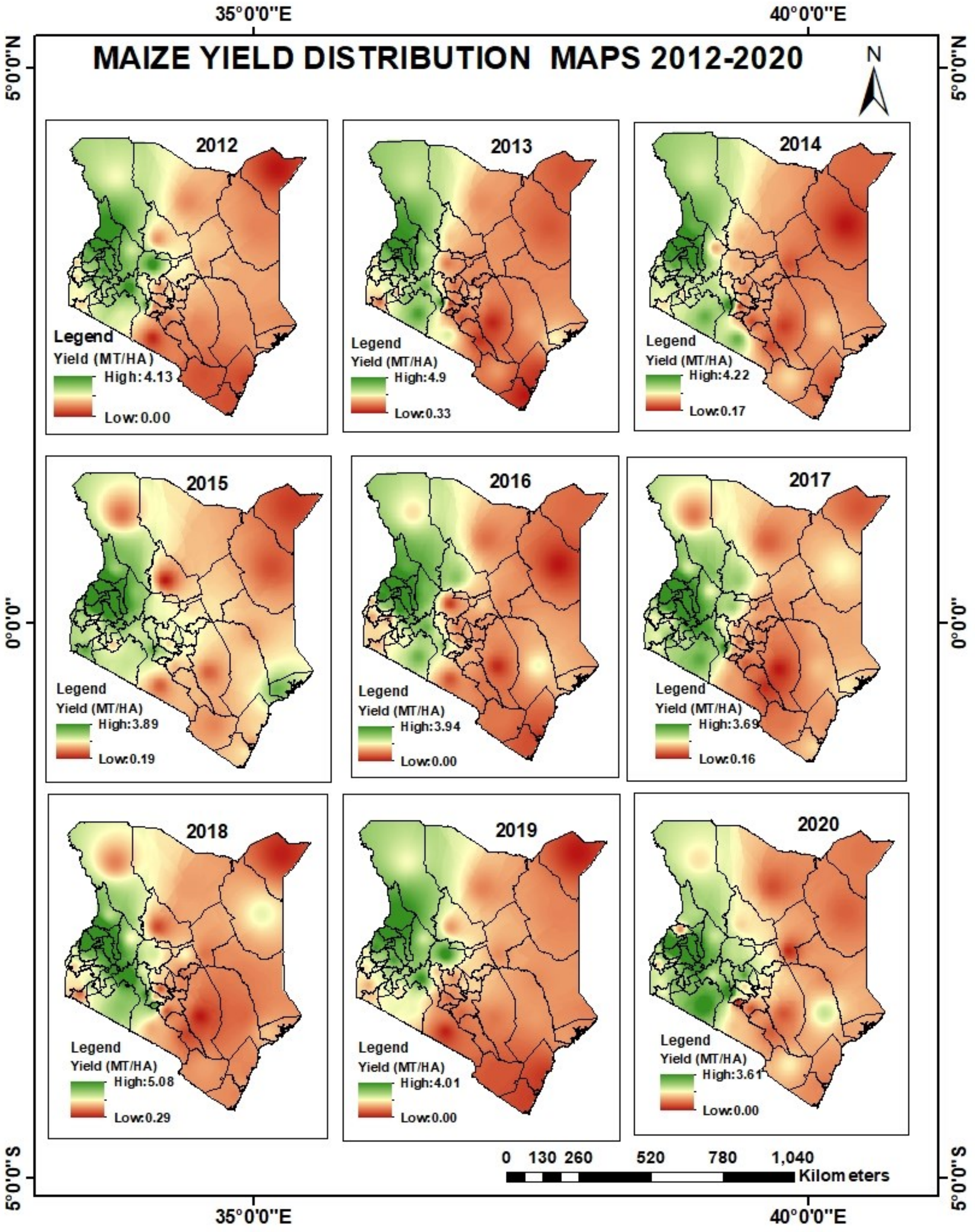

Figure 4.14: Spatial distribution of maize yield 2012-2020.

Generally, the display in the spatial distribution of annual maize yield (**Figure 4.14**) shows that the western and central parts of the country produce more maize as compared to the northern part. This is in agreement with a report by the World Bank Group (2021) which states, that the population of the country is predominantly concentrated in the western, central, and coastal regions, which make up less than 20% of the country's total area, but are home to almost 90% of the population. These regions are also known for their productive agricultural land, which is primarily dependent on rainfall (WBG, 2021). The spatial distribution of maize yield in the North Eastern region shows a decreasing trend from 2012 all the way to 2015 then increases again in 2016. In the central region also, there is a decreasing trend in the spatial distribution of maize yield from 2012- 2016 then the pattern changes in 2017 whereby an increase is observed. Generally, the spatial distribution follows a decreasing trend except for the years 2019 and 2020.

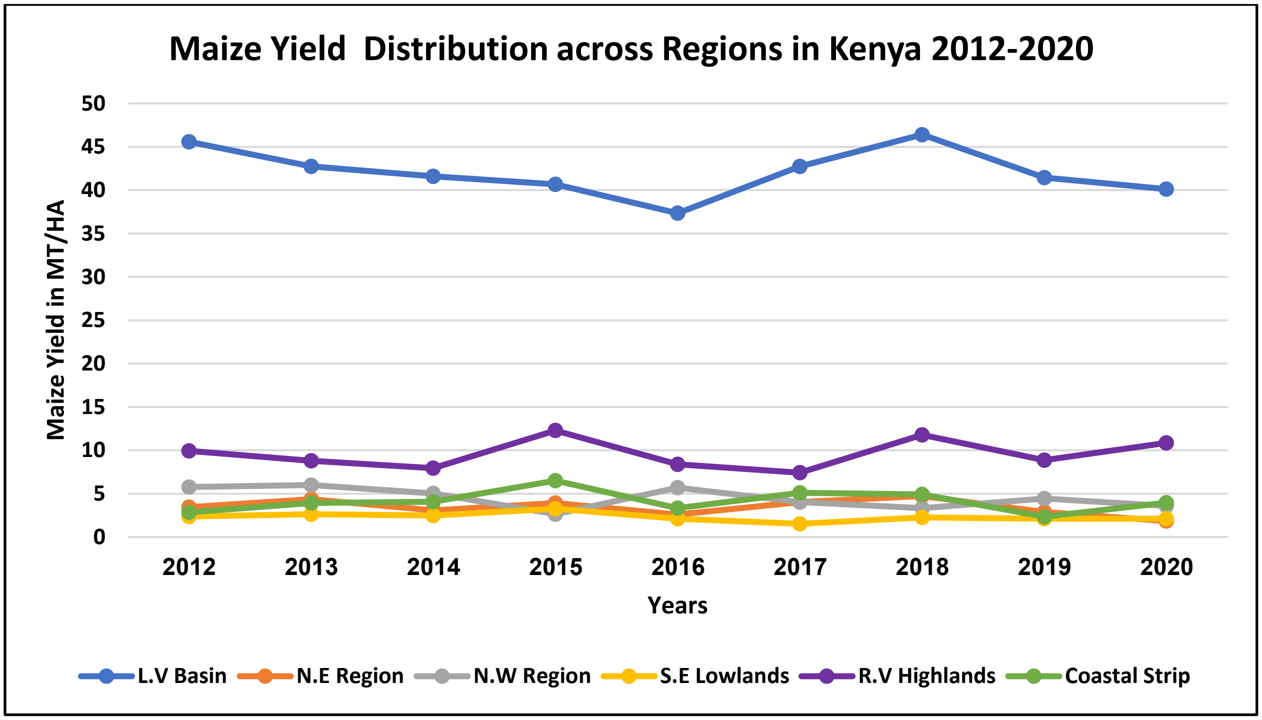

Figure 4.15: Temporal variation of maize yield 2011-2020

Figure 4.15 shows the maize yield distribution across various agro-climatological zones of Kenya. The Lake Victoria basin region records the highest yield throughout the 9 years (ranging from 40.12-46.40 MT/HA) followed by the Highlands East of Rift Valley (7.93-12.27 MT/HA). This is because these areas receive relatively high amount of rainfall throughout the year and these regions have always been leading in maize production in the country. The North Eastern

Region and South Eastern lowlands receive low amounts of rainfall thereby recording low maize yield ranging from 1.83-4.73 MT/HA and 1.52-2.61MT/HA respectively. This is because the northern part of Kenya has always been plagued by incessant droughts since the 1960s. Besides that, this area also experiences severe water scarcity rendering it impossible to produce sufficient maize to feed its population.

4.2.2: Spearman Rank Test Correlation Results of Maize Yield Verses Climatic Parameters

Table 4.1: Spearman rank test correlation results

Zone's yield (*y*)	**Factor (*x*)**	**r**	**R^2**	**T student**	**p value**
LVB_y	Rainfall	0.83	0.694	3.99	0.0053**
	Tmax	0.93	0.871	6.874	0.0002***
	Tmin	0.85	0.730	4.35	0.0034**
RVH_y	Rainfall	0.85	0.723	4.27	0.0037**
	Tmax	0.73	0.538	2.85	0.0246*
	Tmin	0.74	0.551	2.93	0.0219*
CS_y	Rainfall	0.92	0.853	6.38	0.0004***
	Tmax	0.63	0.401	2.17	0.0671*
	Tmin	0.71	0.500	2.65	0.0331*
NWR_y	Rainfall	0.82	0.667	3.74	0.0072**
	Tmax	0.72	0.514	2.72	0.0298*
	Tmin	0.75	0.563	3.00	0.0199*
NER_y	Rainfall	0.33	0.111	0.94	0.3807
	Tmax	0.07	0.004	0.18	0.8647
	Tmin	0.05	0.003	0.13	0.8984
SEL_y	Rainfall	0.50	0.250	1.53	0.1705
	Tmax	0.18	0.034	0.49	0.6368
	Tmin	0.55	0.303	1.74	0.1250

These results (**Table 4.1**) show that variability in climatic parameters that is rainfall, maximum temperature and minimum temperature has an impact on maize yield for four climatological zones. According to the results there's a strong positive correlation between maize yield and the climatic parameters for the, Lake Victoria Basin, Highlands East of Rift Valley, Coastal Strip and North Western Region. In all the four cases, except T-max for the Coastal Strip, the R^2 is 0.5 and above while the p value is <0.05. Indicating that there is a significant relationship between maize yield Rainfall, T-min and T-max. In the North Eastern Region and the South Eastern lowlands however, there was no significant correlation between maize yield and the climatic parameters. The p value >0.05 for both cases. This result validates a study conducted by Mumo et al., (2018b) whereby the correlation between climate parameters and maize yield was higher in the major maize growing stations while the strength of the relationship decreased towards the ASALS. The high correlation values implied that the station is a major contributor of the national harvest and its rainfall variability impacted the national yield. In a study conducted by (Kabata et al., 2021) on the seasonal rainfall variability effect on small holder farmers in Nyeri County, at 1% level of significance, there was a strong positive correlation between rainfall and maize yield. As per a study executed by Mumo et al., (2018b), minimum temperature anomalies exhibited significant detrimental impacts at the Kakamega and Kisii stations, which are crucial maize-growing regions in Kenya's highlands. These two stations, situated in the highlands of Kenya, suggest that the rise in minimum temperature has surpassed acceptable thresholds and is now inflicting negative consequences on maize production. These two stations fall under the Lake Victoria Basin which recorded the highest maize yield according to our study. This study therefore validates our findings that in the Lake Victoria basin, there is a significant correlation between maize yield and minimum temperature at $p= 0.0034$. A similar study conducted by (Chabala et al., 2015) over six districts in Zambia which represents the three agroecological zones of the country showed that only one district, Nyimba, showed a significant variation in maize yield that could be attributed to the climatic variables of rainfall and temperature. (WU et al., 2021) however got results that slightly differ with our findings. In a study exploring the impacts of climate change on maize yield in China using the FGLS model, his results showed that during the 1979-2016 period, temperature negatively impacted maize yield while precipitation was found to have a positive but overall negligible impact. In the North Eastern Region and the South Eastern lowlands however, there was no significant correlation between maize yield and the climatic parameters. The p value >0.05 for both cases. A study conducted by (Omoyo et al., 2015a) on the effects of climate variability on maize yield in the ASALS of lower eastern Kenya confirms our result that the in the South Eastern Lowlands, there is no correlation between climatic variables and maize yield. A study conducted by (Atiah et al., 2022) using the multivariate regression analysis method in Ghana revealed that the climatic parameters of soil moisture, maximum temperature, minimum temperature and precipitation together accounted for 75% of variations of maize yield under wetter than normal conditions.

4.3: Possible impact of land use land cover change on maize yield in Kenya

4.3.1: Land Use Land Cover Classification for The Years 2011 And 2020

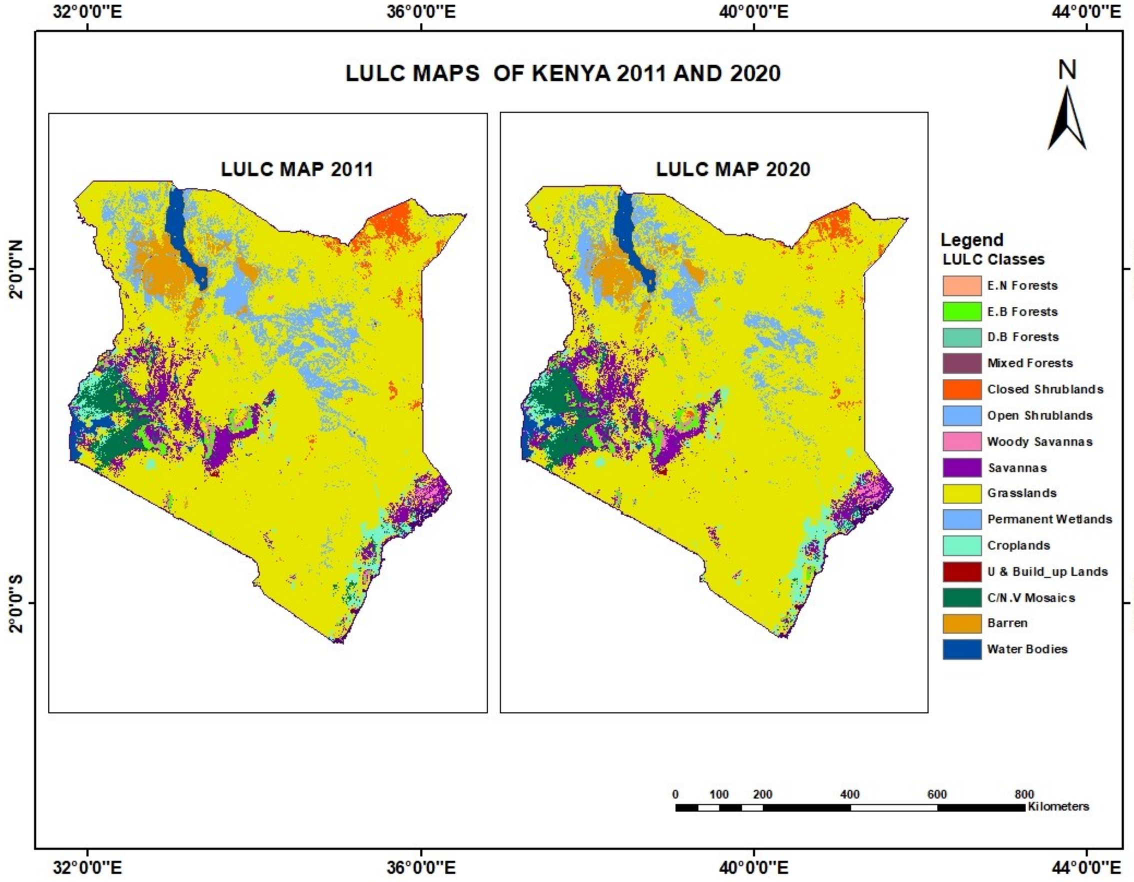

Figure 4.16: LULC maps of Kenya 2011 and 2020

From **Figure 4.16** we can see the spatial differences between the land use and land cover map of 2011 and that of 2020. Open shrublands, closed shrublands and barren land have increased in area between 2011 and 2020 while grasslands, savannas, croplands and water bodies have significantly reduced in area. Other land use classes have also either reduced or increased but not significantly. A study conducted in western Nepal on land cover change and its impact on crop yield for the years 2000, 2010 and 2019 (Bhandari et al., 2022) also established that forest land was increasing while agricultural land was decreasing in the area. The reduction in croplands and water bodies could be as a result of climate variability experienced in the area. This could have a negative impact on maize yield being the staple food in the country. According to a report by the WMO, (2022), the pastureland and cropland areas in East Africa were adversely affected by prolonged drought conditions. The reduction in croplands could also be attributed to increased population leading to subdivision of agricultural land into smaller uneconomic units which eventually affect yield.

4.3.2: Land Use Land Cover Change in Area (Square Meters) From 2011-2020

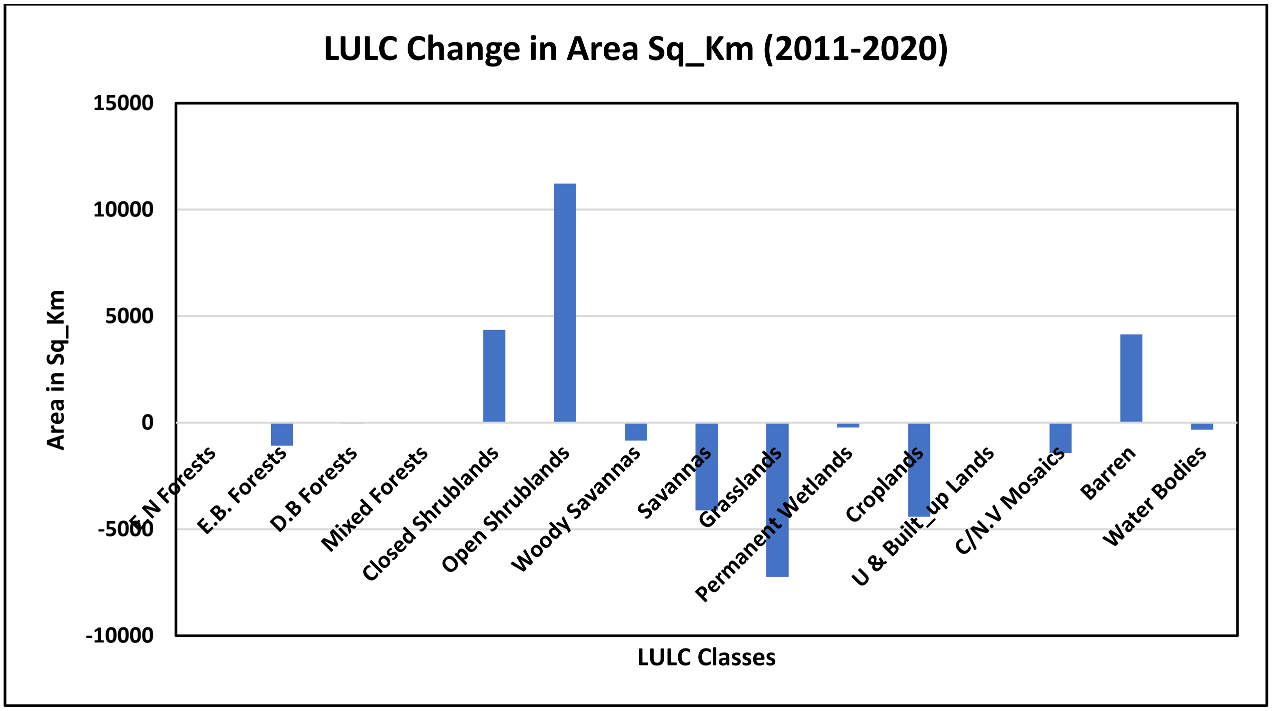

Figure 4.17: LULC Change in area Sq_Km 2011-2020

Figure 4.17 shows that open shrublands increased significantly in area by 11,229km2, closed shrublands by 4365km2 and Barren land by 4145 km2. On the other hand, grasslands recorded the highest decrease in area of about 7235 km2 followed by croplands, 4414km2 and Savannah 4116km2. The decline in croplands could be as a result of urbanization, increased population, establishment of more settlements in areas previously used for cultivation as well as low economic returns from agriculture. Urban and build up lands, mixed forests, deciduous broadleaf forests and evergreen needleleaf forests did not show any significant change in area. A study conducted by Fred Muchuma et al., (2021) also recorded a significant decrease of 5.379 % in annual cropland in Bungoma county for the years 2002-2014. Another study conducted by Onyango et al., (2021) also recorded a decrease in agricultural land over Busia, Siaya, Migori, Homabay and Kisumu counties by about 22.63% from 1978 to 2018. The study however, contrary to our findings, indicated that grasslands had increased during the study period for the few selected counties in western Kenya. This difference could be attributed to the difference in study period and scope of the study. A study conducted by Maina et al., (2020) also showed an increase in bare land by 9.36% in Central Kenya from 1987-2017. Balaka Opiyo et al., (2022) also reported similar results showing a decrease in grasslands by 70.32km2, increase in bare land by 59.77km2 and decrease in water bodies by 8.63km2 between 2010 and 2020 over Migori river watershed. In conclusion, the decline in croplands by 4414km2 as a result of land use changes is likely to have impacted agricultural productivity in Kenya resulting in decline in maize yield.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS.

5.1 Conclusion

The growing frequency and severity of severe weather and climate occurrences are diminishing agricultural productivity, spurring agricultural expansion, and jeopardizing biodiversity and ecosystems. Climate change and the depleting natural resource base may exacerbate disputes over scarce productive land, water, and pastures, as farmer-herder violence has risen over the past decade due to mounting land pressure, particularly in many sub-Saharan countries, as reported by (WMO, 2022). Kenya is particularly vulnerable to the impacts of climate variability and land use changes due to its dependence on rainfed agriculture. Land has been shrinking due to sub-division, combined with unsustainable land management practices thus causing a decline in land productivity. Land use changes caused by urbanization and population increase have also further intensified the decline in agricultural land thus posing a risk to food production and food security. The interlinkages between climate variability, land use and land cover change and maize yield are scanty and unexplored in Kenya. Besides, most of the similar studies focused on smaller study areas within the country and did not combine the aspects of climate variability dynamics and land use land cover change. Hence, this study sought to examine the spatial temporal impacts of climate variability and land use land cover change on maize yield in Kenya for the period of 2012-2020. Maize yield data used in the study was obtained from the Kenya Maize Yield Database while gridded monthly precipitation, maximum temperature and minimum temperature data was obtained from the CRU website. The Land Cover Type Product (MCD12Q1) offered by MODIS was used and analysis was done using ArcGIS and Microsoft Excel. According to the results, the spatial maps highlight prevalence of wetter areas in the Lake Victoria basin and Highlands East of Rift Valley as compared to the North Eastern and North Western Regions. Lake Victoria basin had the highest mean annual precipitation followed by the north western region. Lowest annual rainfall patterns were recorded by the Highlands east of rift valley and the north eastern region. Generally, the OND short rain season shows greater rainfall variability as compared to the MAM long rain season. This variability can be attributed to the influence of El Nino Southern Oscillation Index (ENSO) and Indian Ocean Dipole (IOD) which causes more inter annual variability. The North Eastern Region records the highest Mean Maximum Temperature ranging from 32.79ºC-33.58ºC. This is because the area has always been plagued by incessant droughts since the 1960s and is generally hotter compared to the rest of the country. The mean annual temperature was fairly constant and did not show any trends over time. The Coastal Strip recorded the highest Mean Minimum Temperature ranging from 22.28⁰C-23.27⁰C. The spatial distribution of annual maize yield shows that the western and central parts of the country produce more maize as compared to the northern and eastern parts. This is because the population of the country is predominantly concentrated in the western, central, and coastal regions, which make up less than 20% of the country's total area, but are home to almost 90% of the population. These regions are also known for their productive agricultural land, which is primarily dependent on rainfall. The results of the Spearman rank correlation test show that there's a strong positive correlation between maize yield and the climatic parameters for the, Lake Victoria Basin, Highlands East of Rift Valley, Coastal Strip and North Western Region. In all the four cases, except T-max for the Coastal Strip, the R^2 is 0.5 and above while the p value is <0.05. Indicating that there is a significant relationship between maize yield and the climatic parameters in these regions. It is also important to note that the correlation between climate parameters and maize yield was higher in the major maize growing stations located in the western and central parts of the country while the strength of the relationship decreased towards the arid and semi-arid areas that are often plagued with incessant droughts. The results of the land use land cover classification showed that open shrublands increased significantly in area by 11,229km2, closed shrublands by 4365km2 and Barren land by 4145 km2. On the other hand, grasslands recorded the highest decrease in area of about 7235 km2 followed by croplands, 4414km2 and Savannah 4116km2. The decline in croplands could be as a result of urbanization, increased population, establishment of more settlements in areas previously used for cultivation as well as low economic returns from agriculture. In conclusion, changes in climatic parameters have a positive correlation with maize yield for four out of the six climatological zones studied. This implies that increased climate variability is likely to reduce maize yield thus intensifying food insecurity in the country. Land use land cover changes experiences between 2011 and 2020 also resulted in a decline in croplands and an increase in barren land. The findings suggest that climate variability in the study area has a significant impact on maize yield for four out of six climatological zones as evidenced by decline in precipitation trends for the MAM season which is the long rainy season. Land use and land cover changes also have a negative impact on maize yield through decline in croplands by 4414km2 from 2011 to 2020. This points out the importance of monitoring land use changes to combat further diminishing of agricultural land that would otherwise intensify food insecurity in the country. The climatic parameters did not exhibit statistically significant trends because of the short study period. There is need for the government of Kenya to formulate and enforce policies and frameworks that would integrate climate change and its associated impacts into development planning and implementation, to build resilience and enhance adaptation.

5.2 Recommended Adaptation Measures

In order to enhance adaptive capacity and build resilience to climate variability and change, it is crucial to develop policies and frameworks that provide a clear and concise articulation of overall response priorities. Through the development and adoption of such policies and frameworks, governments can integrate climate change considerations into development planning, budgeting, and implementation across all sectors and levels. These policies should aim to promote a low-carbon development pathway while enhancing adaptive capacity and building resilience to climate variability and change. The research also emphasizes the need for formulating and enforcing land use policies that protect against various causes of land use and cover change. These policies could be developed against the loss of agricultural land due to excessive land subdivision and the conversion of agricultural land to other land uses. Adopting modern technologies in GIS and remote sensing can enable the formulation of informed policies. These technologies can ensure regular updates of land use plans and constant monitoring against land use and cover change. Adaptation measures for crops can include the use of adapted varieties or breeds, which have different environmental optima and/or broader environmental tolerances. This approach can help hedge against the risk of individual crop failure. Additionally, varying planting dates can be an effective adaptive change in crop management to avoid losses in case of delays in the onset of precipitation. Increasing the use of irrigation where possible, can also improve production during reduced rainfall periods. To further spread risks, it is recommended to increase the diversity within production systems. This can be achieved through various means, such as combining different types of production (crop, forest, fish, and livestock) in different ways or increasing the numbers of different species, populations, varieties, or breeds.

5.3 Recommendations for further studies

Based on the outcome of this study and the challenges and shortcomings experienced, the following recommendations are given for further studies; Undertake a more detailed spatial analysis at smaller scales, such as the district or sub-county level, to capture the localized impacts of climate variability and land use changes on maize yield. Secondly, employ higher-resolution satellite imagery, such as Sentinel-2 or Landsat data, to better comprehend the specific dynamics within smaller geographic areas. Thirdly, incorporate socioeconomic factors into the analysis to gain a deeper understanding of the human dimensions of maize yield variability. Fourthly, examine factors like access to resources, socioeconomic status of farmers, adoption of agricultural technologies, and market dynamics, and explore how these elements interact with climate variability and land use change to influence maize yields. Again, it may be important to broaden the study beyond the 2012-2020 timeframe to capture longer-term trends including future projections using appropriate models to comprehend how maize yields have been affected by climate variability and land use change over an extended period. The models could help quantify the contributions of various factors to maize yield variability and assess potential adaptation strategies. Last but not least, use advanced remote sensing techniques, like machine learning algorithms or time series analysis, to extract more detailed information from satellite imagery and other geospatial datasets. These techniques can help identify subtle changes in land use, land cover, and climate variables that may significantly impact maize yield.

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