# ASSESSMENT OF THE IMPACTS OF CLIMATE VARIABILITY AND CHANGE ON MAIZE PRODUCTIVITY IN NAROK COUNTY, KENYA.

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# DECLARATION

This Dissertation is my original work and has not been presented for examination in this University or any other academic institution. All the sources used herein have been acknowledged.

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# DEDICATION

To my daughter Jasmine, for your unconditional love, understanding and being my continuous source of hope and inspiration.

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# ABSTRACT

Maize is an essential staple food crop in Kenya, including Narok County, whose productivity is often constrained by marked variability in the biophysical and socio-economic factors within the production environment. Climate variability and change threaten the sustainability of smallholder agricultural systems and food security in the county. Thus, strategies that can deliver enhanced and sustainable maize yields and food security are of urgent priority to Kenya and Narok County in particular.

This study therefore, aimed to assess the impacts of climate variability and change on maize productivity in Narok county of Kenya. The study used observed daily rainfall, maximum and minimum temperature data for eleven stations in Narok County for the period 1981-2018 obtained from the Kenya Meteorological department, annual maize yield data expressed in MT/ha from the Ministry of Agriculture, Livestock, Fisheries and Cooperatives and CNRM model outputs. Intra-seasonal climate characteristics of onset and cessation dates, number of rainy days, wet spell length, dry spell length, length of the growing season, seasonal total rainfall, maximum temperature, minimum temperature, temperature range and Growing Degree Days (GDD) were analyzed. The double mass curve was used to test for data homogeneity. Time series analysis was employed to determine temporal distribution of the data sets. The *Instat Plus* statistical package Version 3.36 was used to determine rainfall characteristics at station level. Pearson's correlation coefficient was used to determine the degree of association between pairs of study variables. The relationship between intra-seasonal climate characteristics and maize yields was determined using the multiple linear regression technique.

Rainfall onset dates for most stations indicated an increasing trend, implying late onset of rains in recent years. The cessation dates for the rainy seasons depicted a decreasing trend hence early rainfall cessation in most of the study stations. The length of growing season indicated a decreasing trend, implying shorter/ reduced length of the growing season. The seasonal total rainfall for MAM season decreased over most stations. Dry spell length increased over the study period. Conversely, the intra-seasonal wet spell lengths indicated decreasing trend, signifying shorter lengths of wet spell over the study area. The number of rainy days during MAM season indicated a decreasing trend, implying reduced rainy days within the season. GDD, temperature range, maximum and minimum temperatures indicated an increasing trend over the study period 1981-2018 for all the study stations.

The results further revealed increased climate variability under future climate (2021-2050) based on both RCP4.5 and RCP8.5 emission scenarios; with more increased climate variability based on RCP8.5 compared to RCP4.5. Both emission scenarios project increased temperature and rainfall during the period 2021-2050. Future climate will more severely impact maize yields under RCP8.5 as compared to RCP4.5. By the year 2050, maize yields are projected to decline by 2.5% based on RCP4.5 and 10.3% based on RCP8.5 emission scenarios. Consequently, effective adaptation strategies to climate variability and change impacts including adoption of drought tolerant early maturation maize varieties and relay cropping in regions with increased lengths of growing season will be key in ensuring increased and sustainable maize productivity and food security in Narok County.

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| | |
|---|---|
| AR5 | Fifth Assessment Report of the Intergovernmental Panel on Climate Change |
| CCCMA | Canadian Centre for Climate Modelling and Analysis |
| CNRM | National Centre for Meteorological Research |
| CORDEX | Coordinated Regional Downscaling Experiment |
| CRU | Climate Research Unit |
| CSIRO | Commonwealth Scientific and Industrial Research Organization |
| CV | Coefficient of Variability |
| CRU | Climate Research Unit |
| DSL | Dry Spell Length |
| ESMs | Earth System Models |
| GCM | General Circulation Model |
| GDD | Growing Degree Day |
| GDP | Gross Domestic Product |
| ICHEC | Irish Centre for High-End Computing |
| IPCC | Intergovernmental Panel on Climate Change |
| ITCZ | Inter-Tropical Convergence Zone |
| MAE | Mean Absolute Error |
| MAM | March- April- May |
| MIROC | Model for Interdisciplinary Research on Climate |
| MLND | Maize Lethal Necrosis Disease |
| MLR | Multivariate Linear Regression |
| MOHC | Met Office Hadley Centre |
| MPI-M | Max Planck Institute of Meteorology |
| MPI-ESM-LR | Max Planck Institute Earth System Model-Low Resolution Grid |
| NCCRS | National Climate Change Response Strategy |

| | |
|---|---|
| NOAA | National Oceanographic and Atmospheric Administration |
| OND | October- November- December |
| RCA4 | Rossby Centre Regional Atmospheric Model |
| RCMs | Regional Climate Models |
| RCP | Representative Concentration pathways |
| SDGs | Sustainable Development Goals |
| SSA | Sub-Saharan Africa |
| T max | Maximum Temperature |
| T min | Minimum Temperature |
| T range | Temperature range |
| UNDP | United Nations Development Program |

# CHAPTER ONE

## 1.0 INTRODUCTION

This chapter entails, the background information, the statement of the problem, study objectives, hypotheses tested, research questions and the justification for this study.

### 1.1 Background

Climate change is the biggest global, regional and local challenge in the 21st century that is threatening the achievement of sustainable development goals (SDGs). The most notable impacts are being felt in the SDGs 1 and 2, targeting to end poverty and hunger and consequently food insecurity through sustainable agriculture production by the year 2030 (UNDP, 2015).

Climate change refers to statistically significant variation in mean state of the climate, often manifested by changes in mean and/or variability of its properties that lasts for a long period of time (Majahodvwa & Masuku, 2013). Climate variability on the other hand, refers to variation in the mean state and other statistics of climate on all temporal and spatial scales, beyond individual weather events (IPCC, 2007).

The agriculture sector in most developing African countries including Kenya, is the mainstay of the country's economy, providing 75% of employment opportunities, ensuring food security and an invaluable source of income among farming communities (Ministry of Agriculture., 2009). It is also a key sector that drives sustainable development goals (Kariuki, 2018).

Globally, maize is considered an important cereal crop. In Africa, maize is the number one cereal crop produced in aggregate quantity compared to other cereal crops (Macauley & Ramadjita, 2015). In East Africa maize serves as a dominant staple food crop, and accounts for about 27.1% of all crops grown, followed by sorghum (8.6%) while coffee accounts for 3.1% (Mumo, 2018).

Maize production in Africa increased in the last decade, and spread in both the driest and wettest regions in Africa. It is increasingly replacing other cereal crops including rice, millet and sorghum, particularly in Southern and Eastern Africa where maize has become an important staple crop (Murenzi, 2019).

Climate variability and change associated extreme conditions would impose adverse impacts on agricultural productivity, thereby negating the desired outcomes from the agricultural sector that comprise, both national economic growth and community livelihoods (Masambaya, 2018).

Climate change threatens to significantly decrease cereal crop yields under rain-fed conditions in Africa. This is mainly as a result of increased water stress due to high rates of evapotranspiration, shortened and disrupted growing season length, and proliferation of pests, weeds and diseases (Niang et al., 2014).

Increasing global average temperature is projected to result in severe droughts in semi-arid areas, coastal inundation and damage from storms (IPCC, 2014) . These adverse impacts have already been observed and are increasing in frequency and in severity in almost all socio-economic sectors in Kenya. Rain-fed agriculture will bear the largest brunt of the impact (Government of Kenya, 2010). Threats to the crop subsector will likely result in yield losses for every 1$^{o}$C of warming (Lobel et al., 2011), and in extreme cases force significant tracts of cropland out of production in Kenya (Stephen et al., 2015).

Since 1960, the entire world has been experiencing increasing warming of the atmosphere. The average temperature in Kenya increased by 1$^{o}$C, translating to 0.21$^{o}$C/decade. Temperatures in the hottest months of December-January-February increased by 0.29$^{o}$C and 0.25$^{o}$C in the cooler months of June-July-August (Masambaya, 2018). Furthermore, rainfall increased in the October-November-December (OND) rainy season and decreased during March-April-May (MAM) season. Generally, the pattern of rainfall has become quite unreliable (Parry et al., 2012).

Over time, the climate of Kenya has become highly variable, with deleterious secondary manifestations such as droughts, floods, frost, hailstorms, and strong winds among others, often fluctuating between all ranges of extremes across key climatic elements. Climate change will therefore exacerbate risks posed by these climatic extremes (IPCC, 2014).

Kenya’s climate has been successively warmer in the past three consecutive decades (Ochieng, 2016). Rising surface temperatures, erratic and unreliable patterns of rainfall and increased frequency and severity of climate related extreme weather events are projected to negatively impact agricultural production, as most crops within the tropics grow close to their optimum temperatures (Conway, 2009). These have serious consequences for climate sensitive livelihoods and food security situation in Africa.

Maize remains an important staple food in the diet of a large proportion of the Kenyan population and an important source of calories in local diets and provides 42% of dietary nutrition value (Wanjala, 2016; Mumo, 2018). In terms of the land under cultivation, the portion under maize accounts for more than 40% in Kenya and 51% of all staples produced in the Country (Ministry of Agriculture, 2011).

Rain-fed agriculture is the mainstay of Narok County's economy, livelihood, income source, and staple food for most of its rural population (KFSSG, 2016). On average, the county produces 3.5 to 4 million 90kg bags of wheat and maize annually (Narok County Government, 2013). However, the sector and in particular crop farming is extremely vulnerable to climatic shocks (Herrero et al., 2010). The absence of crop and enterprise diversification strategies, further threatens to exacerbate the vulnerability of smallholder farming communities (Kariuki, 2018).

Maize production in the country increased steadily from the 1960s to the mid- 1970s mainly due to the Green revolution, improved agricultural technology comprising introduction of new hybrid cultivars, fertilizer and improved farm management practices (Mumo 2018). However, from 1994 there has been a decline in crop yields largely contributing to maize consumption deficit over the years. This has thus broadened the gap between production and consumption, in addition to heightening the frequency of shortages of supply (Kariuki, 2018).

In Kenya, maize is cultivated by smallholder farming communities in rural areas, who rely mainly on rainfall for its production, with fluctuations in rainfall threatening its optimization within the country (Stephen et al., 2015). In the recent decades, there has been rapid population growth in the country, significantly exerting more pressure on available natural resources. This has made the local domestic demand for maize to exceed the local supply, thereby transforming Kenya into a net importer of maize (Wandaka, 2013). Rising temperatures during the long rainy season (MAM), have been observed to shorten crop growth and development stages and reduce both the quality and quantity of maize yields in Kenya. This has consequently decreased income from maize (Wandaka, 2013) .

Maize availability and food security in Kenya and in Narok County in particular, are intricately linked. Adequate availability and accessibility of maize, both at household and national levels is an indication of food security (Kariuki, 2018). The adverse climate change impacts on agriculture have significantly reduced local maize productivity, consequently compromising Kenya's food security (Mati, 2000), and by extension, severely threatening the achievement of Kenya's Big Four Agenda on realizing national food security and the national development goals under Kenya's vision 2030.

Many documented studies, concur that climate change will significantly reduce yields of maize under rain-fed agriculture production conditions (Jones &Thornton, 2003; Rowhani, Lobel et al., 2011), characterized by low soil fertility (Mumo, 2018) as is the case in Narok County of Kenya. It is in this regard that this study sought to assess the impact of climate variability and change on maize productivity in Narok County of Kenya.

## 1.2 Problem Statement

Climate is a critical input and determinant of the success and profitability of rain-fed agriculture production and consequently an enabler of the overall economic performance in agriculture dependent countries such as Kenya. Maize is an important staple food crop in most households in Narok County and also a source of income. Local production of maize in the country is purely rain-fed.

Despite the importance of maize in Kenya and in Narok County in particular as a staple food crop, its productivity has been highly variable in the past decades resulting in food insecurity, malnutrition, famine and increased poverty levels. The variability in maize yields could be attributed to catastrophic impacts of climate variability and change manifested by rising temperatures, erratic and unreliable rainfall patterns often resulting in crop failures, mediocre yields and famine. This has often forced both national and county governments to divert resources that were originally earmarked for economic development to support distribution of relief food and importation of maize to offset the maize production deficit.

Therefore, strategies that can deliver increased and sustainable maize productivity and food security in Narok are of urgent priority. It is in this regard, and the need to achieve one of the country's Big Four Agenda that aim to ensure national food security and tremendous gains in both the economy and achieving both the country's development goals under vision 2030 and the global sustainable development goals targeting to end poverty and extreme hunger, that this study sought to assess the impact of climate variability and change on maize productivity in Narok County of Kenya.

## 1.3 Objectives of the study

The overall objective of this study was to assess the impact of climate variability and change on maize productivity in Narok County of Kenya, with a view of understanding their implications on maize production and sustainable food security.

The specific objectives of the study were:

a) To determine the intra-seasonal characteristics of climate with respect to rainy seasons onset and cessation dates, number of rainy days, length of wet spells, length of dry spells, length of growing season and growing degree days in Narok County.
b) To determine inter-annual variability of maize yields in Narok County of Kenya.
c) To investigate the effect of climate variability attributes in (a) on yields of maize in Narok County.
d) To determine the future impact of climate variability and change on maize yields in Narok County of Kenya for the period 2021- 2050.

## 1.4 Research Hypothesis

In this study, two null hypotheses were formulated and tested:

$H_{o1}$: Climatic variability does not account for the inter-annual variability in maize yields in Narok County of Kenya.

$H_{o2}$: Future climate will not adversely affect maize yields in Narok County of Kenya.

The corresponding alternative hypotheses tested were:

$H_1$: Climatic variability accounts for the inter-annual variability in maize yields in Narok County of Kenya.

$H_1$: Future climate will adversely affect maize yields in Narok County.

## 1.5 Research Questions

In order to analyze the specific objectives of this study, the following research questions guided the analysis:

a) What have been the observed patterns of variability in the rainfall and temperature characteristics in Narok County?
b) How do the intra-seasonal climatic characteristics affect maize yields in Narok County?
c) What will be the levels of maize yields under future climate of Narok County by the year 2050?

## 1.6 Justification and Significance of the study

Maize is an essential staple food crop in Kenya, as well as in Narok County, its productivity is often constrained by marked variability in socio-economic and biophysical factors within the production environment. With climate change impacts on agriculture projected to worsen into the future, it is imperative to evaluate the effect of current and past climatic variability on the productivity of maize, as a basis for informing measures and agricultural policies that would assure sustained maize productivity and food security through enhanced adaptive capacity and resilience building of smallholder farming systems.

Many studies to determine the impact of climate variability and change on agriculture have been carried out both at national and specific agro-ecological zones and for specific crops. However, most of these studies only focused on climatic means (Jones and Thornton, 2003; Bilham, 2011; Wandaka, 2013). It is noteworthy that beyond changes in climatic means, other climate variability manifestations such as alterations in rainy season onset and cessation dates, length of growing season, wet spell length, dry spell length, and intensity of extreme events among others would give sound bases for tracking and understanding the impacts of climate variability and change on the yields of maize (Kariuki, 2018; Solomon et al., 2007; Rowhani et al., 2011).

Findings from this study will inform the formulation of relevant agricultural policies in Narok County and in Kenya at large that would increase and sustain maize productivity and assure food availability. Consequently, the study will significantly contribute to the realization of the national development goals under Kenya’s vision 2030 and Kenya’s Big four Agenda aimed at ensuring food security, and the global sustainable development goals (SDGs 1 and 2) aimed at eradicating hunger and extreme poverty.

## 1.7 Underlying Assumption of the study

This study was built on two assumptions. First, that crop management and routine farm practices employed by maize farmers are in conformity to the recommended agronomic practices, and that maize crop growth and productivity are not constrained by poor farming practices, weeds, pests and diseases. Secondly, the variations in maize yields are caused by variations in climate only.

# CHAPTER TWO:

# LITERATURE REVIEW

## 2.0: Introduction

This chapter reviews the available literature on the interactions between climate and agriculture globally, in Sub-Saharan Africa, and at national and local levels. This is followed by a review on maize growth, development and morphology, climate influences on maize growth and development, and climate and crop growth modelling.

## 2.1 Impact of Climate Variability and Change on Agriculture

Climate is a key input and determinant of the success and profitability of rain-fed agricultural productivity in Sub-Saharan Africa countries, especially those that are located within the tropics (Mumo, 2018). IPCC (2007), confirms beyond reasonable doubt that climate change will severely impact water availability, agricultural production, food security, human health and biodiversity in most parts of the world, with even more severe impacts in sub-Saharan Africa. Furthermore, smallholder farmers will be the most affected with the rising temperature patterns and cereal crop productivity is likely to decrease in the low latitude regions. Agriculture is very susceptible to space-time variations in weather and climate often manifesting in rising temperatures, unreliable patterns of rainfall and extreme weather events including droughts, floods, heatwaves and frost among others. Declining agricultural production has been observed to correlate with these extreme climatic events (IPCC, 2007).

Developing countries in Africa will bear the brunt of climate change and variability impacts, largely due to the interaction of climate change with multiple stressors such as their low adaptive capacity exacerbated by their geographic exposure to fragile agroecosystems, extreme poverty, population pressure, increased water stress and scarcity, land degradation, food and nutrition insecurity, low-income levels and overreliance on rain-fed agriculture production (IPCC, 2007).

Kenya is already faced with adverse climate variability and change impacts, largely due to her location in the tropics and great reliance on climate sensitive agriculture that is at risk of unreliable rainfall and rising temperature patterns that directly affect crop and livestock productivity (Mumo, 2018; Ochieng, 2016; NCCRS, 2010). The NCCRS report further notes that, there has been notable climate change impacts in most sectors in Kenya, with rain-fed agriculture being the most severely affected.

There is increasing consensus among documented studies that, climate change threatens the sustainability of agricultural production systems thus posing a serious challenge to the vulnerable rural smallholder farmers whose livelihoods rely on rainfall (Olutegbe & Fadairo, 2016; Boko et al., 2007). It is noteworthy, that these smallholder agricultural production systems are directly affected by erratic and unpredictable rainfall patterns, resulting in reduced and/or mediocre yields or total crop failure (Kulukusuriya, 2006).

Climate change impacts manifested by shortened growing season length, increased water scarcity and proliferation of pests, weeds and diseases are known to significantly reduce agricultural crop yields. On the other hand, increased heat and water stress are observed to have negative impacts on crop productivity (Masambaya, 2018; Adhikari, 2015).  Furthermore, increased heat stress within the flowering and grain-filling phenological-phases of crop growth, results in low quality/ mediocre crop yields, low grain count and weight respectively (Adhikari, 2015)

The success and profitability of any agricultural activity greatly relies on the right timing of the rainy season onset and cessation dates, length and distribution of rainfall throughout the growing season that eventually determines the amount of water available to the crops (Murenzi, 2019; Marković, 2015; Ati et al., 2002). Marković (2015) noted that adequate and well distributed moisture within the soil throughout the growing season from planting to maturity is paramount for optimal crop growth. Temperature and rainfall are the two key determinants of the success and profitability of crop yields and productivity within the tropics (Mumo, 2018; Conway, 2009).

Conway (2009), noted that most crops within the tropics have optimal growth within and/ or close to certain favorable temperatures, and that few days of deviation from these optimal conditions would have deleterious effects on the final crop yields. Notwithstanding, temperature and rainfall distribution within the season will have differential impacts on yields depending on the phenological stages involved (Chen, 2004). Water and heat stresses during crop growth and development will have adverse effects on canopy development that would result in reduced yields (Steduto, 2012). The rising temperatures would benefit crop yields in the high latitudes and altitudes, but exacerbate water stress and moisture deficiency in the lowland areas thereby resulting in reduced and poor-quality yields (Mumo, 2018; Ochieng, 2016).

Increased temperatures will increase heat stress. In maize, increased heat stress during flowering and grain filing stages has been observed to reduce yield quantity and quality (Mumo, 2018). Rainfall variability has been observed to exacerbate soil moisture stress during crop growth stages thus, shortening the crop growth stages, increases pollen sterility and decreases the leaf area and shutting of stomata to lessen water loss and consequently low quality and mediocre crop yields (Wandaka, 2013; Mumo, 2018; Marković, 2015; Masambaya,2018). A clear understanding of climatic extremes and their occurrence is imperative, as it informs the choice of early maturing cultivars (Mati, 2000).

Increased frequency and severity of droughts, late onset, early cessation and erratic patterns of rainfall and prolonged length of dry spells during the growing season continues to be a significant threat to smallholder rain-fed farmers in Kenya (Stephen et al, 2015). Maize plants are susceptible to increased water stress, particularly within the critical phases of flowering to the start of the grain-filling (Omoyo, 2015). Maize yields had significant correlation with amount of water during the flowering stage within the US Corn Belt (Runge & Hons, 1998).

Globally, an increase in temperature of 1℃ translates to a decline in cereal crop yields of up to 10% in most regions of the world except for the high latitude countries (Lobell *et al.*, 2011). Furthermore, crop yields will significantly decline by 10 – 20% in many parts of Africa by 2055 (Mumo, 2018). In East Africa, maize yields would decrease in 65% of available cropland under rain- fed or drought conditions; with 40% of its maize yields expected to be lost by end of the 21st century (Mumo, 2018; Adhikari, 2015)).

Under semi-arid conditions in Pakistan, observed rainfall during various phenological stages of maize was found to be highly correlated with the yields of maize. For a growing season with total rainfall amounts between 135 mm and 530 mm, rainfall during the vegetative stage showed a strong relationship with maize yield ($r = 0.61$), while rainfall during the reproductive phase had $r= 0.6$ with maize yield (Murenzi, 2019; Rasul and Rashid, 2011).

Intra- seasonal temperature characteristics have been observed to be negatively correlated with maize yields while rainfall characteristics were positively correlated with maize yields in Rwanda (Murenzi, 2019). This author further noted increased future climatic variability under RCP8.5 compared to RCP4.5. These scenarios indicate that rainfall, minimum and maximum temperatures are projected to increase under RCP8.5 in most regions of Rwanda. Based on model outputs from the AquaCrop model while simulating future yields of maize, this author further observed that maize yields would decrease more under RCP 8.5 compared to RCP4.5 during the September to January season.

Many studies to determine the impact of climate variability and change on agriculture have been carried out both at national and specific agro-ecological zones for specific crops, while focusing mainly on climatic means (Jones and Thornton, 2003; Bilham, 2011; Wandaka, 2013). This study bridges the existing gap, by assessing impacts of climate variability and change on maize yields, with special focus on intra-seasonal climate characteristics using observed daily climate data.

## 2.2 Maize Growth, Development and Morphology

Maize crop growth cycle entails important developmental stages namely, the initial, vegetative, flowering (silking and tasseling) and the final grain filling and ripening stage (Belfield & Brown, 2011). These can further be summarized into two major phases, namely the vegetative phase and the reproductive phase (Table 1).

**Table 1: Vegetative and Reproductive phases of Maize**

| **Vegetative phases** | **Reproductive phases** |
|---|---|
| VE: Emergence | RI: Silking |
| V1: Appearance of the first leaf | R2: Blister |
| V2: Appearance of the second leaf | R3: Milk |
| V3: Appearance of the third leaf | R4: Dough |
| V(n): The nth leaf | R5: Dent |
| VT: Tasseling | R6: Physiological maturity |

**(Source: Murenzi, 2019).**

Maize seedlings emerge under suitable soil temperature and posture conditions. Germination occurs after 4 to 5 days under favorable conditions, otherwise maize seeds take slightly longer to germinate, often between 5 to 21 days (Murenzi, 2019). Planting depth, soil moisture and soil temperature are the major limiting factors for optimum germination of maize seeds (Murenzi, 2019). Two to three weeks after germination, the maize crop is able to withstand any environmental changes. The third leaf stage is the critical stage that determines the number of leaves and ear shoots to be produced. Table 2 presents the maize growth stages and their approximate days after seedling emergence.

**Table 2: Maize growth stages and their approximate days after emergence (Source: Murenzi, 2019)**

| Growth Stage | Approximate time following seedling emergence (days) | Environmental impact |
|---|---|---|
| V3 | From 8 to 10 days | The leaves and ear shoots are determined. At this stage maize plant can be destroyed by the persistence of flooding |
| V6 – V8 | From 21 to 36 days | Maize is developing above the soil and is at risk of wind and hail. The plant requires adequate moisture and nutrients. |
| V12 – V17 | From 36 to 60 days | Number of grains per ear and rows size is determined at this stage. The stress in the kernel is due to moisture and nutrient deficiencies. |
| VT – R1 | From 54 to 62 days | This stage is represented by the visibility of tassels and ear shoots. Final yield is affected by water stress |
| R2 | From 66 to 74 days | This stage is known as swelling phase. Kernels contain almost 85% of moisture. |
| R3 | From 76 to 86 days | This is the milky stage. Moisture stress is the main cause to reduce yield. The kernel contains 80% of moisture. |
| R4 | From 84 to 88 days | This is the Dough stage. Dry weight is formed and kernel contains 70% moisture. |
| R5 | From 90 to 100 days | This is the Dent stage. Moisture stress can reduce the kernel weight and 55% of moisture is in the kernel |
| R6 | From 105 to 120 days | The kernel is fully developed. Dry weight accumulation is at the maximum. This stage is known as the Physiological maturity. Heavy rains can lead to grain spoilage through rotting and germination. |

## 2.3 Climatic and Soil conditions suitable for growing Maize

Maize growth is optimal in areas with deep, fertile and well drained soils that receive total seasonal rainfall amounts above 500mm. Though the crop is fairly tolerant to soil acidity, it fails to grow in highly acidic soils (Murenzi, 2019). Drought and water logging have deleterious effects on growth and development of the maize plant (Maddonni, 2011). With severe droughts during the critical flowering stage, the crop would be adversely affected and depending on the growth stage would result in complete crop failure.

Increasing temperatures in excess of the threshold levels exacerbate soil water stress causing further negative effects on the productivity of the maize crop. Temperatures of between 30℃ to ≥ 35℃ during the reproductive stage affect the viability of pollen, fertilization and consequently grain formation hence reducing productivity. On the other hand, temperatures lower than 10℃ affects the germination and initial growth of maize seedlings (Plessis, 2003). In a suitable environment with an optimal temperature of 20℃, germination takes place in 5 to 6 days (Plessis, 2003). Germination of the seed is faster and less variable in soils with temperatures between 16℃and 18℃. Temperatures below 10℃ retard the growth of maize.

Maize plant requires 120- 140 frost free days within the season for optimal growth and development. More frost days have catastrophic consequences on mature plant leaves and retard grain filling (Plessis, 2003). Every millimeter of water yields 10 to 16 kg of maize grain (Plessis, 2003).

Effective weed control in the first few weeks after planting is vital in eliminating competition for available moisture, light and nutrients between the maize plants and weeds. Weed infestations reduces annual maize yields by 10% (Plessis, 2003). Solar radiation also plays an important role in maize growth and development during silking and grain filing phases, with a decrease in solar radiation within these stages significantly reducing maize grain and biomass yields (Yunshan Yang, 2019).

## 2.4 Climate and Crop growth Modelling

### 2.4.1 Climate Models

Global circulation models (GCMs) have been developed as essential tools for large scale prediction of the average weather conditions (Dixson *et al.,* 2013). These have improved capability of simulating global climate data at continental scales; However, these GCMs are limited in their ability to simulate and reproduce features at local-, dynamic- and sub-grid scales (Murenzi, 2019). Murenzi (2019), also noted that the existing differences in the spatial resolution between GCMs and regional climate models are the main constraints in direct application of climate model data outputs to climate studies at local level. Even with enhanced spatial resolution of GCMs for the future, it remains imperative to downscale their outputs for applicability and use in climate studies at local level (Srinivas, 2013). Downscaling is critical in refining the coarse horizontal resolution of GCM outputs to finer resolutions in order to generate local data; often achieved by linking global scale predictions to regional dynamics in order to generate climate variables specific to a particular region (Dixson *et al.,* 2013).

Currently, downscaling is used in climate simulation by many projects, and one of those projects is the Co-ordinated Regional Climate Downscaling Experiment (CORDEX), launched by World Meteorological Organization under its World Climate Research Program in 2009. This project has been able to generate dynamical simulations at very finer resolutions, with a horizontal resolution of $0.448^0$ (Approximately 50km) in Africa (Giorgi et al., 2009). The CORDEX framework uses a rotated grid with a horizontal resolution of $0.448^0$ (approximately 50 Kilometers) in generating simulations (Giorgi et al., 2009). The framework also provides projections of Greenhouse gases, carbon cycle and feedback mechanisms (Masambaya, 2018). Climate change scenarios provide formidable tools for simulating future climate based on different levels of greenhouse gas emissions (GHG) caused by both natural and anthropogenic activities (Masambaya, 2018).

Representative Concentration Pathways (RCPs), constitute a consistent set of projections which represent four unique future pathways of radiative forcing, GHG emissions and atmospheric concentrations of air pollutants and land use (Masambaya, 2018; IPCC, 2014). RCPs offer inclusive storylines describing the level of radiative forcing in $Wm^{-2}$ by the year 2100 generated using the parallel approach (Masambaya, 2018).

RCPs are named based on their level of radiative forcing by the year 2100. Essentially, there are four categories namely, RCP2.6, RCP4.5, RCP6.0 and RCP8.5, corresponding to radiative forcing levels of 2.6Wm$^{-2}$, 4.5Wm$^{-2}$, 6.0Wm$^{-2}$ and 8.5Wm$^{-2}$ respectively (Masambaya, 2018). Table 3 summarizes the characteristics of the four Representative Concentration Pathways.

**Table 3: Description of Representative Concentration Pathways (Source: Masambaya, 2018)**

| **Parameter** | **Description** | **Radiative Forcing (Wm$^{-2}$)** | **$CO_2$ Concentration (ppm)** | **Pathway** |
|---|---|---|---|---|
| RCP2.6 | The lowest scenario that depicts concerted efforts to reduce GHGs emission and increase carbon sequestration. | 2.6 Wm$^{-2}$ before 2100 then declines | 490 ppm before 2100 then declines | Peak and decline |
| RCP4.5 | A low scenario characterized by stabilization of GHG emission by mid-century followed by a sharp decline subsequently | 4.5 Wm$^{-2}$ before 2100 then declines | 650 ppm before 2100 then declines | Stabilization without overshoot |
| RCP6.0 | An intermediate scenario that denotes a steady increase in GHG emissions that stabilizes in the last decade of the 21st century | 6.0 Wm$^{-2}$ at stabilization after 2100 | 650 ppm at stabilization after 2100 | Stabilization without overshoot |
| RCP8.5 | High concentration pathway with continuous increase in emissions of GHG up to 2100 | 8.5Wm$^{-2}$ in 2100 | 1370 ppm in 2100 | Rising |

### 2.4.2 Aqua-Crop Model

The AquaCrop model developed by the Food and Agriculture Organization (FAO) of the United Nations, is a water productivity model based on the concept of yield response to crop water use, it simulates crop biomass of herbaceous crops from actual crop transpiration under different biophysical and farm management conditions (Sharda, 2020). It is an important model for simulating the relationship between climate, crop and water. The model has been validated and applied for several crops under different biophysical and management conditions (Sharda, 2020; Murenzi, 2019; Droogers, 2005; Hsiao *et al.*, 2009). The model input data includes: climate data comprising rainfall, maximum temperature, minimum temperature and solar radiation, atmospheric concentration of $CO_2$ data, crop data, irrigation data, field management data, soil profile data, and groundwater data. The climatic data comprise: daily, dekadal or monthly rainfall, temperature, reference evapotranspiration and atmospheric concentration of $CO_2$ data. Figure 1 presents AquaCrop model flow chart and the interactions among different drivers of the model.

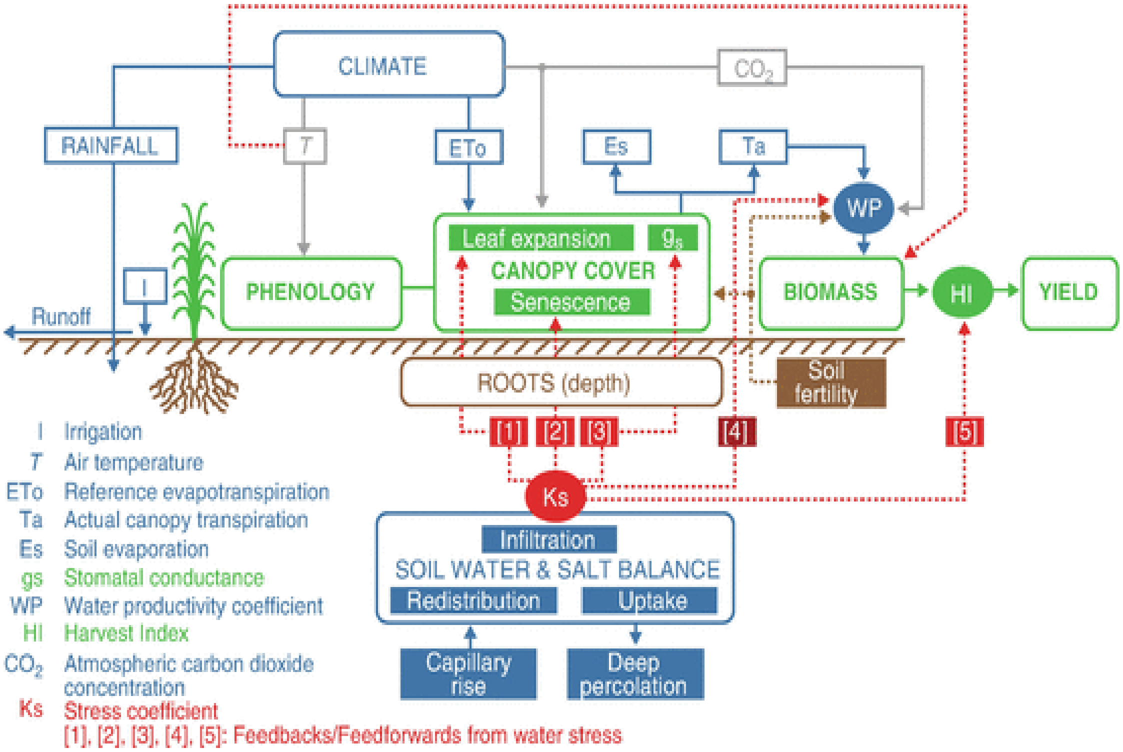

**Figure 1: AquaCrop model flow chart and the interactions among different drivers of the model. (Source: Steduto et al., 2009)**

## 2.5 Conceptual Framework

Figure 2 presents the conceptual framework, showing the relationship between the different aspects and activities carried out in this study.

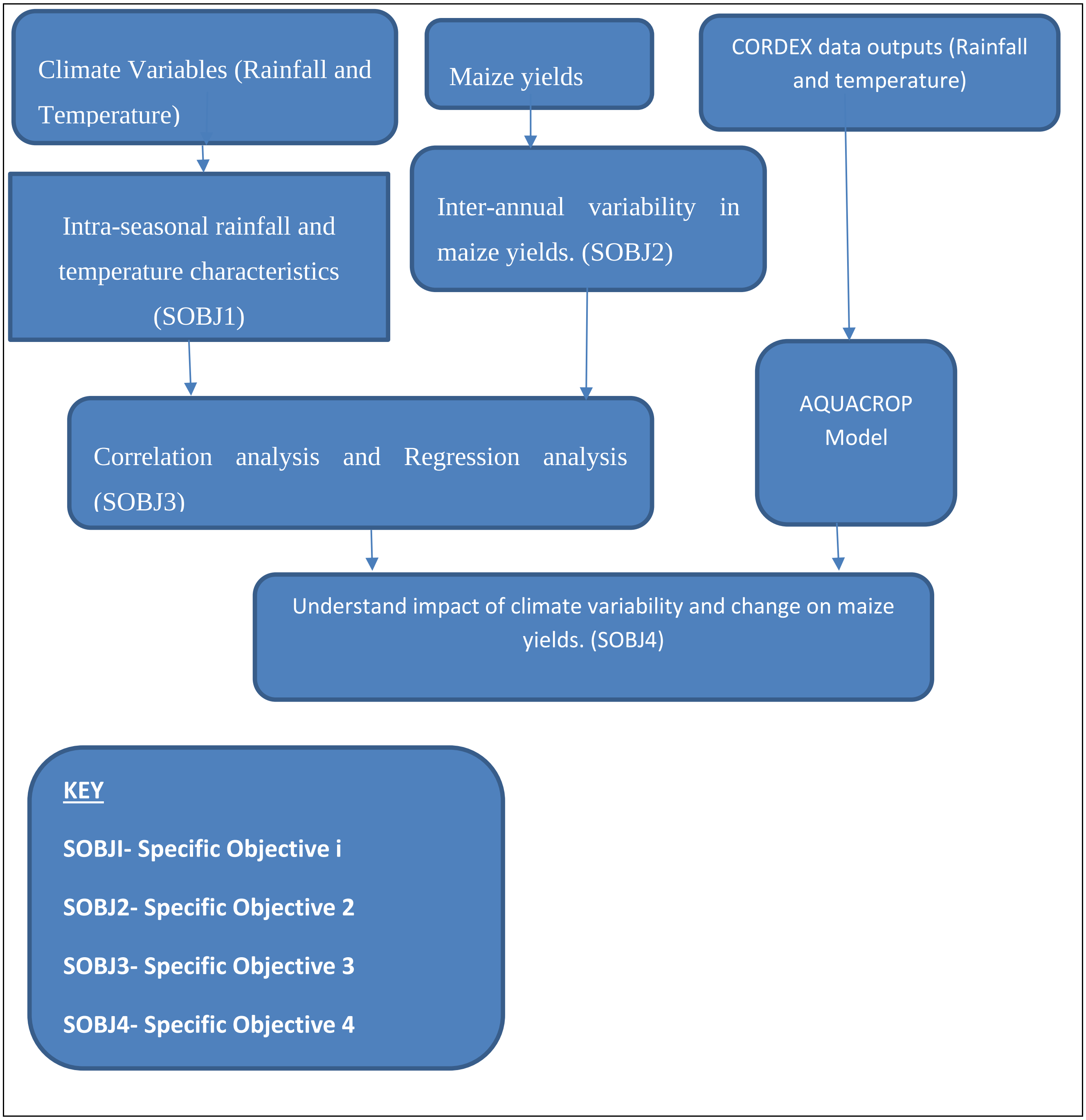

**Figure 2: Conceptual Framework**

# CHAPTER THREE

# DATA AND METHODOLOGY

## 3.0 Introduction

This chapter presents in detail, a description of the study area, various types of data and their sources, methodology and tools employed to achieve the specific objectives of the study.

## 3.1 Area of Study

This study was carried out within the semi-arid Narok County within the Rift Valley region of Kenya located between latitudes $0^{o}$ $50^{''}$ and $1^{o}$ $50^{''}$ South and longitudes $34^{o}$ $28^{''}$ and $36^{o}$ $25^{''}$ East. The county, covers an area of about 17,944km$^{2}$ and at an altitude of about 1827m above sea level (Narok County Government, 2013). Figure 3, shows the map of Narok County.

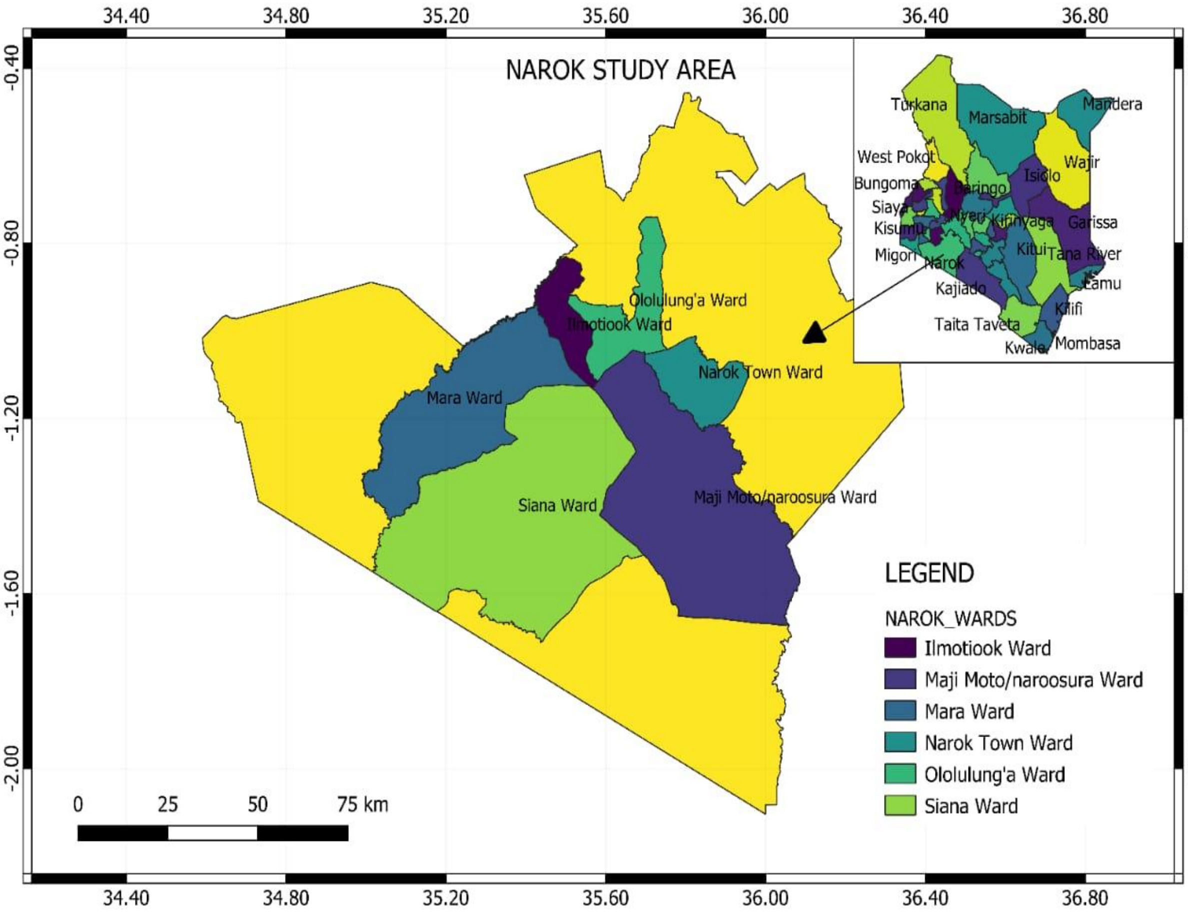

**Figure 3: Map of Narok County.**

The County's climate is strongly influenced by altitude and physical features. The County can be classified into five agro-climatic zones, namely, humid, sub-humid, semi-humid, arid and semi-arid (Narok County Government, 2013). It receives bi-modal rainfall that is strongly influenced by the passage of the intertropical convergence zone (ITCZ). The long rainy season occurs from March to May (MAM), while the short rainy season is from October to December (Narok County Government, 2013). The County receives mean annual rainfall ranging from 500mm during drier months to 2500mm during wet months, with mean temperature ranging between $12^oC$ and $28^oC$ (Narok County Government, 2013).

According to the Kenya National Population and Housing Census of 2019, Narok County had 1.157.873 persons, of whom 579,042 were male and 578,805 were female (KNBS, 2019). The county consists of four main livelihood zones, namely, mixed farming, Agro-pastoral, Pastoral and Formal Employment (KFFSG, 2016). The MAM rainy season, is the main cropping season in the County. Barley, wheat, beans, maize and Irish potatoes are the major crops grown in the county with wheat and maize being the most widely grown crops and contribute the highest proportion county revenues (Narok County Government, 2013). Maize production contributes 60, 75 and 90% of food to households in the agro-pastoral, mixed farming and pastoral livelihood zones respectively (KFFSG, 2016).

## 3.2 Data Types and Sources

This section presents the types and sources of data used in this study.

### 3.2.1 Observed Data

This study used observed daily rainfall, maximum temperature and minimum temperature for eleven meteorological stations distributed across Narok County. These stations are presented in Table 4.

**Table 4: Location of study Meteorological stations.**

| Number | Meteorological Station | Sub- County | Longitude | Latitude | Elevation (m) |
|---|---|---|---|---|---|
| 1. | Kilgoris | Kilgoris | 34.88 | -1 | 1789 |
| 2. | Elementaita | Narok North | 35.88 | -0.61 | 2596 |
| 3. | Olchorro | Narok North | 36.01 | -0.83 | 2709 |
| 4. | Mosiro | Narok East | 36.16 | -1.48 | 1830 |
| 5. | Narok | Narok North | 35.86 | -1.09 | 1889 |
| 6. | Oloololo | Kilgoris | 34.98 | -1.25 | 1884 |
| 7. | Loita | Narok South | 35.81 | -1.65 | 2045 |
| 8. | Nyangores | Narok South | 35.43 | -0.7 | 2256 |
| 9. | Abossi | Emurua Dikirr | 35.1 | -0.965 | 1869 |
| 10. | Cottars Camp | Narok West | 35.38 | -1.5 | 1837 |
| 11. | Governor’s Camp | Narok West | 35.03 | -1.28 | 1884 |

Data for these stations were obtained from the Kenya Meteorological Department (KMD), for the period 1981-2018. Annual maize yields data for the period 1982-2015, expressed in metric-tons per hectare (MT/ha), were obtained from the Ministry of Agriculture, Livestock, Fisheries and Cooperatives.

### 3.2.2 Model Data

The study used daily rainfall, maximum temperature and minimum temperature data, obtained from the Coordinated Regional Downscaling Experiment (CORDEX), RCA4, and Regional Climate Model (RCM). The downscaled data was available for the historical period 1971-2005 and one GCMs over Africa for RCP4.5 and RCP8.5 and running in the transient mode for the period 1951-2100 at a horizontal resolution of 50 km (0.448 degrees) over Africa (Murenzi, 2019). The Global Circulation Model (GCM) dynamically downscaled by RCA4, used the National Centre for Meteorological Research model (CNRM) outputs. The study also used Climate

Research Unit timeseries version 3.22 (CRU TSv3.22) datasets to validate the model outputs. The data comprised of monthly precipitation, maximum temperature and minimum temperature data.

### 3.3 Data Quality control

This section describes the data control methods that were used in this study. The methodology entailed estimation of missing data and homogeneity tests.

#### 3.3.1 Estimation of missing data

As an important part of the data quality control, taking care of the discontinuity and missing data is ideal for meaningful analysis and recommendation for utilization of results. Missing data was estimated using the correlation method, in which missing records were computed using equation 1.

$$X_{\text{period missing}} = r_{xy} . Y_{\text{period}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, $X_{\text{period missing}}$ is the missing value to be estimated

$r_{xy}$ is the correlation coefficient

$Y_{\text{period}}$ is the data value of the station with the highest correlation coefficient with the station with missing data.

#### 3.3.2 Data Homogeneity test

Data homogeneity tests for temperature and rainfall data were carried out using the double mass curve technique. This technique entailed plotting cumulative records of rainfall, maximum temperature, and minimum temperature of one station against those of another station. Narok meteorological station with proven homogeneous datasets was used as a reference station. A straight-line plot was considered indicated that the data collected was homogeneous and therefore fit to be used in the analysis of this study. Where there was deviation from the general linear plot, Equation (2) was used to adjust inconsistent data records.

$$P_a = (b_a/p_o) * b_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

$P_{a:}$ the adjusted data

$b_{a:}$ the observed data

$b_{o:}$ the slope of the line to which records are adjusted

$P_o$: the slope of the deviated line through observed data

The analysis of variance test (covariance) was used to test the significance of an apparent break in the double mass curve, based on the Fisher's distribution. The F-test statistic which represents the ratio of the among-period variance to the within period variance. The null hypothesis that was formulated and tested was $H_o$: the break point was not statistically significant and didn't need to be adjusted, whereas the alternative hypothesis $H_a$: the break point was statistically significant and needed to be adjusted. The computed f value was then compared to the tabulated value of the F distribution at 5% significance level. If the computed F- value was greater than the tabulated f-value, the null hypothesis was rejected, signifying statistically significant break and therefore data needed to be adjusted.

## 3.4 Determination of the Intra-Seasonal Climate Variability

This section presents the tools and methods used to analyze the intra- seasonal climate characteristics. Rainfall related characteristics included, onset and cessation dates, number of rainy days, length of growing season, wet spell length, dry spell length, and seasonal total rainfall. Temperature characteristics comprised the seasonal mean maximum and mean minimum temperatures, temperature range and Growing degree days.

### 3.4.1 Rainfall Characteristics

The intra-seasonal variability in rainfall for both MAM and OND seasons entailed, first organizing the daily rainfall data in a format that was compatible with the *INSTAT plus statistical analysis package*.

These characteristics were analyzed using the following criteria and approaches:

i. Rainy season onset date was considered to be a day later than 1st March for the MAM season and 1st October for the OND season when the cumulative rainfall for 5 days exceeded 25 mm, with 3 consecutive rainy days (Ininda, 2016).
ii. Cessation date was considered to be the earliest probable day after 1st May and 1st December for the MAM and OND seasons respectively, when the soil water balance reaches zero with a fixed average of 5 mm of evapo-transpiration per day, and 100 mm/meter of the maximum soil water holding capacity (Murenzi, 2019).
iii. Length of growing season was considered to be the number of days between the onset and cessation dates (Murenzi, 2019).
iv. The number of rainy days in a season was considered to be the days in a season with at least 1 mm of rainfall recorded in 24hours from 9.00 a.m. to 9.00 a.m. local time of the following day.
v. Total seasonal rainfall amounts were obtained by summing up all the rainfall recorded within the season (Murenzi, 2019).
vi. Length of wet spell was considered to be the number of consecutive wet days within the season with rainfall amounts of at least 1 mm.
vii. Length of dry spell was considered to be the number of consecutive dry days within the season with rainfall amounts of less than 1 mm.

### 3.4.2 Temperature Characteristics

The temperature characteristics were determined from the observed daily temperature data using the following methodologies.

i. The Seasonal trend of maximum and minimum temperatures were determined by plotting these parameters against time, and trend lines were fitted onto the data. The regression equation of the trend line of the form given by equation (3) was generated.

$$\boldsymbol{Y = bX + c} \qquad \textbf{(3)}$$

Where, Y= Maximum/minimum temperature/ temperature range in $^{o}$C
b is the slope of the trend line
c is the intercept of the trend line with the y-axis
x is time

Negative values of the slope signified decreasing trends of the parameter, while positive values signified increasing trends.

### Growing Degree Day

The growing degree days (GDD), was calculated on daily time steps using equation 4 and then summed up over the time period of the respective maize phenological stages across the growing season using equation 4.

$$\boldsymbol{GDD = (\frac{T_{max} + T_{min}}{2}) - T_b} \qquad (4)$$

Where:

GDD is the growing degree days

$T_{max}$ is maximum temperature

$T_{min}$ is minimum temperature

$T_b$ is base temperature/threshold temperature of the crop, considered to be $10^oC$ for maize.

Since Equation (4) only computes GDD for on daily basis, the total GDD for the entire phenological stage/growing season was calculated using equation (5)

$$\boldsymbol{GDD = \sum_{i=1}^{n} (\frac{T_{max} + T_{min}}{2}) - T_b} \qquad (5)$$

Where:

n = number of days over which the summation was done.

$T_{max}$ is maximum temperature

$T_{min}$ is minimum temperature

$T_b$ is base temperature for maize.

### 3.5 Climate Variability and maize yield

The coefficient of variation (CV) was used to determine the variability in the intra-seasonal climate characteristics and inter-annual maize yields over the study period (1981-2018) in Narok County. CV is a critical measure for analyzing how individual climate data points and maize yields vary about their long term mean values. The general formula for the coefficient of variation that was adopted in this study is given in equation (6).

$$\boldsymbol{CV = \frac{S}{M} * 100} \qquad (6)$$

Where:

CV is the coefficient of variation
S is the standard deviation
M is the mean value of the study parameter (maximum temperature, minimum temperature, rainfall and maize yield).

Higher coefficient of variation values from Equation 6, indicate greater levels of dispersion around the mean, while lower values of coefficients of variation signify lower levels of dispersion around the mean.

### 3.6 **Relationship between maize yields and intra-seasonal climate characteristics**

This study used the correlation and regression methods to determine the degree of association between the study variables and the relationship that exists between the characteristics of climate variability and maize yields respectively.

### 3.6.1 Correlation Analysis

Pearson's correlation coefficient (r) was used to measure the strength of the association between the intra-seasonal rainfall and temperature characteristics and maize yields in Narok County. The equation used was of the form given in equation (7)

$$\mathrm{rxy} = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})\,(y_i - y)}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2 .\ \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad \mathbf{(7)}$$

Where: $r_{xy}$ is the correlation coefficient, n is the sample size, $x_i$ and $y_i$ are the independent and dependent variables respectively and $\bar{x}$ and $\bar{y}$ are the mean values of the variables being correlated (x and y).

The Student t- test was used to test the statistical significance of the computed correlation coefficients in (equation 7) at 95% confidence level by comparing the computed t-statistic given by equation (8) and the tabulated value of the student t-distribution at (n-2) degrees of freedom.

$$\boldsymbol{t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}}} \text{ ................................ } \mathbf{(8)}$$

Where: n is the number of observations, r is the correlation coefficient to be tested and t is the computed student t- statistic with n – 2 degrees of freedom. The correlation coefficient was considered to be statistically significant, if the computed value of the student-t statistic was greater than the tabulated t-value.

### 3.6.2 Regression Analysis

The climatic characteristics corresponding to the statistically significant correlation coefficients in 3.6.1 above were regressed on maize yields in order to develop a multiple linear regression model of the form given in equation (9).

$$\boldsymbol{Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots + \beta_n x_n + \varepsilon} \qquad \mathbf{(9)}$$

Where Y is the dependent variable (maize yield), ε = error term, $\beta_o$ is a constant representing the y-intercept, $\beta_1, \beta_2$ ... and $\beta_n$ are the regression coefficients and $x_1, x_2$ … and $x_n$ are the independent variables (predictors) represented by rainfall and temperature characteristics. The adequacy of the fitted multiple linear regression model was tested using the coefficient of determination $R^2$, $R^2 = 0$, signified lack of fit, $R^2=1$ implied a perfect fit. The analysis of variance was used to test the significance of the fitted regression line. Larger values of F indicate stronger relationship between the study variables, smaller F values imply weaker relationship between the study variables.

### 3.7 Assessing the impact of climate change on maize yield.

AquaCrop model was used to analyze the impacts of climate variability and change on the yields of maize in Narok County. This model was calibrated using daily rainfall, maximum and minimum temperature data for the period 1981-2018. The AquaCrop model was preferred because of its low demand for data, user-friendly interface and strong emphasis on the relationship between crop yield, climate and water (Hsiao *et al*., 2009). The model is simple, accurate and robust. It simulates yield responses to water stress for numerous herbaceous plants (Murenzi, 2019).

The CORDEX model output was used to simulate future climate information based on RCP4.5 and RCP8.5 emission scenarios. The skill of the CORDEX-RCM models in simulating rainfall and temperature over Narok was evaluated using correlation (equation 7 in section 3.6.1) and the Mean Absolute Error (equation 10).

$$\text{MAE} = \frac{1}{N} \sum_{i=1}^{n} |F_i - O_i| \quad \text{………………….. (10)}$$

Where, F are the simulated values and O are the observed values, N is the number of pairs.

The model was considered to have better skill, if the MAE value was smaller (closer to zero) and the correlation coefficient values were higher (closer to 1).

The simulated temperature and rainfall data from CORDEX-RCMs were compared with the Climate Research Unit (CRU) data of the same period. The future climate data was for the time period 2021 –2050. Future yields of maize were also simulated over the same period.

# CHAPTER FOUR:

# RESULTS AND DISCUSSION

## 4.0 Introduction

This chapter presents and discusses in detail results of this study. These results are presented sequentially in accordance with the specific objectives of the study.

## 4.1. Homogeneity Test

The double mass curves for rainfall, maximum temperature and minimum temperature for Kilgoris station are presented in Figures 4 to 6.

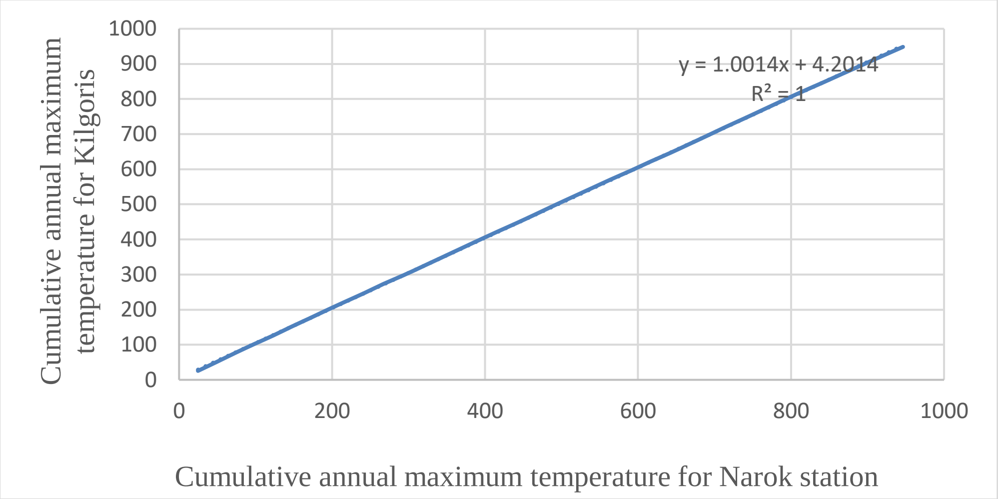

**Figure 4: Double mass curves for maximum temperature for Kilgoris**

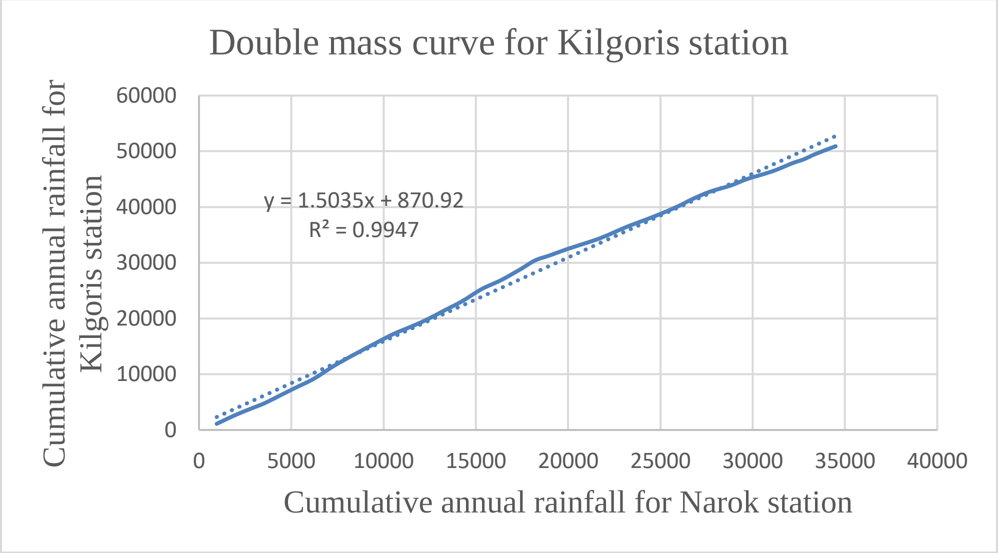

**Figure 5: Double mass curves for Rainfall for Kilgoris**

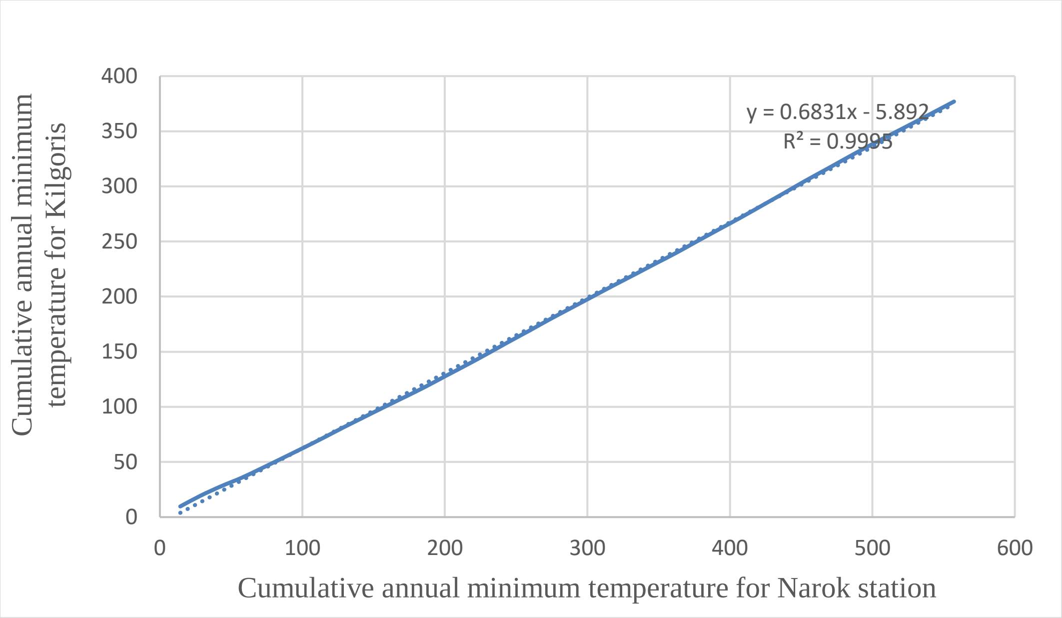

**Figure 6: Double mass curves for minimum temperature for Kilgoris.**

The straight-line plots in these figures indicated that the data were homogenous and therefore fit for use in this study except for Kilgoris station, with an apparent break in its rainfall double mass curve. Table 5 shows the computed F-ratios for stations considered in this study.

**Table 5: Computed F-ratios for rainfall for Narok County stations**

| Station | Sample size (N) | Year of Breakpoint | Critical F | Computed F-ratios |
|---|---|---|---|---|
| Abossi | 38 | 1996 | 3.9702 | 0.4766 |
| Cottar's | 38 | 2014 | 3.9702 | 0.0059 |
| Elementaita | 38 | 2005 | 3.9702 | 0.5418 |
| Governor's | 38 | 2000 | 3.9702 | 0.1854 |
| Kilgoris | 38 | 1996 | 3.9702 | 11.2564 |
| Loita | 38 | 1998 | 3.9702 | 1.9424 |
| Nyangores | 38 | 2002 | 3.9702 | 0.5214 |
| Olchorro | 38 | 1993 | 3.9702 | 5.345 |
| Oloololo | 38 | 2012 | 3.9702 | 2.2735 |
| Mosiro | 38 | 2005 | 3.9702 | 2.6612 |

From Table 5, Kilgoris station had a significant break in slope. The break was corrected ahead of data analysis using equation (2). The value of the correction factor was 1.1342. Results of double mass curves for other stations are presented in Appendix I.

## 4.2 Intra- seasonal rainfall characteristics

This section presents results for the rainy season onset dates, cessation dates, number of rainy days, growing season length, total seasonal rainfall, wet spell and dry spell lengths for both the MAM and OND seasons.

### 4.2.1 Rainy Season Onset and Cessation Dates

Table 6 presents the rainy season onset and cessation dates for MAM and OND season.

**Table 6: Mean rainy season onset and cessation dates**

| **Meteorological station** | **Rainy Season Onset dates** | | **Rainy season cessation dates** | |
|---|---|---|---|---|
| | **MAM** | **OND** | **MAM** | **OND** |
| Narok | 17th March | 18th October | 20th May | 5th December |
| Nyangores | 11th March | 7th October | 27th June | 9th December |
| Olchoro | 27th March | 21st October | 14th May | 3rd December |
| Loita | 25th March | 30th October | 10th May | 4th December |
| Elementaita | 22nd March | 18th October | 14th May | 2nd December |
| Abossi | 10th March | 8th October | 25th May | 2nd December |
| Kilgoris | 9th March | 5th October | 3rd June | 5th December |
| Oloolo | 12th March | 20th October | 30th May | 4th December |
| Mosiro | 23rd March | 30th October | 8th May | 3rd December |
| Governors Camp | 9th March | 11th October | 21st May | 3rd December |
| Cottar's Camp | 17th March | 19th October | 14th May | 3rd December |
| **Mean Date** | 16th March | 18th October | 17th May | 4th December |
| Day of the year | 76 | 291 | 138 | 339 |

The onset and cessation dates for the MAM rainy season are differentiated by study stations. They range between the first to the third dekad of March, with the earliest onset determined in the first dekad of March, around 9th March in Kilgoris and Governor's stations. The latest onset date was on 27th of March in Olchorro station. During the OND rainy season, the onset dates occur between the first and third dekads of October. The earliest onset was detected on 5th October in Kilgoris, whereas the latest onset was on 30th October in Mosiro and Loita stations. The mean onset date over Narok County was found to be on the 76th day (16th March) and 291st day (18th October) for MAM and OND seasons respectively. For MAM season, the earliest cessation was observed on 8th of May in Mosiro, whereas the latest cessation was on 27th of June in Nyangores. The mean cessation date for Narok was on the 138th day (17th May) and the 339th day (4th December) for MAM and OND seasons respectively.

### 4.2.2 Length of Growing Season

Table 7 presents the mean length of growing season for all the stations used in this study.

**Table 7: Length of Growing Season**

| Station Name | Mean Length of Growing season | |
|---|---|---|
| | MAM | OND |
| Narok | 64 | 42 |
| Nyangores | 101 | 64 |
| Olchorro | 49 | 43 |
| Loita | 46 | 35 |
| Elementaita | 47 | 45 |
| Abossi | 77 | 52 |
| Kilgoris | 86 | 58 |
| Oloololo | 96 | 66 |
| Mosiro | 48 | 35 |
| Cottar’s Camp | 58 | 45 |
| Governor’s Camp | 71 | 45 |
| Mean (days) | 74 | 52 |

Nyangores station had the longest mean length of growing season of 101 days during MAM season and 64 days in OND season. On the contrary, Loita station had the shortest mean length of growing season of 46-days in MAM and 35-days in OND seasons respectively. Narok County had a mean length of growing season of 74-days in MAM and 52-days during OND seasons respectively. Based on the lengths of the growing season, Nyangores, Oloololo and Kilgoris stations have greater prospects for crop agriculture during both MAM and OND seasons. Therefore, maize farmers in these areas should take advantage of the long growing seasons to enhance their productivity through increasing acreage under maize and consideration for relay cropping to maximize on excess soil moisture beyond maize crop maturation.

### 4.2.3 Number of rainy days

Table 8 presents the number of rainy days observed in MAM and OND seasons across the study stations.

**Table 8: Number of Rainy days**

| Station Name | Mean Season number of Rainy days | |
|---|---|---|
| | MAM | OND |
| Narok | 32 | 24 |
| Nyangores | 48 | 41 |
| Olchorro | 25 | 20 |
| Loita | 21 | 15 |
| Elementaita | 33 | 23 |
| Abossi | 46 | 36 |
| Kilgoris | 43 | 36 |
| Oloololo | 38 | 30 |
| Mosiro | 44 | 12 |
| Cottar’s Camp | 27 | 17 |
| Governor’s Camp | 33 | 27 |
| Mean (days) | 36 | 25 |

Nyangores station had the highest number rainy days in MAM (48 days) and OND (41 days) seasons. Based on the number of rainy days, there are greater prospects for crop agriculture (maize) in Nyangores, Abossi and Kilgoris areas. On the contrary, Loita station had the least number of rainy days in MAM (21 days) and OND (15 days). Narok county had a mean of 36-rainy days in MAM and 25- rainy days in OND season respectively.

### 4.2.4 Seasonal total rainfall

Table 9 presents the mean seasonal total rainfall for all the stations analyzed in this study.

**Table 9: Seasonal total Rainfall**

| Station Name | Seasonal Total Rainfall (mm) | |
|---|---|---|
| | MAM | OND |
| Narok | 334 | 189 |
| Nyangores | 593 | 374 |
| Olchorro | 228 | 124 |
| Loita | 270 | 138 |
| Elementaita | 274 | 205 |
| Abossi | 396 | 250 |
| Kilgoris | 452 | 339 |
| Oloololo | 425 | 284 |
| Mosiro | 465 | 172 |
| Cottar’s Camp | 278 | 137 |
| Governor’s Camp | 364 | 247 |
| Mean (mm) | 406 | 223 |

Olchorro station recorded the least mean seasonal total rainfall in both MAM (228 mm) and OND (124 mm) seasons. The highest mean seasonal total rainfall was recorded in Nyangores station with seasonal total rainfall of 593 mm in MAM and 374 mm in OND season. The mean seasonal total rainfall recorded in Narok County was 406 mm in MAM and 223 mm during OND season respectively. Based on the seasonal total rainfall, Nyangores station provides the most favorable amounts of rainfall for crop agriculture.

### 4.2.5 Seasonal Lengths of dry and wet spells

Table 10 presents the seasonal lengths of dry and wet spell over Narok County.

**Table 10: Seasonal Lengths of wet and dry spells**

| **Station Name** | **Wet spell length (days)** | | **Dry spell length (days)** | |
|---|---|---|---|---|
| | **MAM** | **OND** | **MAM** | **OND** |
| Narok | 15 | 11 | 35 | 45 |
| Nyangores | 26 | 21 | 26 | 28 |
| Olchorro | 12 | 8 | 49 | 46 |
| Loita | 11 | 8 | 60 | 88 |
| Elementaita | 19 | 13 | 50 | 47 |
| Abossi | 25 | 16 | 26 | 30 |
| Kilgoris | 20 | 18 | 25 | 27 |
| Oloololo | 18 | 13 | 31 | 36 |
| Mosiro | 10 | 7 | 67 | 99 |
| Cottar’s Camp | 14 | 9 | 44 | 63 |
| Governor’s Camp | 16 | 12 | 37 | 41 |
| Mean (days) | 17 | 13 | 41 | 51 |

Loita station had the longest duration of dry spells in both MAM (60 days) and OND (88 days) seasons. Nyangores station had the shortest dry spell lengths in both MAM (26 days) and OND (28days) seasons. Nyangores station had the longest length of wet spell in both MAM (26 days) and OND (21days) seasons. Mosiro station had the least length of wet spells in both seasons, with 10 days in MAM and 7 days in OND season There is, therefore, greater opportunity for enhancing maize production in Nyangores, Abossi and Kilgoris areas based on the longer durations of wet spells favorable for crop agriculture and the corresponding shorter durations of dry spells.

### 4.3 Inter-annual variability in Rainfall characteristics

This section presents the results for coefficient of variation (CV) and of trend analysis for rainfall characteristics.

#### 4.3.1 Temporal variability of onset dates

Figures 7 to 15 present time series plots of seasonal onset dates for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations respectively.

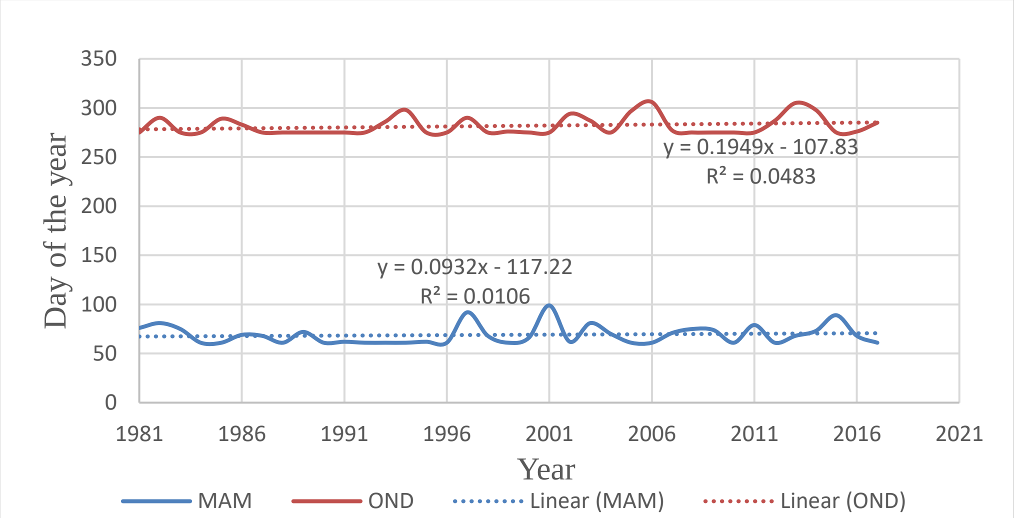

Figure 7: Time series plot of seasonal onset dates for Kilgoris station.

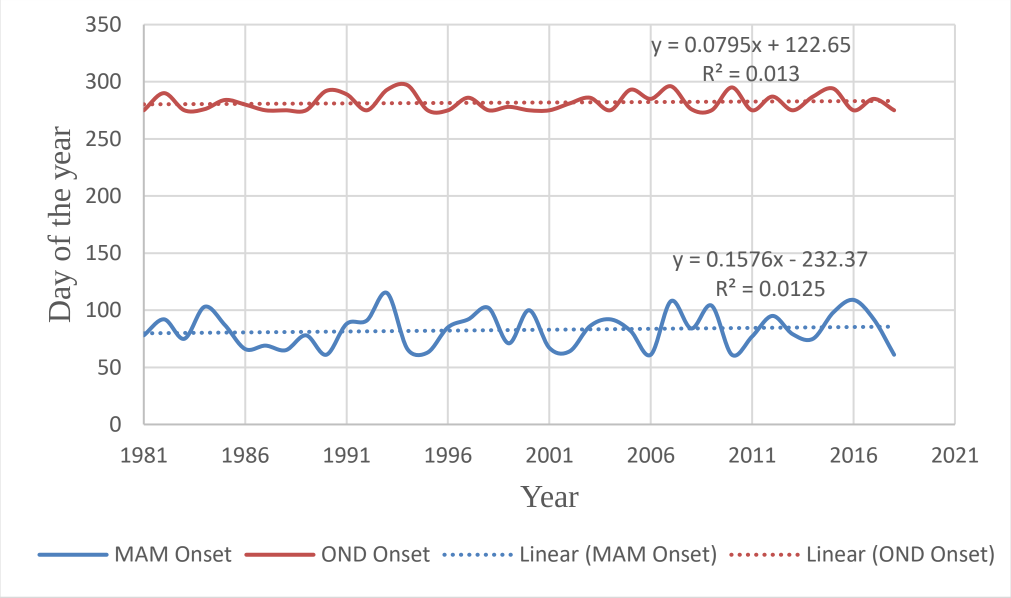

Figure 8: Time series plot of seasonal onset dates for Elementaita station.

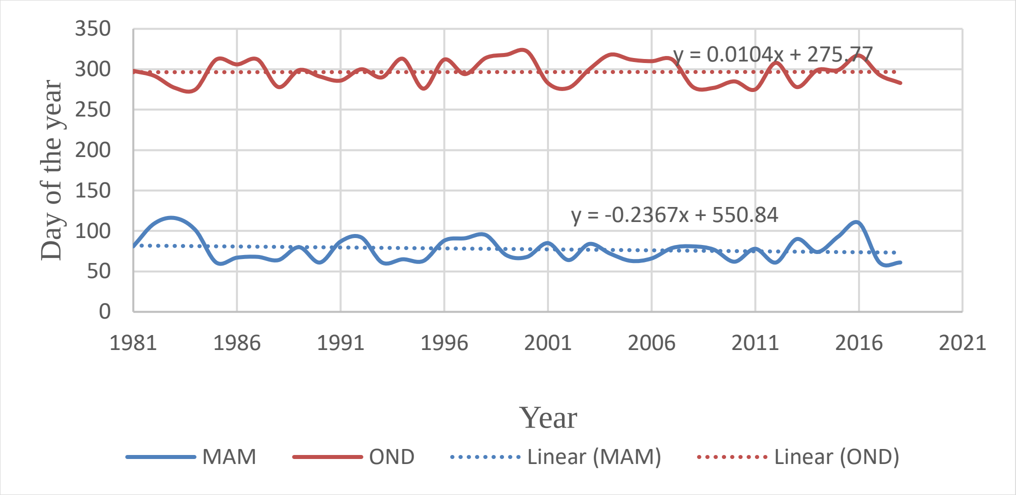

**Figure 9: Time series plot of seasonal onset dates for Narok station**

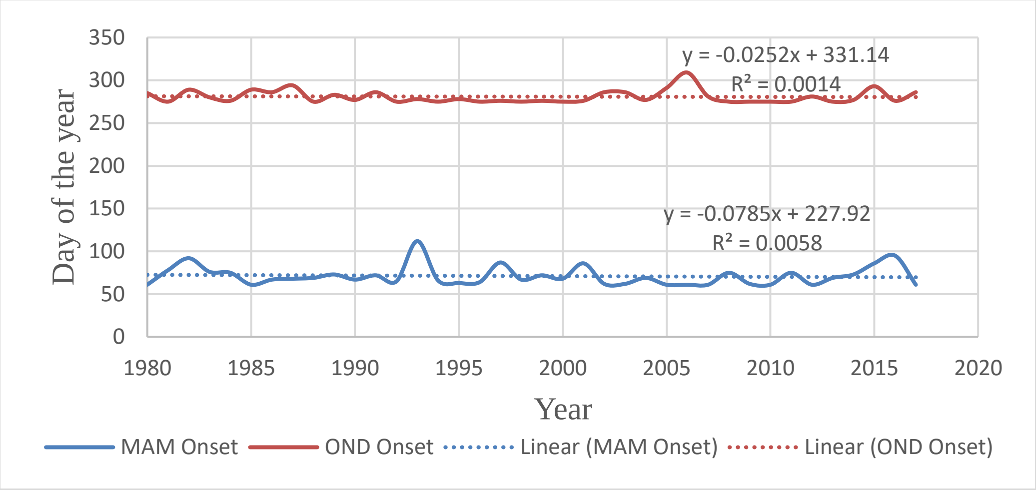

**Figure 10: Time series plot of seasonal onset dates for Nyangores station**

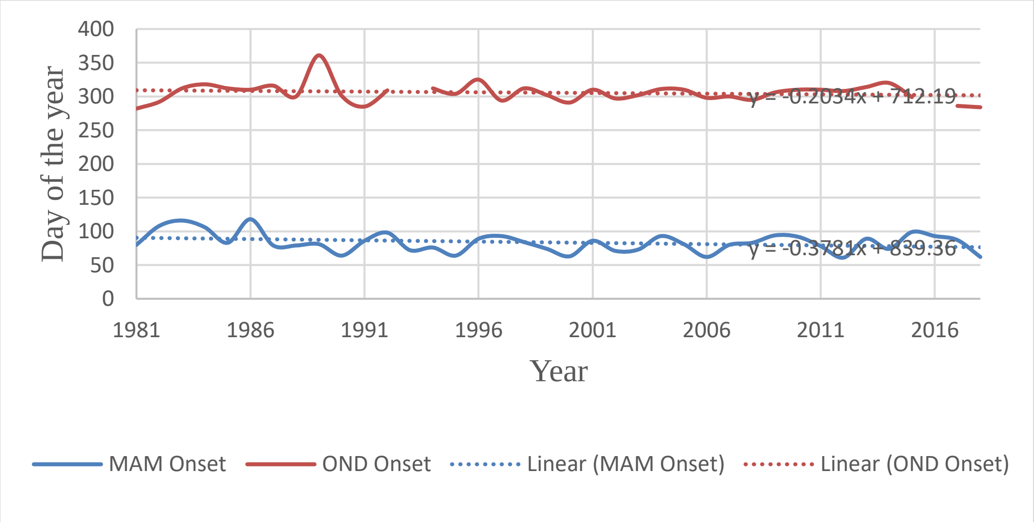

**Figure 11: Time series plot of seasonal onset dates for Mosiro station**

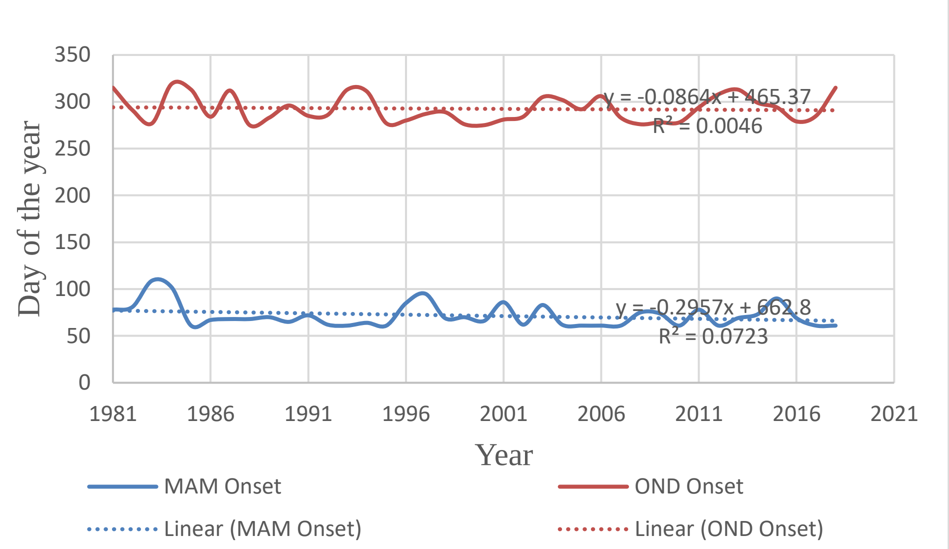

**Figure 12: Time series plot of seasonal onset dates for Oloololo station**

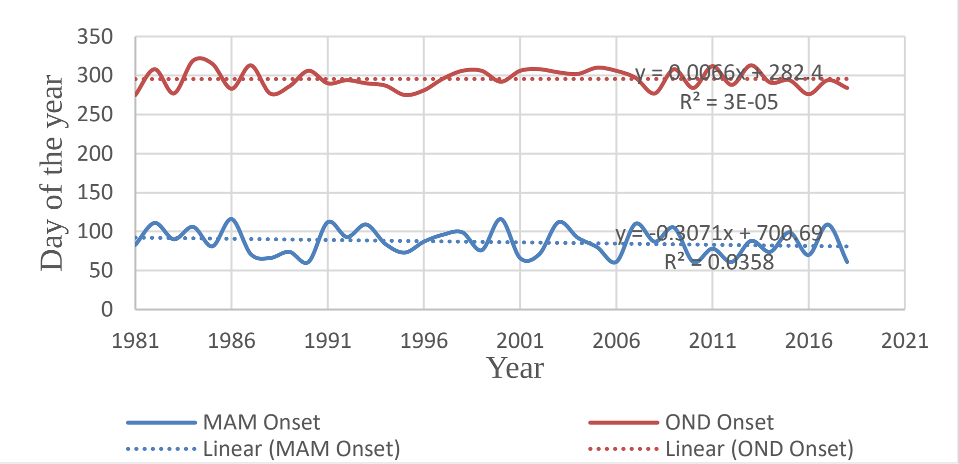

**Figure 13: Time series plot of seasonal onset dates for Olchorro station**

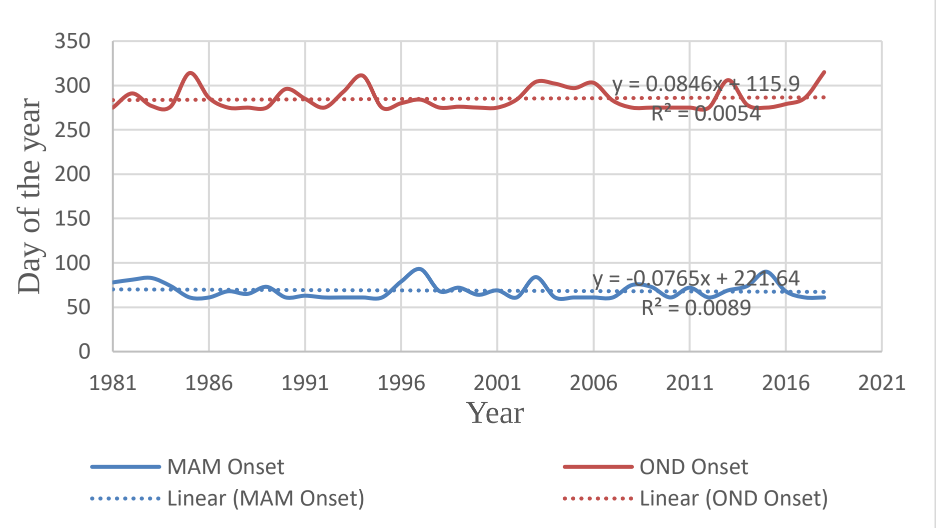

**Figure 14: Time series plot of seasonal onset dates for Governor's station**

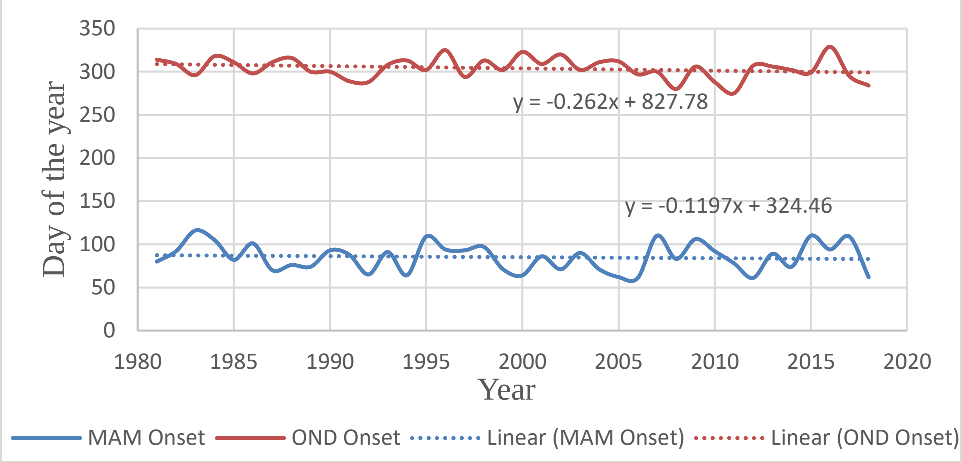

**Figure 15: Time series of mean seasonal onset dates for Loita station**

Kilgoris and Elementaita stations depicted increasing trends in rainy season onset dates in both seasons, signifying delayed onset dates in recent years during both MAM and OND seasons. Late onset dates in MAM and OND seasons presents crop farmers around Kilgoris and Elementaita great opportunities to delay planting of their maize crop and timely plan subsequent agricultural activities. Conversely, Nyangores, Mosiro, Oloololo and Loita stations depicted decreasing trends in seasonal onset dates in both MAM and OND seasons, signifying early onset dates. Early onset dates present crop farmers around Nyangores, Mosiro and Oloololo great opportunities to plant their maize early and timely plan subsequent agricultural activities. Narok station depicted an increasing trend in the MAM season onset dates and a corresponding decreasing trend in the OND season onset dates, implying delayed onset dates in MAM and early onset dates in OND season. The early onset dates in OND presents maize farmers with the opportunity to shift their planting seasons to earlier dates. Olchorro and Governor's stations depicted increasing trends in OND seasonal onset dates and corresponding decreasing trends in MAM seasonal onset dates, implying delayed onset dates during OND season and early onset dates during MAM season. The early onset dates during MAM season presents maize farmers with the opportunity to shift their planting seasons to earlier dates

### 4.3.2 Temporal Variability of Cessation date

Figures 16 to 24 present the time series of rainy season cessation dates for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations respectively.

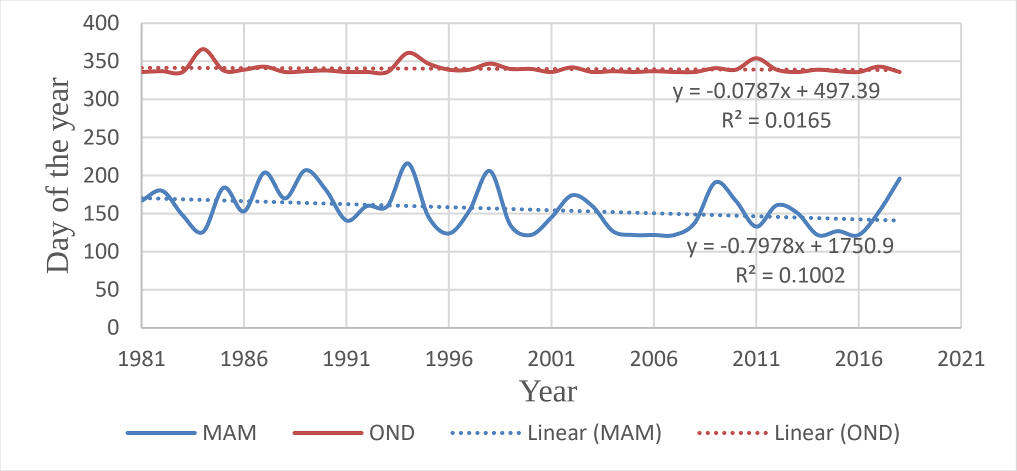

Figure 16: Time series of seasonal cessation dates for Kilgoris station from 1981 to 2018

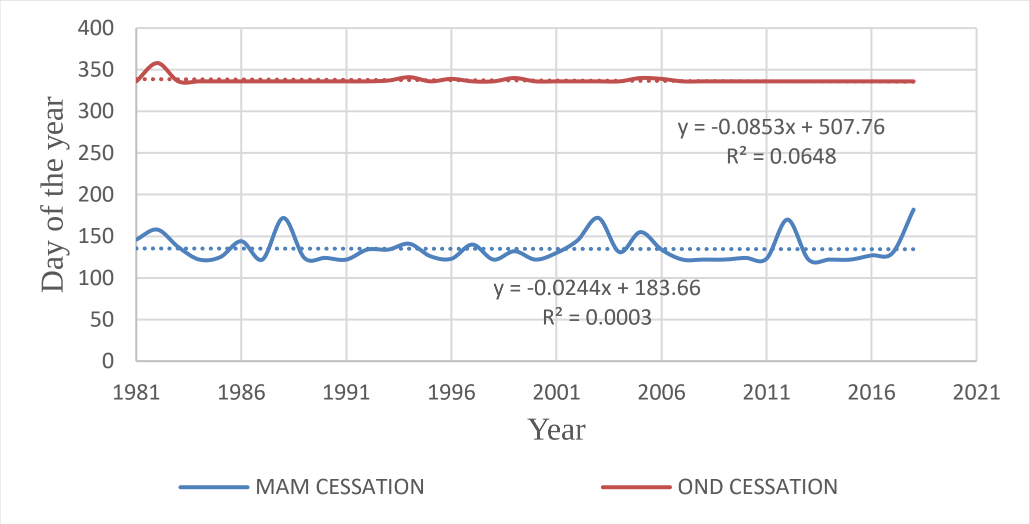

Figure 17: Time series of seasonal cessation dates for Elementaita station from 1981 to 2018

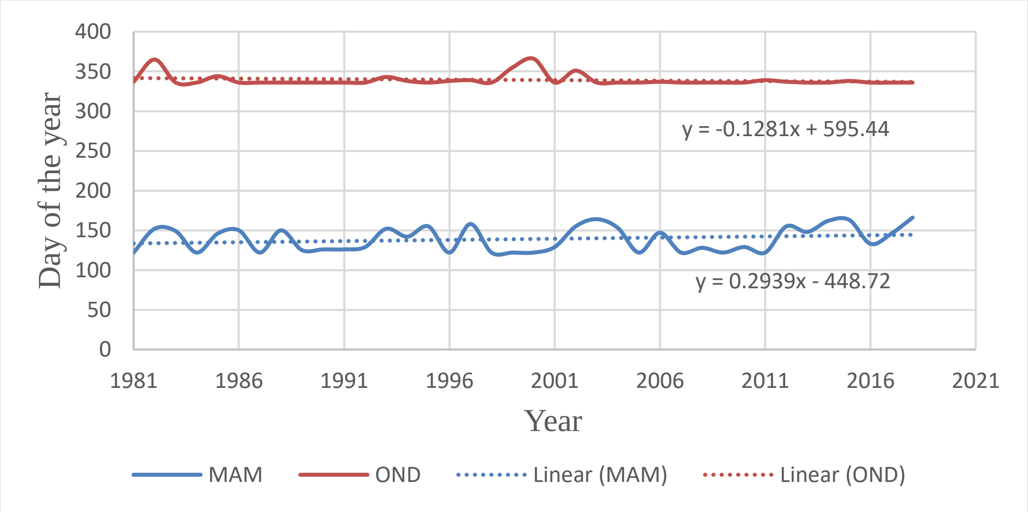

Figure 18: Time series of seasonal cessation dates for Narok station from 1981 to 2018

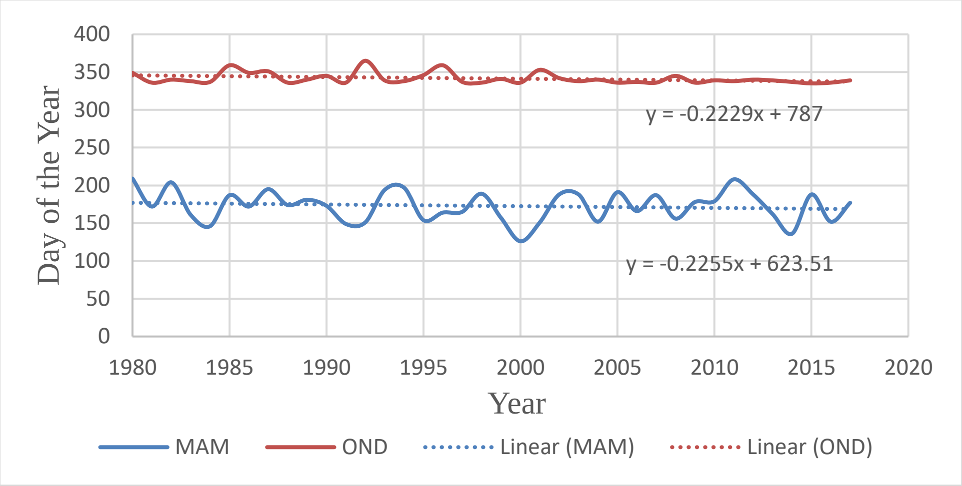

**Figure 19: Time series of seasonal cessation dates for Nyangores station from 1981 to 2018**

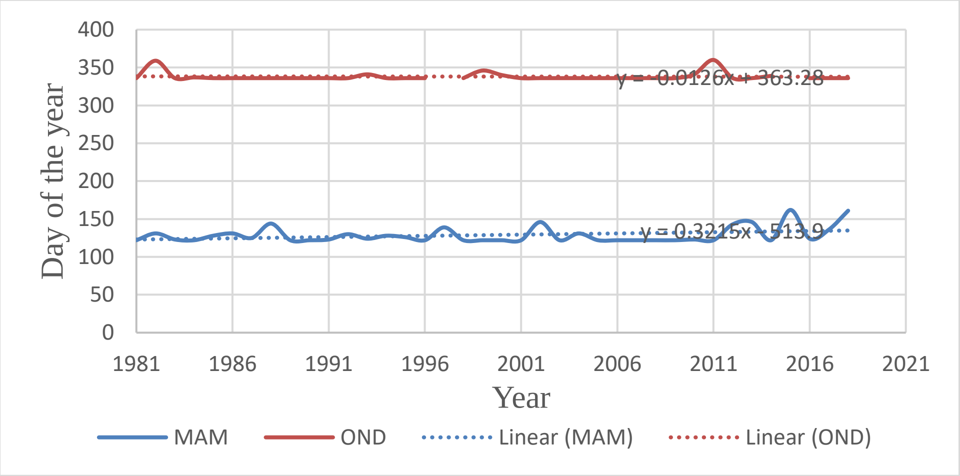

**Figure 20: Time series plot of seasonal cessation dates for Mosiro station from 1981 to 2018**

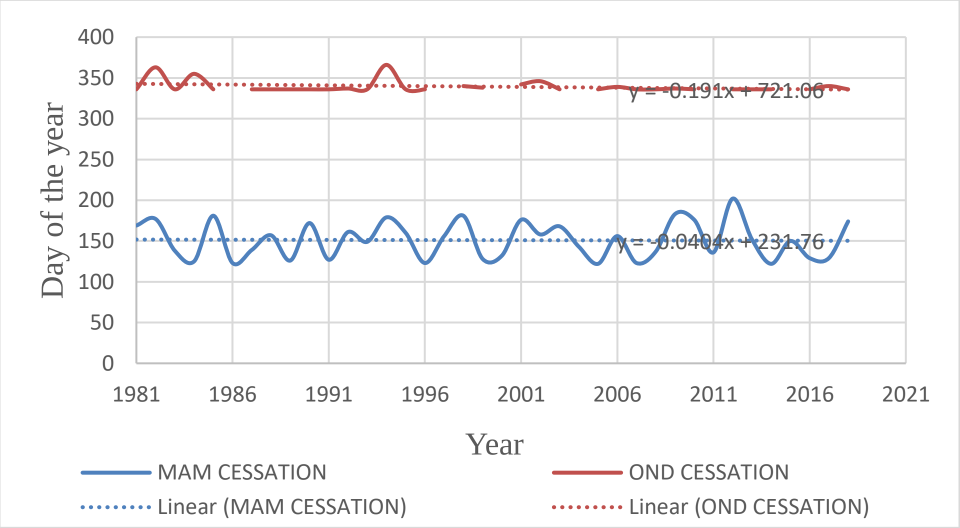

**Figure 21: Time series plot of seasonal cessation dates for Oloololo station from 1981 to 2018**

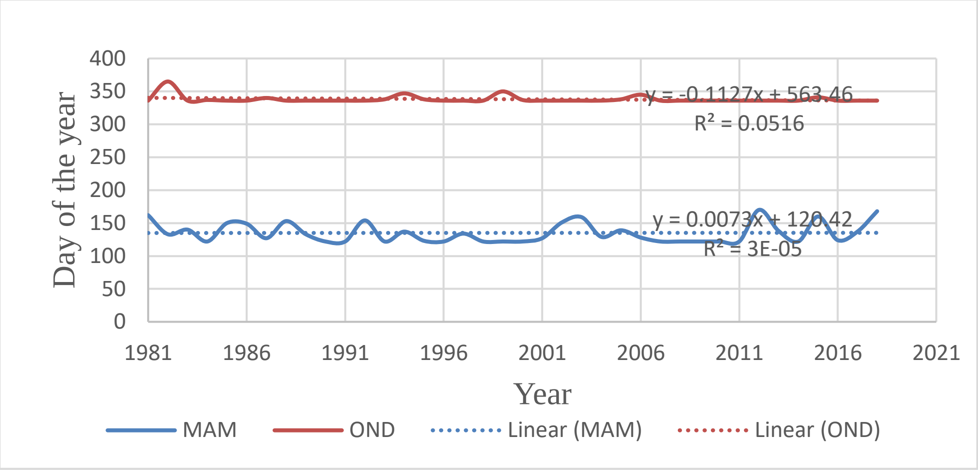

**Figure 22: Time series plot of seasonal cessation dates for Olchorro station from 1981 to 2018**

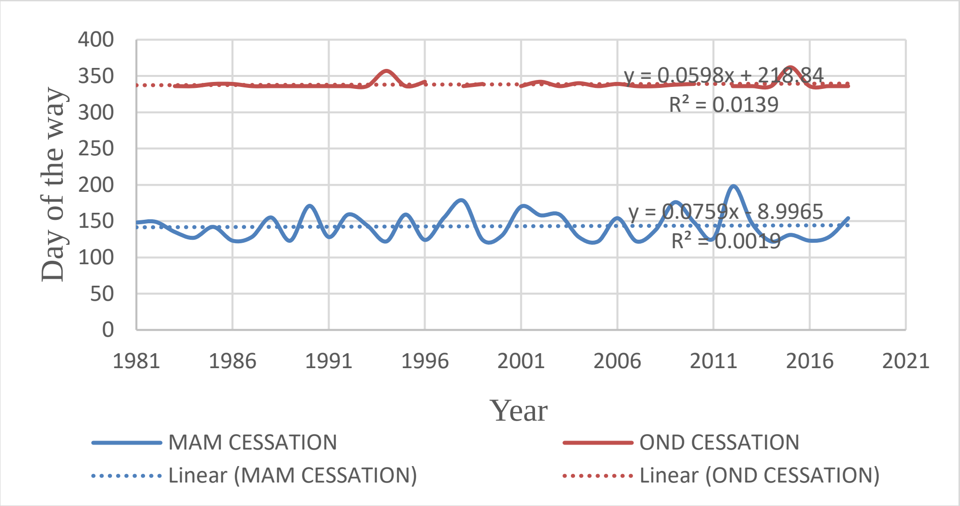

**Figure 23: Time series plot of seasonal cessation dates for Governor's station**

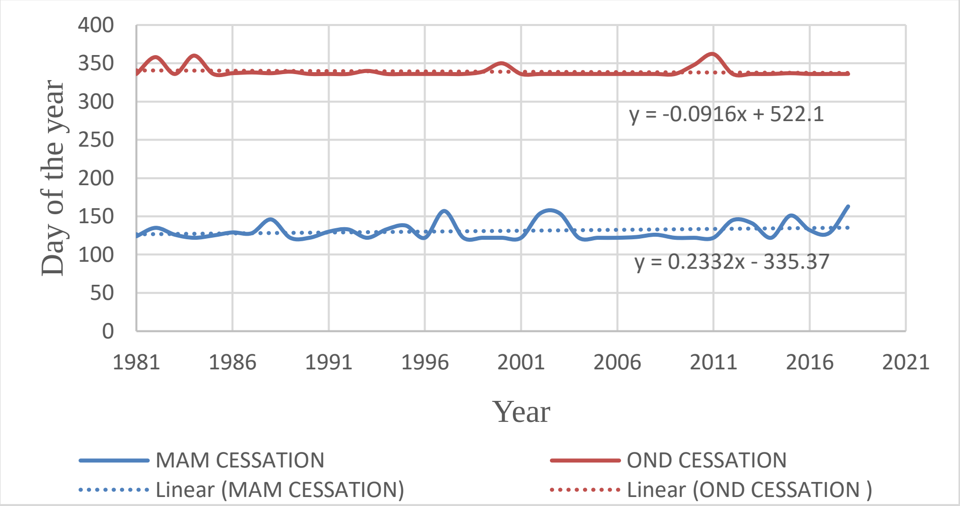

**Figure 24: Time series plot of mean seasonal cessation dates for Loita station**

Kilgoris, Elementaita, Nyangores and Oloololo stations depicted decreasing trends in rainy season cessation dates in both MAM and OND seasons. The observed trends imply early cessation dates in both seasons. Delayed onset dates accompanied by early cessation dates signals reduced growing season length in Kilgoris, Elementaita, Nyangores and Oloololo stations during MAM and OND seasons. On the other hand, Narok, Mosiro, Olchorro and Loita stations depicted increasing trends in cessation dates in MAM and a corresponding decreasing trends in cessation dates during OND season, implying delayed cessation dates during MAM and early cessation dates in OND season. Governor's station depicted increasing trends in seasonal cessation dates during both MAM and OND seasons, implying late cessation dates in MAM and OND seasons around Governor's station. Delayed cessation dates during MAM season presents an opportunity for maize farmers around Narok, Mosiro and Olchorro stations to relay maize production in subsequent seasons and optimize soil moisture use and maize production

### 4.3.3 Temporal variability in mean length of growing season

Figures 25 to 33 present the time series plots for the mean length of growing season for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations.

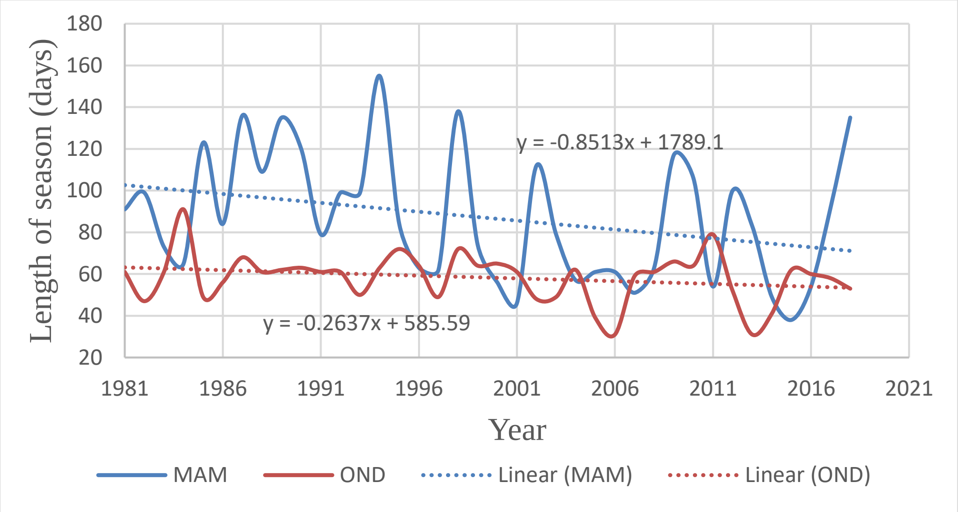

**Figure 25: Time series of the mean length of growing season for Kilgoris station**

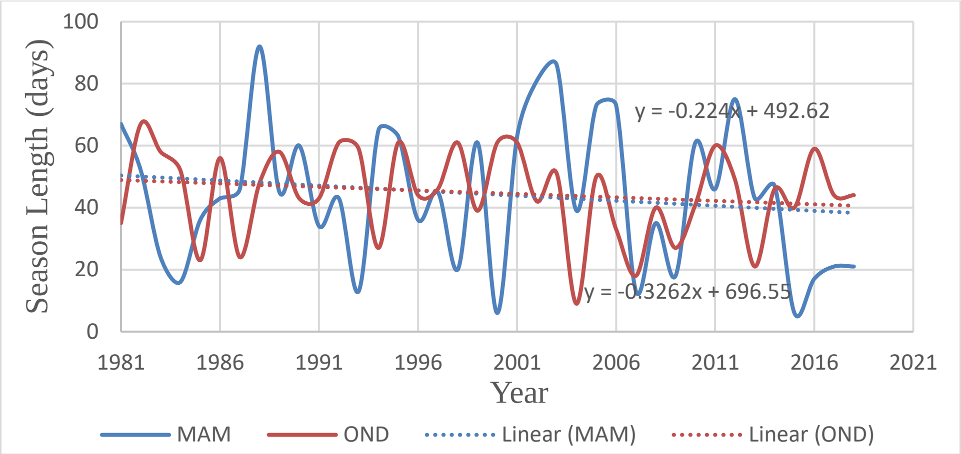

Figure 26: Time series of the mean length of growing season for Elementaita station

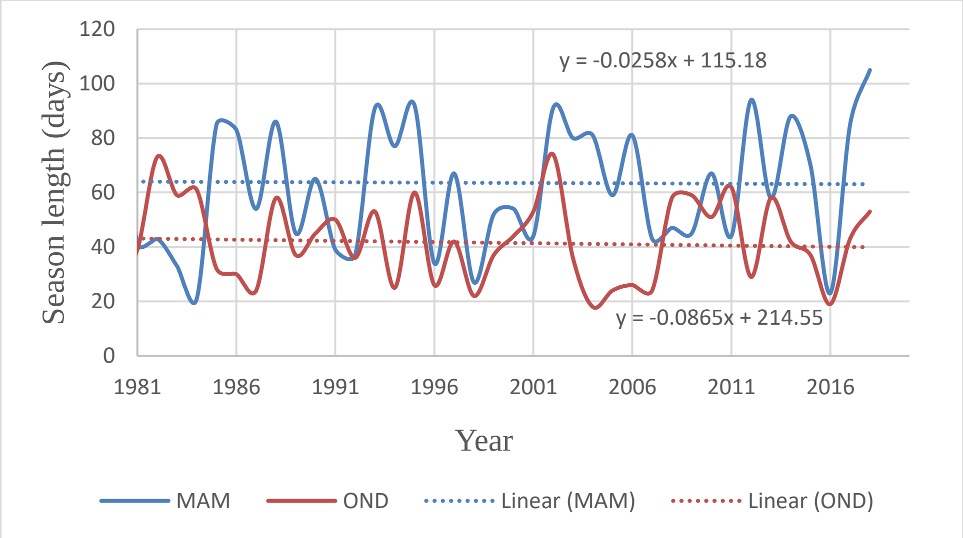

Figure 27: Time series of the mean length of growing season for Narok station

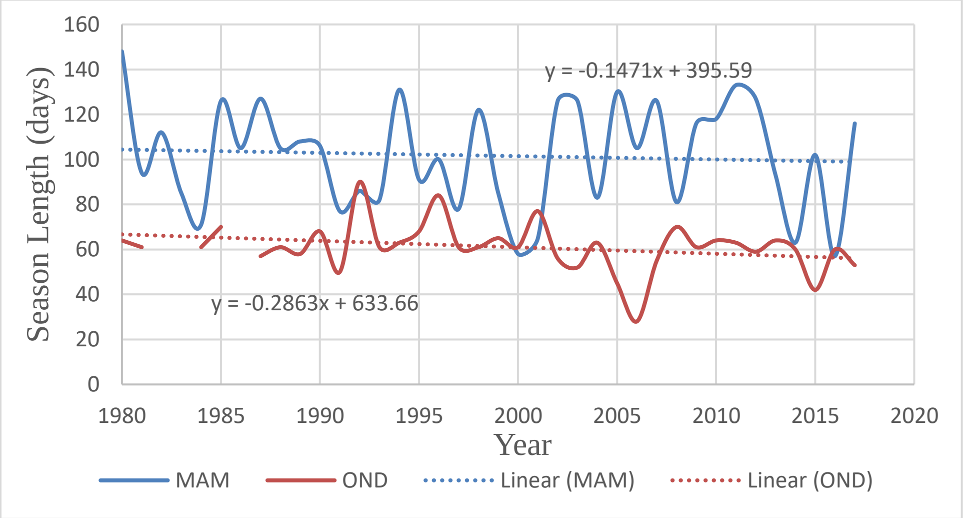

Figure 28: Time series of the mean length of growing season for Nyangores station

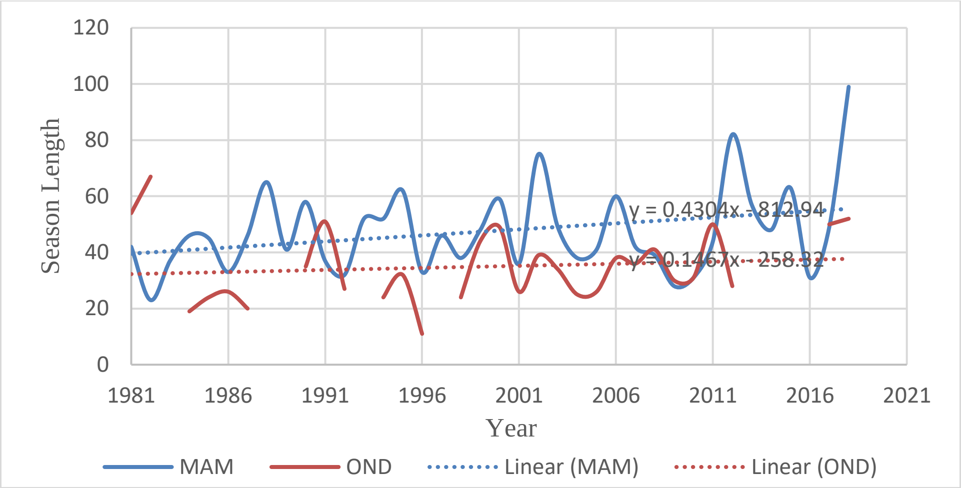

Figure 29: Time series plot of the mean length of growing season for Mosiro

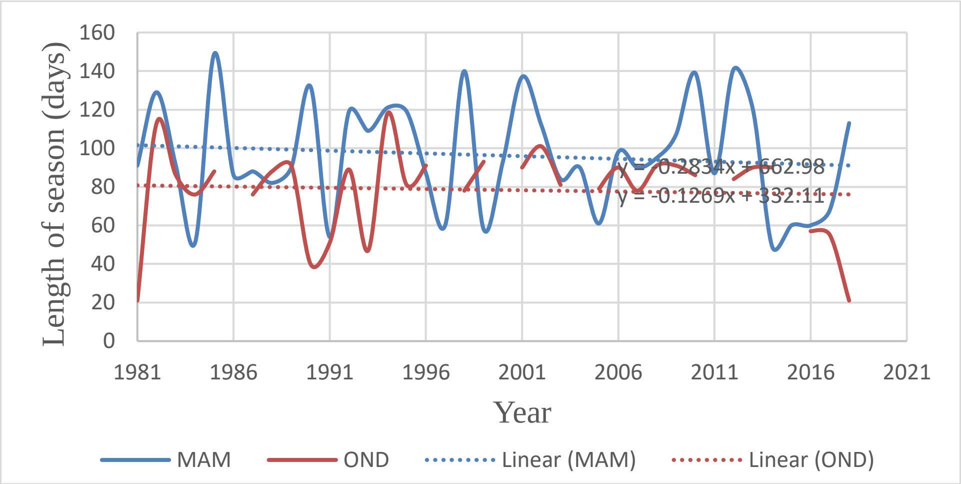

Figure 30: Time series plots of the mean seasonal length of growing season for Oloololo station

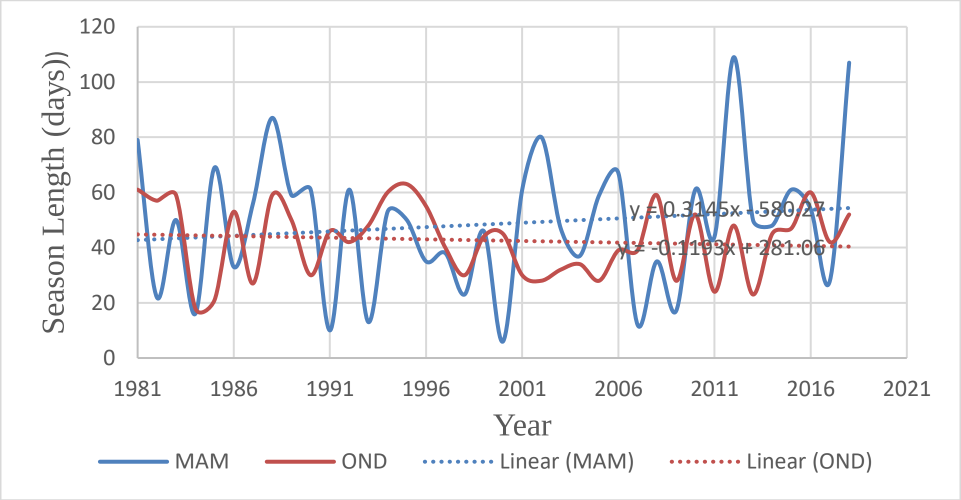

Figure 31: Time series plots of the mean seasonal length of growing season for Olchorro station

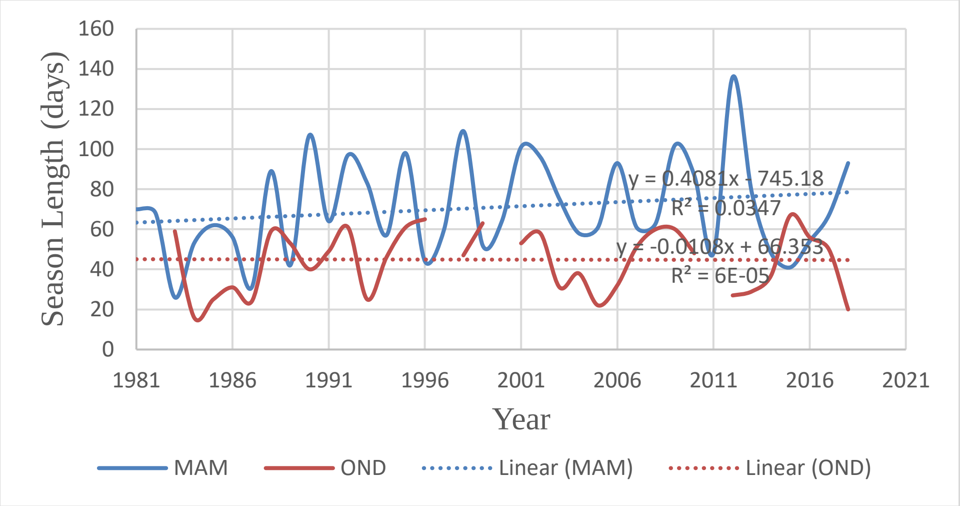

**Figure 32: Time series plots of the mean seasonal length of growing season for Governor's station**

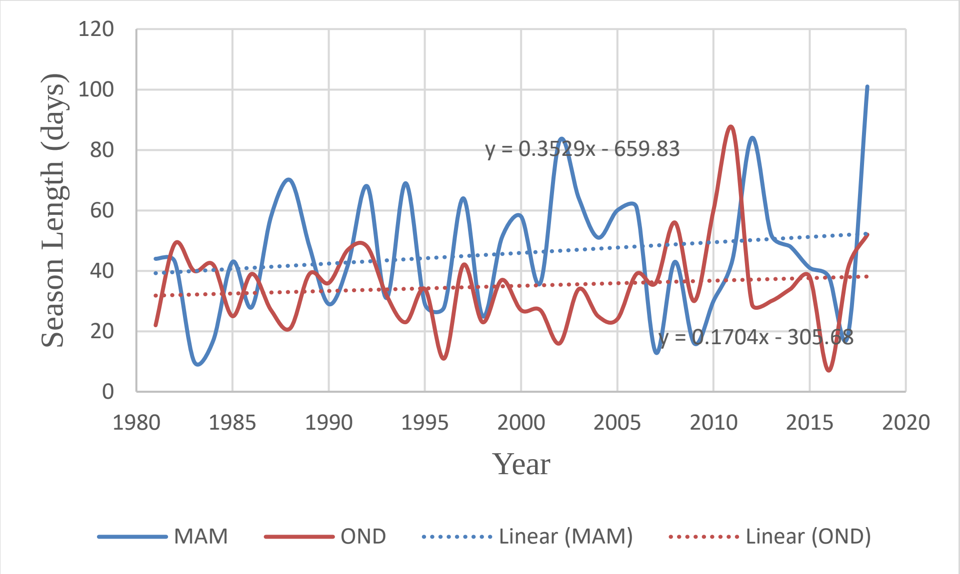

**Figure 33: Time series plot of the seasonal length of growing season for Loita station**

Kilgoris, Elementaita, Narok, Nyangores, and Oloololo stations depicted decreasing trend in the mean length of growing season in both MAM and OND seasons, signifying shortening of the length of the growing season. On the contrary, Mosiro, Olchorro and Loita stations depicted increasing trends in mean length of growing season during both MAM and OND seasons, implying longer mean lengths of growing season around Mosiro and Olchorro stations in MAM and OND season. Therefore, greater prospects for crop agriculture around Mosiro and Olchorro stations in both MAM and OND seasons. Governor’s station depicted increasing trend in mean seasonal growing length during MAM season and a corresponding decreasing trend in mean lengths of growing season during OND season, implying longer lengths of growing season in MAM and shorter lengths of growing season during OND. The delayed onset dates accompanied by corresponding early cessation dates in both seasons are the main cause of the shortened length of growing season. This calls for a farmers' shift from growing the current longer duration maize varieties around these stations towards adoption of shorter/ earlier maturation maize varieties.

### 4.3.4 Seasonal total Rainfall

Figures 34 to 42 present the time series plots of seasonal total rainfall for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations.

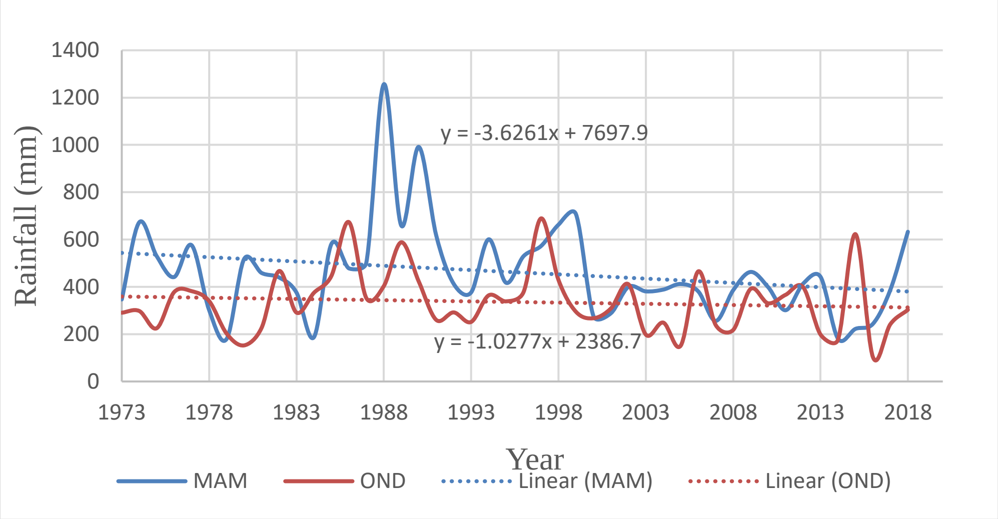

**Figure 34: Time series of seasonal total rainfall for Kilgoris station**

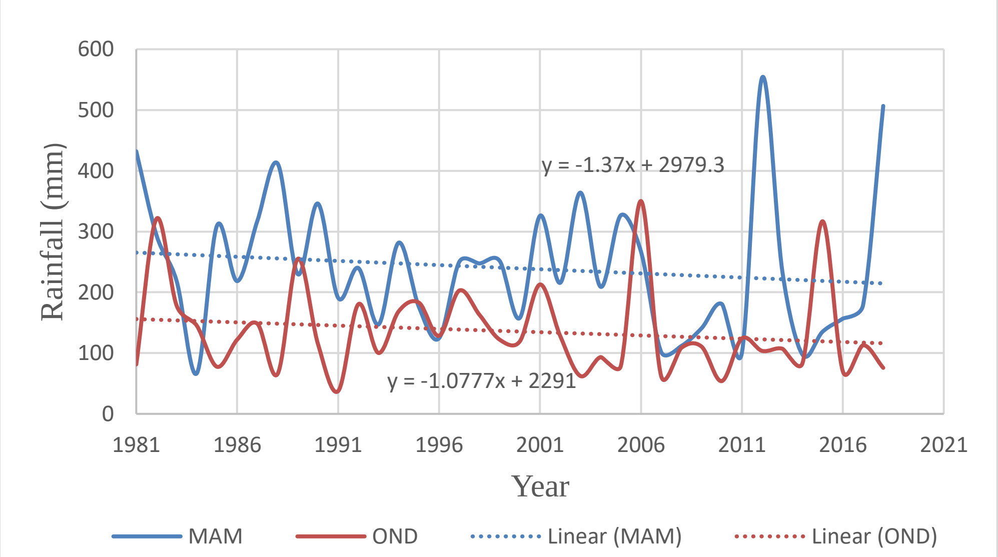

**Figure 35: Time series of seasonal total rainfall for Elementaita station**

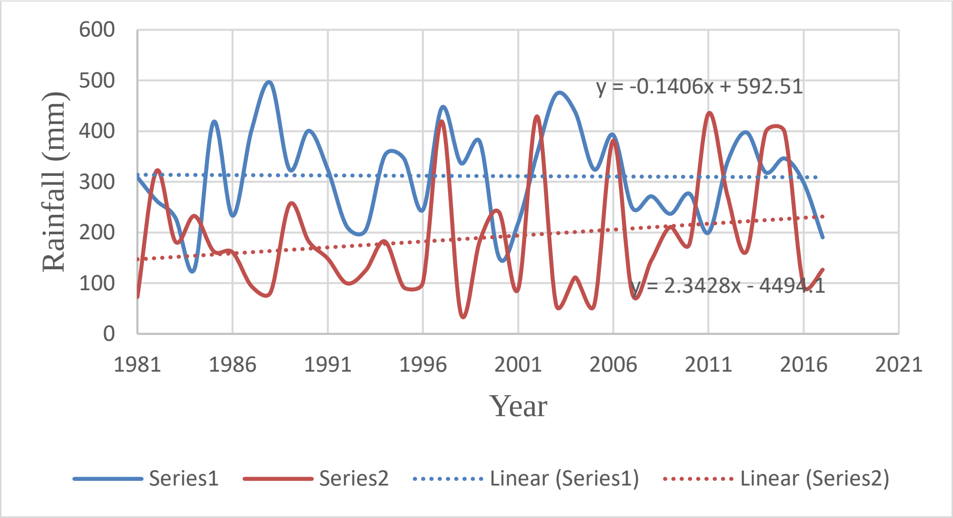

**Figure 36: Time series of seasonal total rainfall for Narok station**

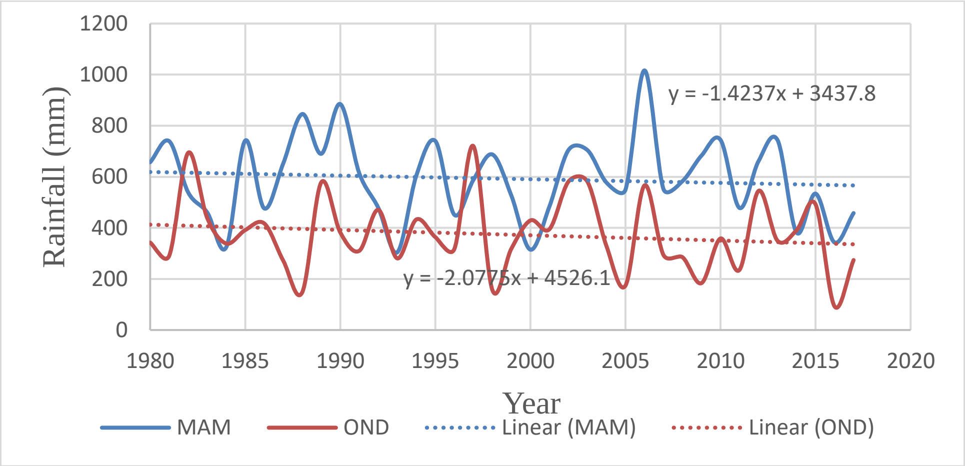

**Figure 37: Time series of seasonal total rainfall for Nyangores station**

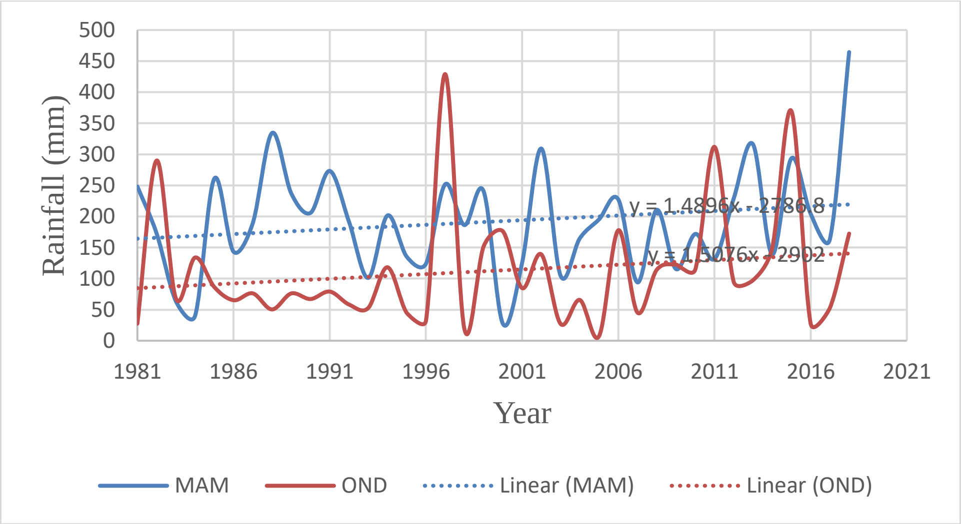

**Figure 38: Time series plot of seasonal total rainfall for Mosiro station**

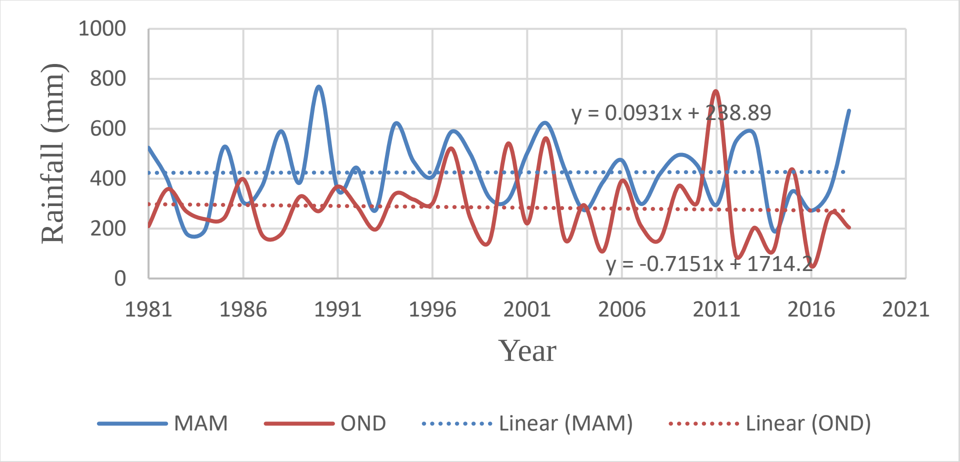

Figure 39: Time series plot of seasonal total rainfall for Oloololo station

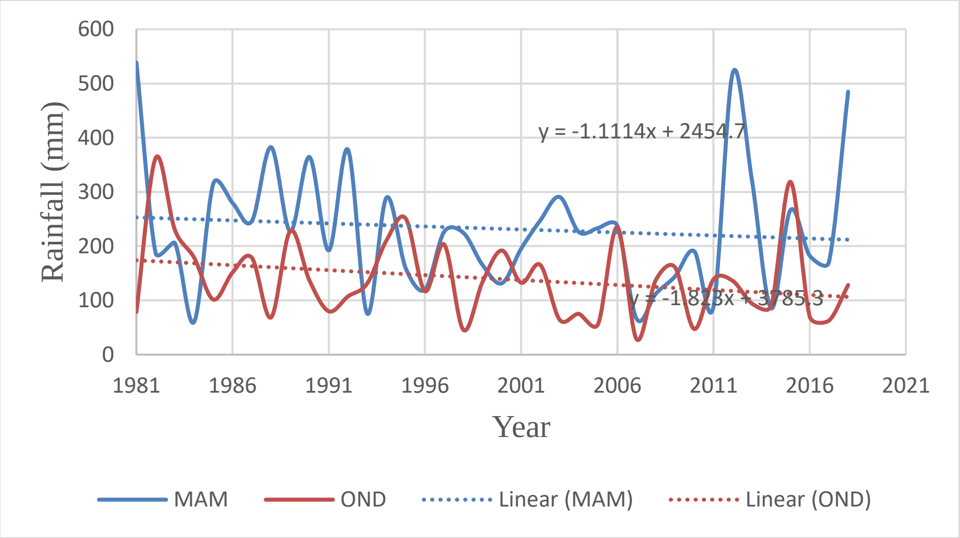

Figure 40: Time series plot of seasonal total rainfall for Olchorro station

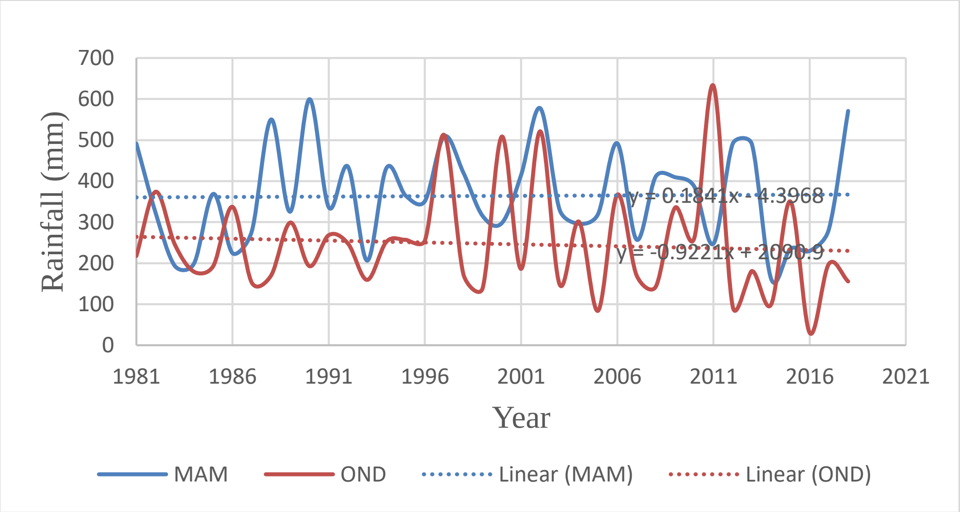

Figure 41: Time series plot of seasonal rainfall total for Governor's station

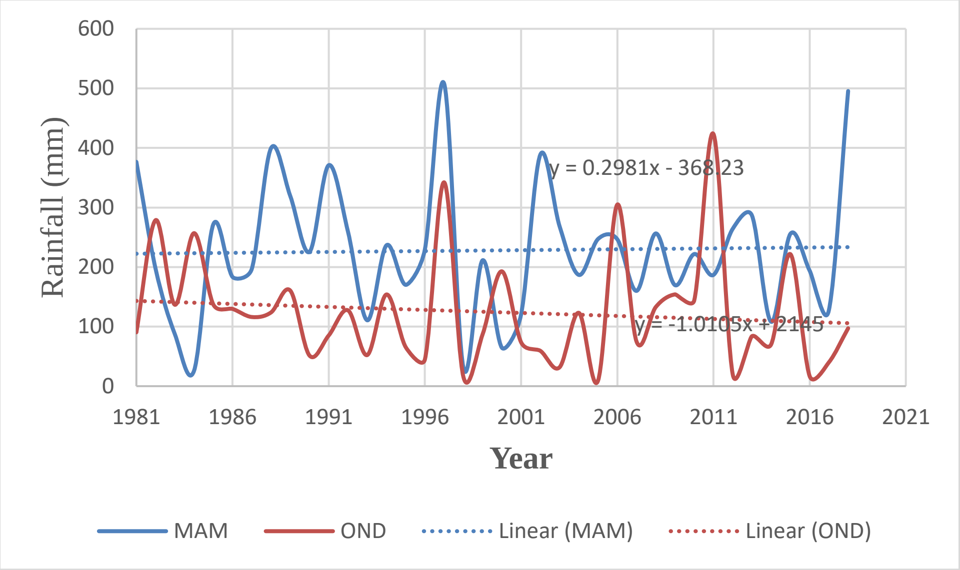

**Figure 42: Time series of mean seasonal total rainfall for Loita station**

Kilgoris, Elementaita, Nyangores and Olchorro stations depicted decreasing trend in seasonal total rainfall in both MAM and OND seasons, signifying reduced mean total rainfall in both seasons. On the contrary, Mosiro and Oloololo stations depicted increasing trends in seasonal total rainfall in both MAM and OND seasons, implying increasing seasonal total rainfall in both MAM and OND seasons. Narok station depicted decreasing trend in MAM seasonal total rainfall and an increasing trend in the OND seasonal total rainfall, implying reduced season total rainfall in MAM and increased season total rainfall in OND season. This observation is in agreement with Parry et al., (2012), who projected decreased rainfall in MAM season and increased rainfall during OND season. Governor's and Loita stations depicted increasing trend in MAM seasonal total rainfall and a corresponding decreasing trend in OND seasonal rainfall. Implying increasing seasonal total rainfall in MAM and decreasing seasonal total rainfall during OND season around Governor's and Loita stations.

### 4.3.5 Seasonal number of rainy days

Figures 43 to 51 present the time series of mean number of rainy days in Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations respectively.

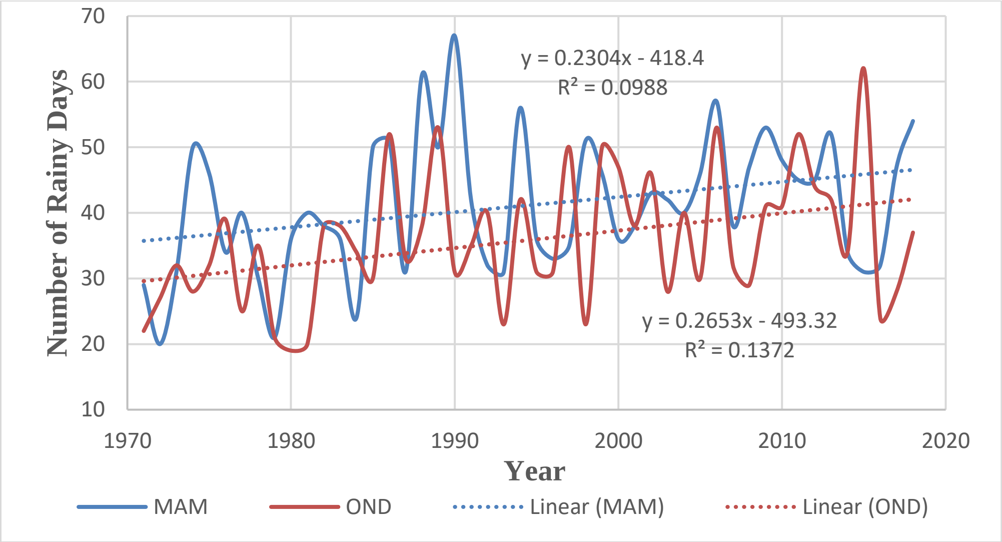

**Figure 43: Time series plots of mean seasonal number of rainy days for Kilgoris**

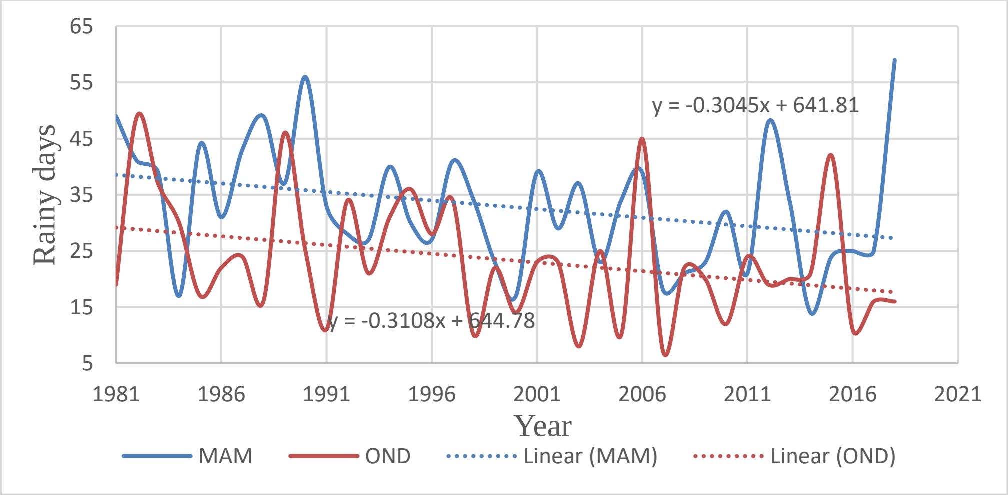

**Figure 44: Time series of the mean seasonal number of rainy days for Elementaita station**

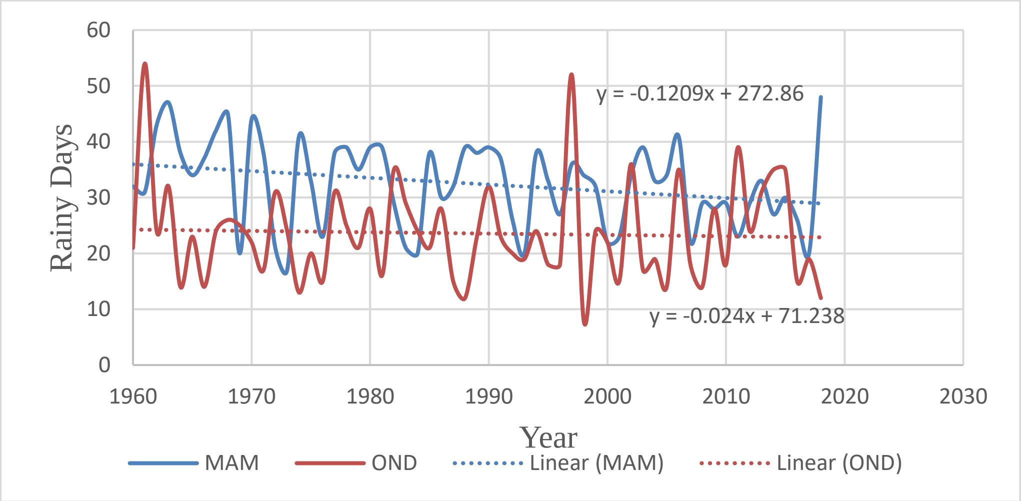

**Figure 45: Time series of the mean seasonal number of rainy days for Narok station**

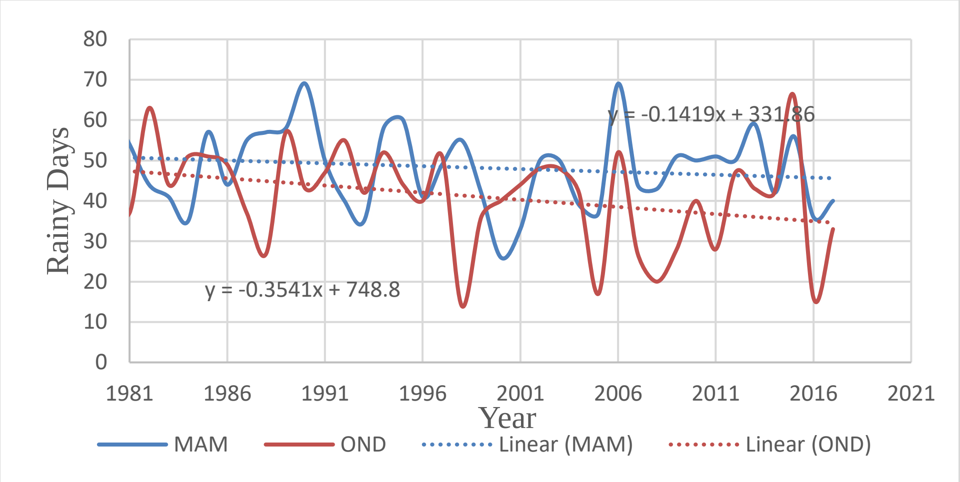

**Figure 46: Time series plot of the mean seasonal number of rainy days for Nyangores station**

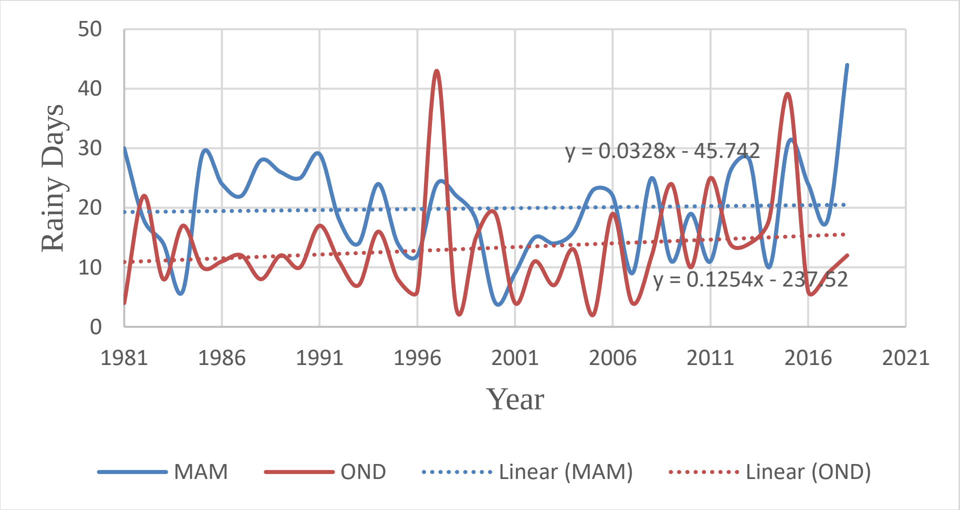

**Figure 47: Time series of mean seasonal number of rainy days for Mosiro station**

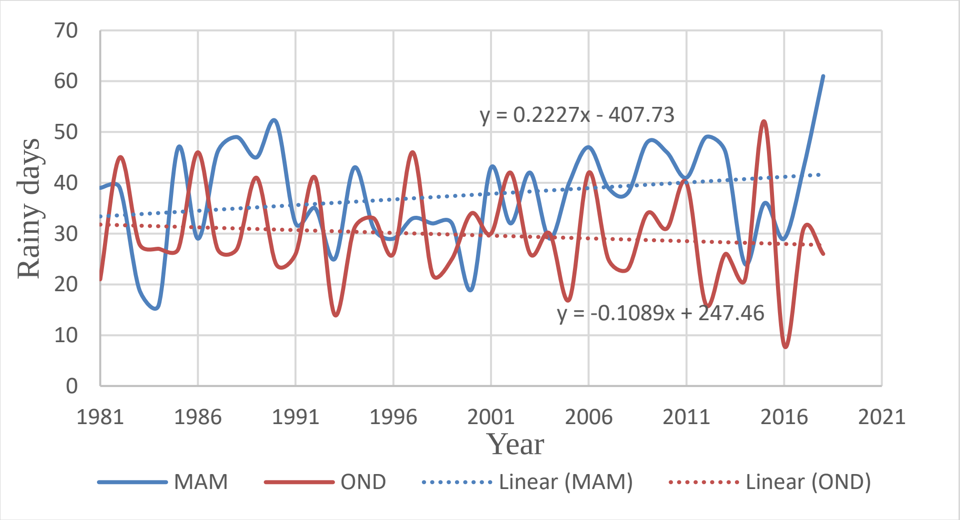

**Figure 48: Time series plot of mean seasonal number of rainy days for Oloololo station**

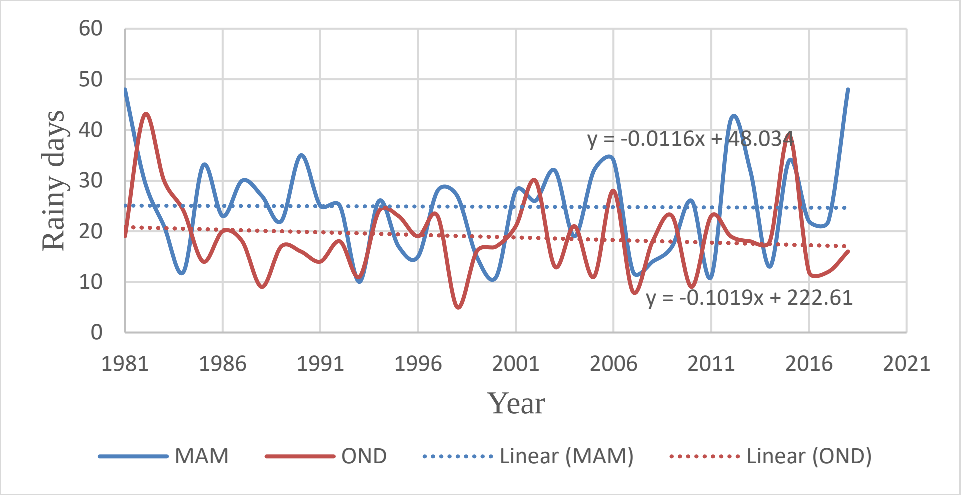

Figure 49: Time series plot of mean seasonal number of rainy days for Olchorro station

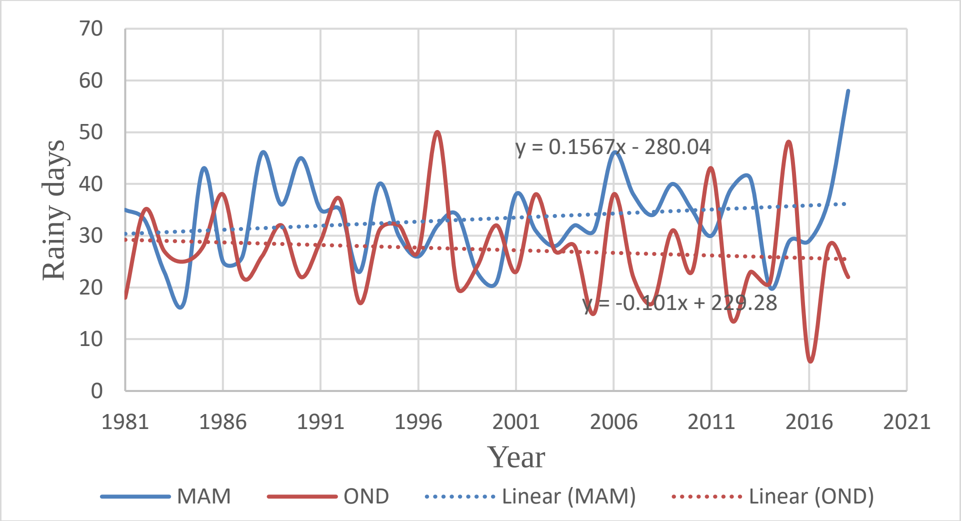

Figure 50: Time series plot of mean seasonal number of rainy days for Governor's station

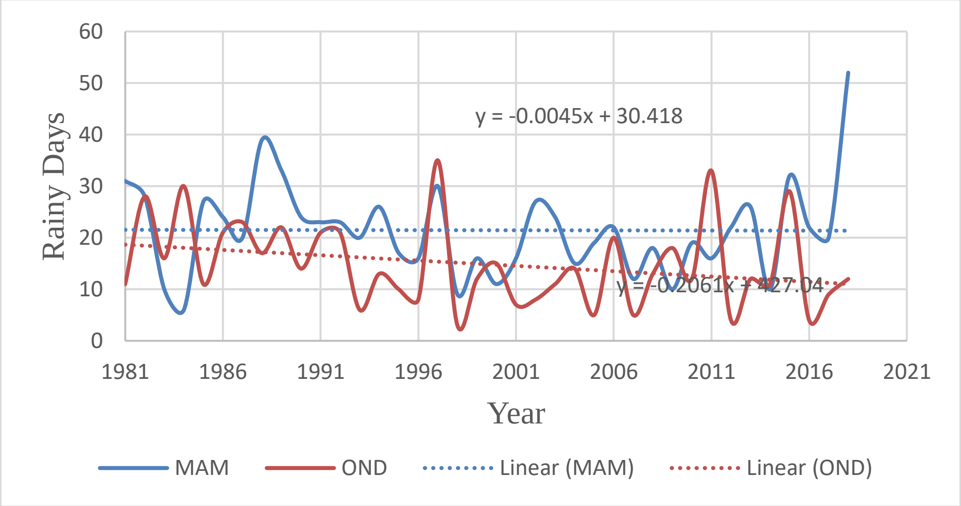

Figure 51: Time series plot of mean seasonal number of rainy days for Loita station

Kilgoris and Mosiro stations depicted increasing trends in the mean seasonal number of rainy days, signifying increasing number of rainy days in both MAM and OND seasons and therefore wetter conditions in MAM and OND seasons. Therefore, there are higher prospects for crop agriculture around Kilgoris and Mosiro stations. On the contrary, Elementaita, Narok, Nyangores, Olchorro and Loita stations depicted decreasing trends in the mean seasonal number of rainy days during both MAM and OND seasons, implying reduction in the number of rainy days in both seasons and decreasing prospects for crop agriculture. Oloololo and Olchorro stations depicted increasing trends in MAM seasonal number of rainy days and decreasing trends in OND seasonal number of rainy days, implying increasing number of rainy days during MAM and consequently decreasing number of rainy days during OND seasons respectively.

### 4.3.6 Temporal variability in mean seasonal lengths of wet spells

Figures 52 to 60 present the time series plots of the mean seasonal lengths of wet spell for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations respectively.

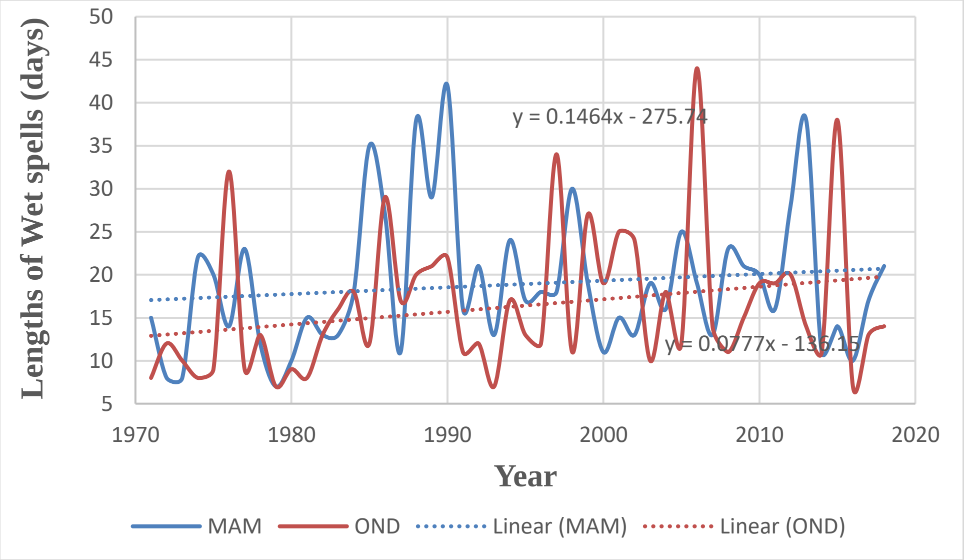

**Figure 52: Time series of the mean seasonal length of wet spell for Kilgoris**

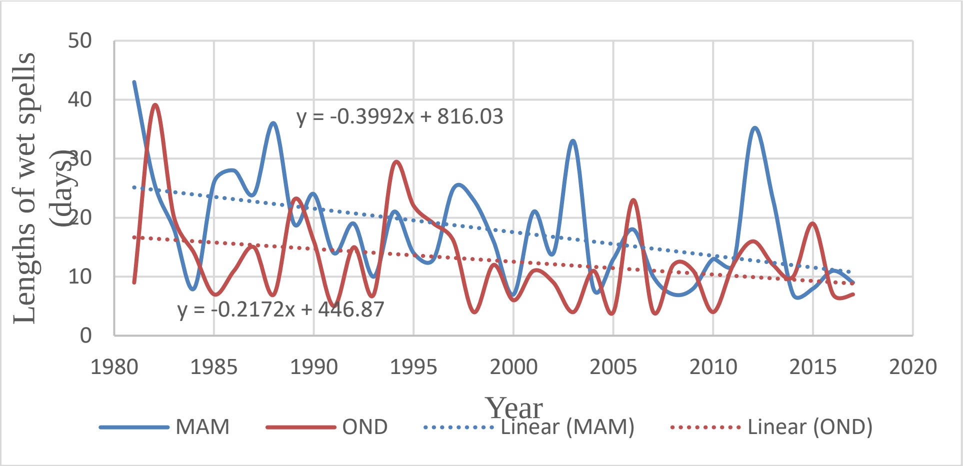

**Figure 53: Time series of the mean seasonal length of wet spell for Elementaita station**

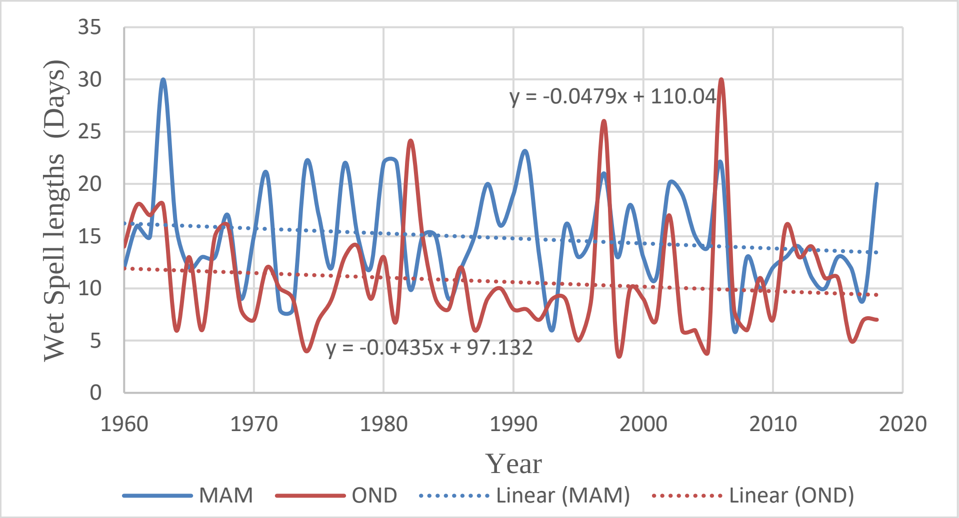

**Figure 54: Time series of the mean seasonal length of wet spell for Narok station**

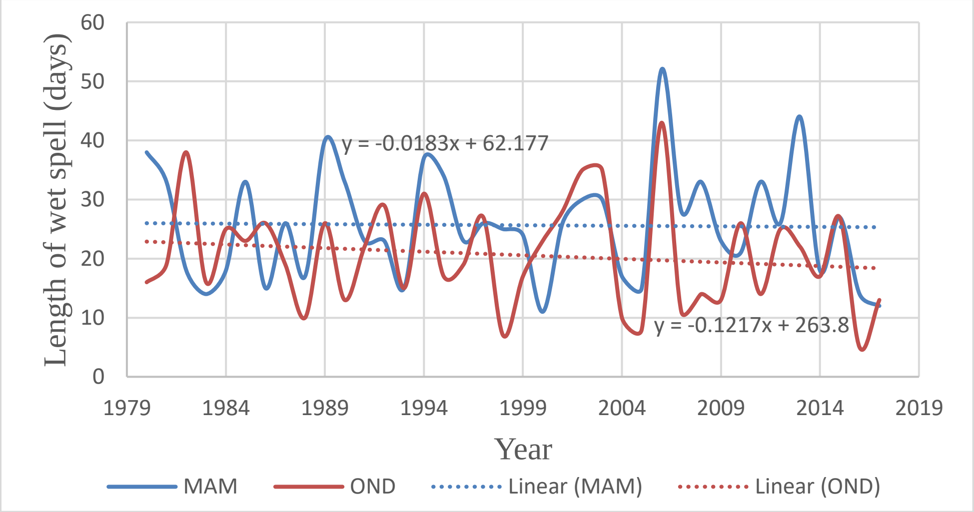

**Figure 55: Time series of the mean seasonal length of wet spell for Nyangores station**

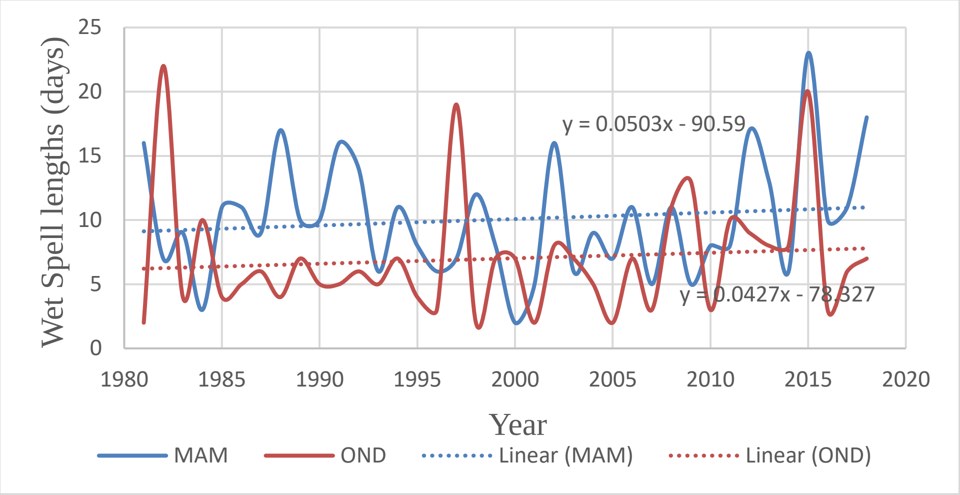

**Figure 56: Time series plots of mean seasonal lengths of wet spell for Mosiro station**

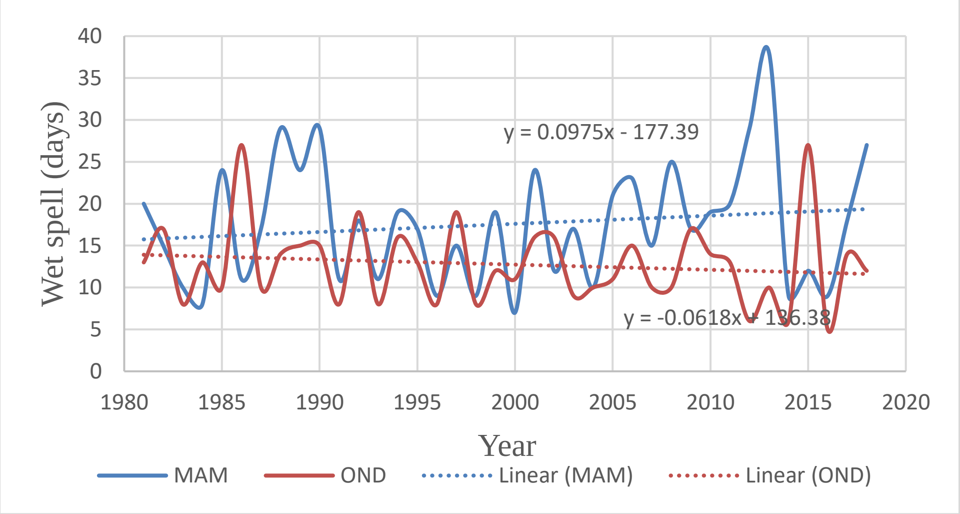

**Figure 57: Time series plots of mean seasonal lengths of wet spell for Oloololo station**

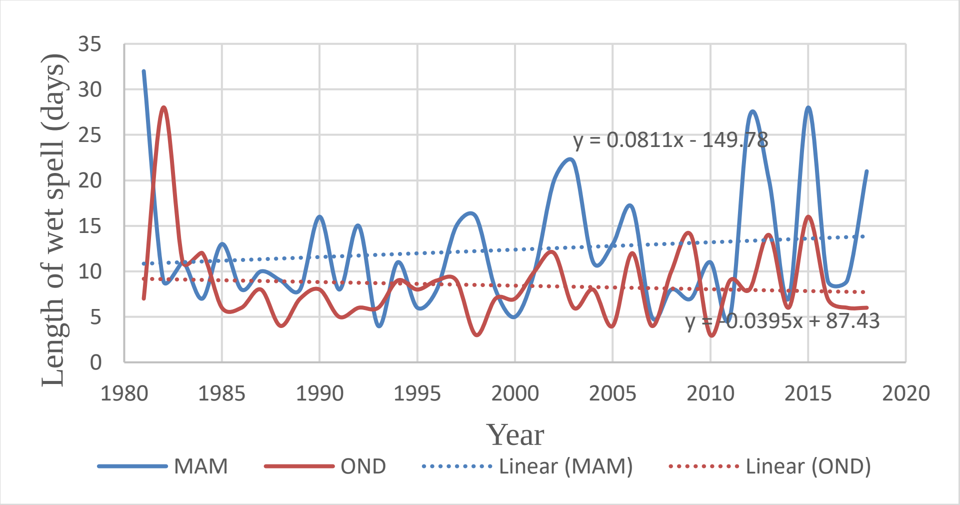

**Figure 58: Time series plot of mean seasonal lengths of wet spell for Olchorro station**

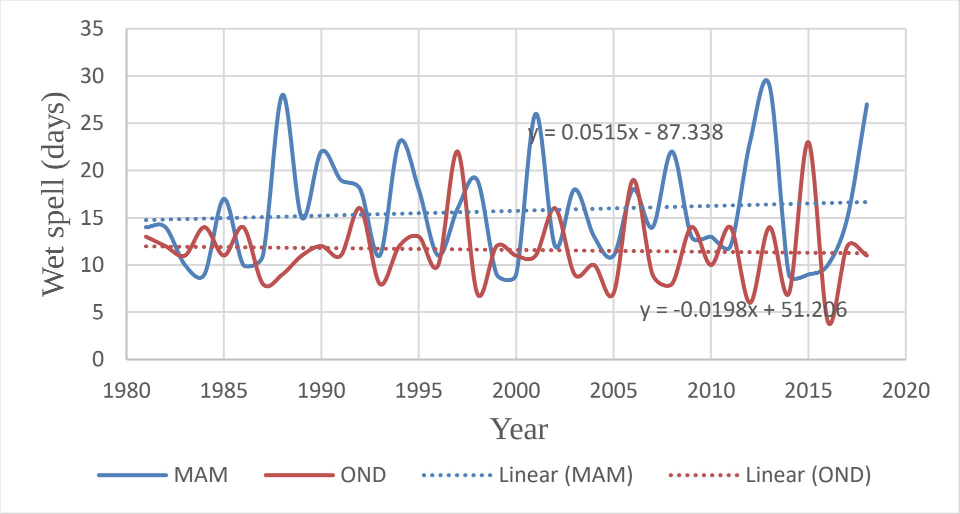

**Figure 59: Time series plot of mean seasonal length of wet spell for Governor's station**

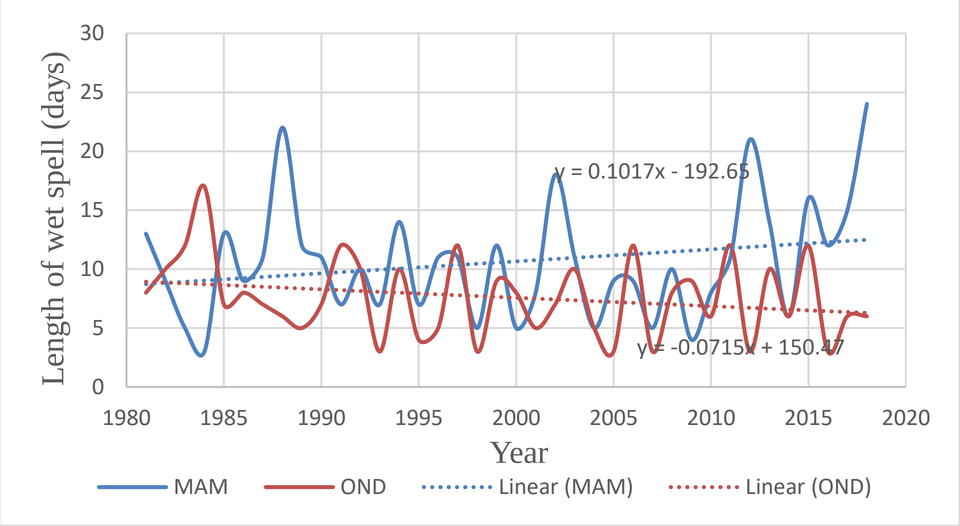

**Figure 60: Time series plot of mean seasonal length of wet spell for Loita station**

Kilgoris and Mosiro stations depicted increasing trends in the mean seasonal lengths of wet spell during both MAM and OND seasons, implying an increase in the lengths of wet spell around Kilgoris and Mosiro stations and therefore, greater prospects for crop agriculture. On the contrary, Elementaita, Narok and Nyangores stations depicted decreasing trends in the mean seasonal length of wet spell, hence reduced mean season wet spell length during both MAM and OND seasons. Oloololo, Olchorro, Governor's and Loita stations depicted increasing trends in mean seasonal lengths of wet spell during MAM season and decreasing trends in OND mean seasonal lengths of wet spell, implying increasing lengths of wet spell in MAM and decreasing lengths of wet spell during OND seasons respectively. This calls for adoption of earlier maturation maize varieties by farmers in these areas.

### 4.3.7 Temporal variability in the mean lengths of Dry spells

Figures 61 to 69 present the time series plots of lengths of dry spell for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor’s and Loita stations respectively.

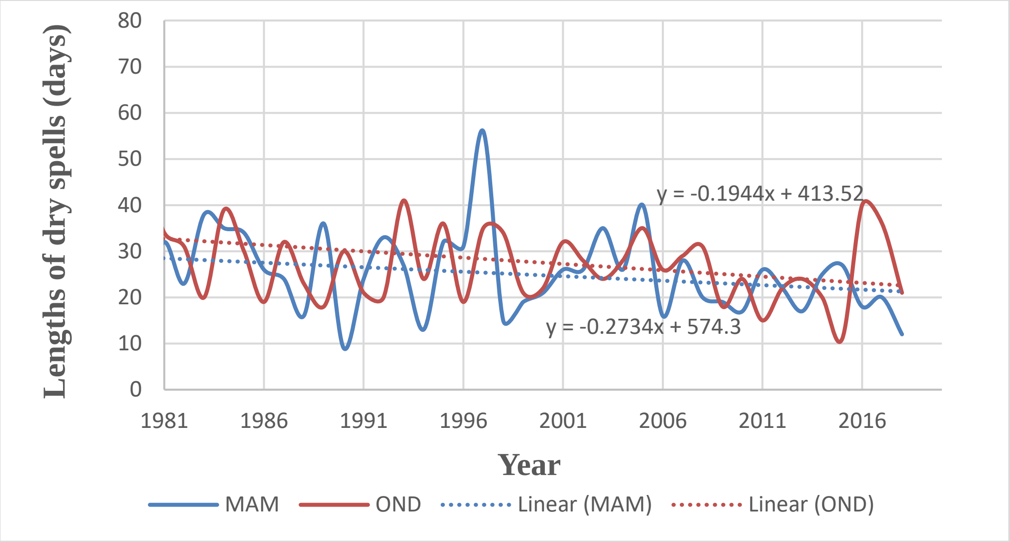

**Figure 61: Time series of the mean seasonal dry spell length for Kilgoris**

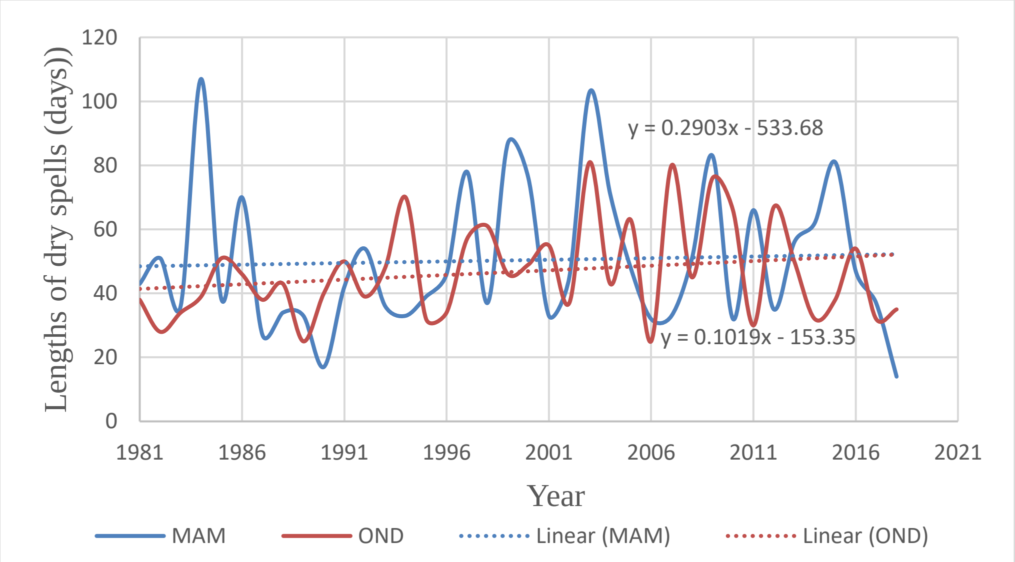

**Figure 62: Time series of the mean seasonal dry spell length for Elementaita station**

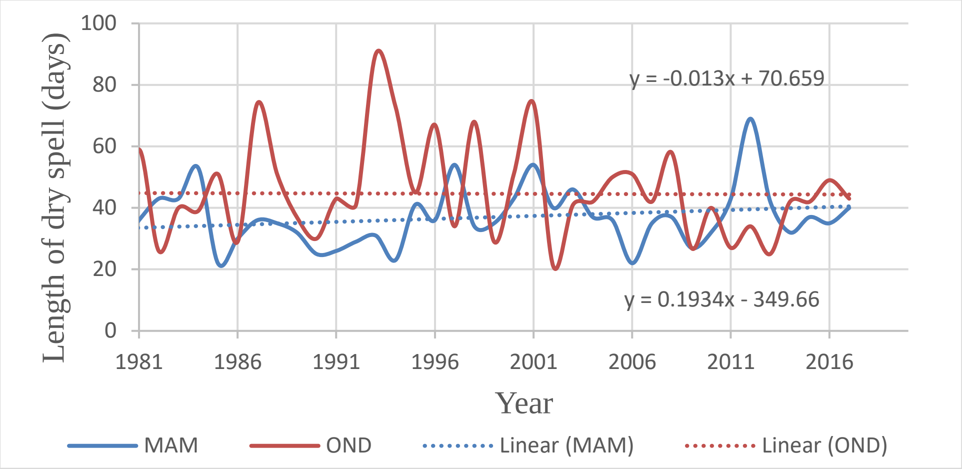

Figure 63: Time series of the mean seasonal dry spell length for Narok station

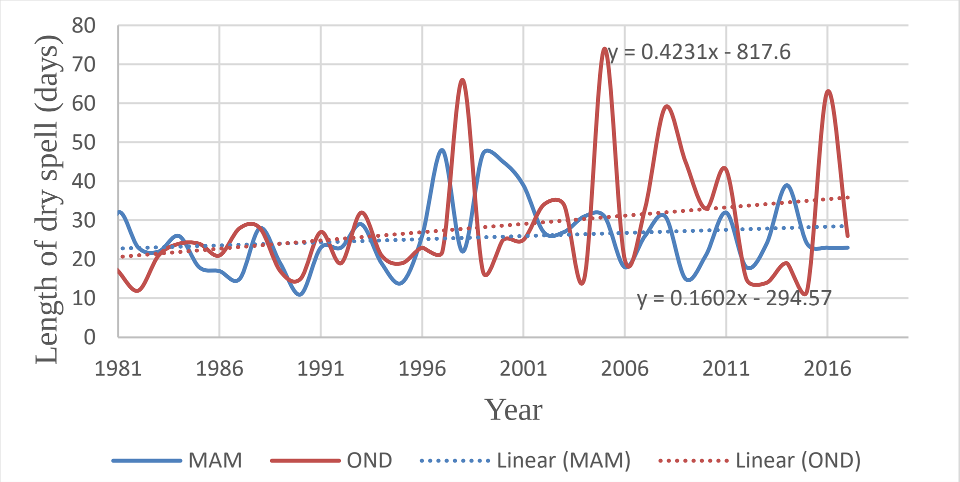

Figure 64: Time series of the mean seasonal dry spell length for Nyangores station

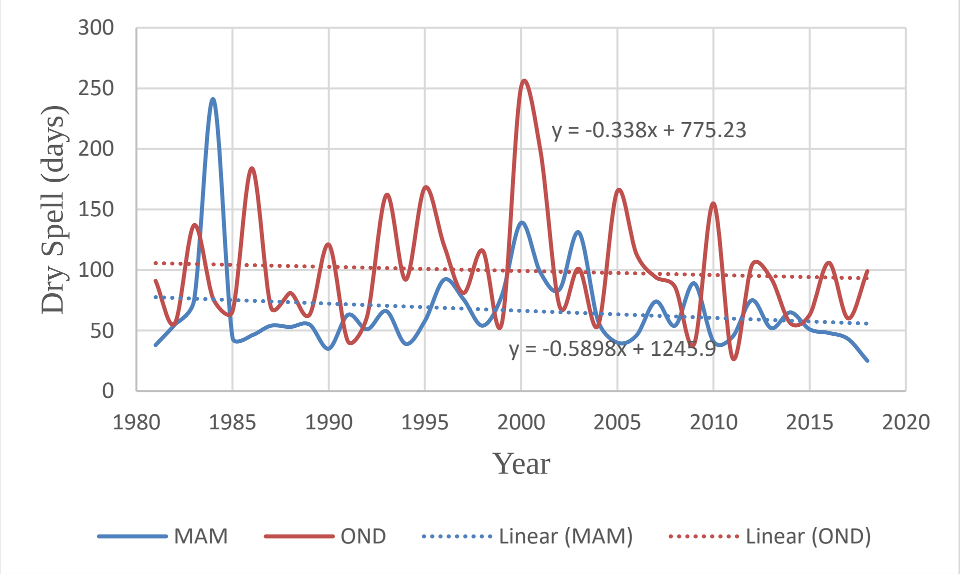

Figure 65: Time series plot of mean seasonal lengths of dry spell for Mosiro station

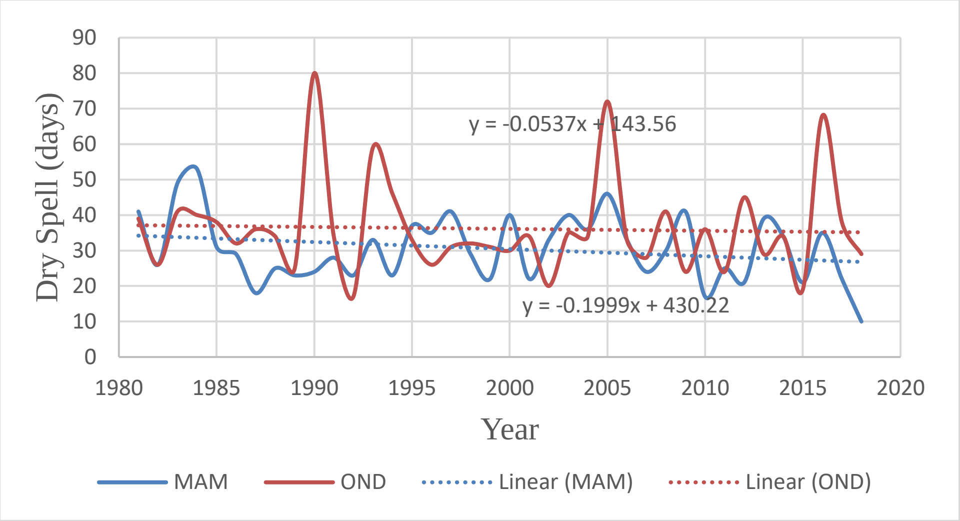

**Figure 66: Time series plots of mean seasonal lengths of dry spell for Oloololo station**

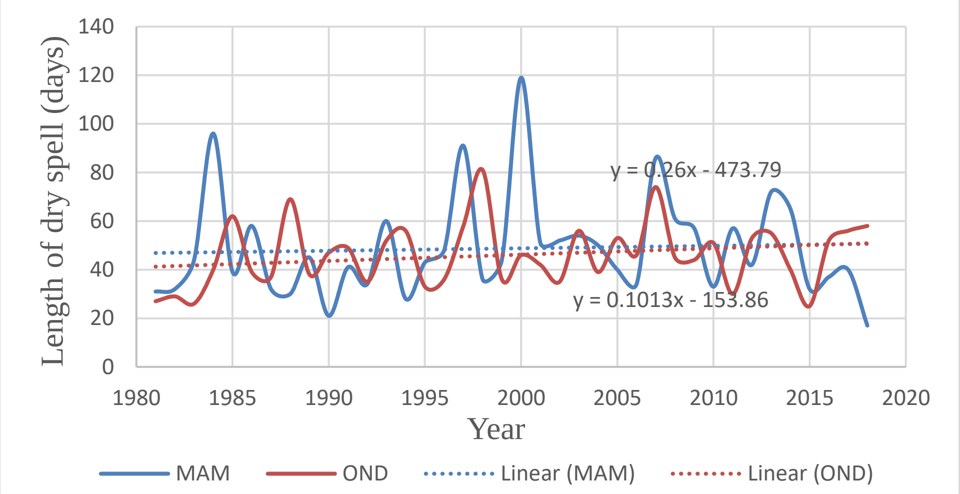

**Figure 67: Time series plots of mean seasonal lengths of dry spell for Olchorro station**

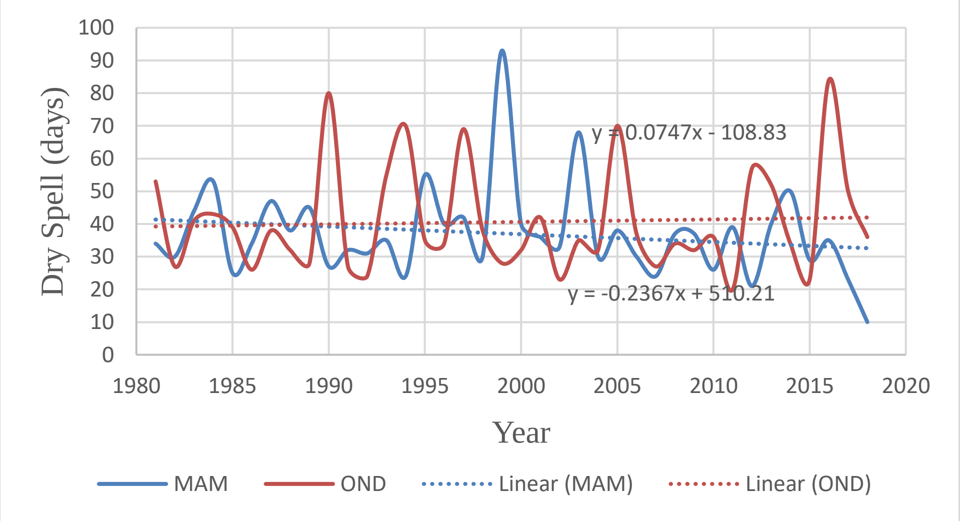

**Figure 68: Time series plots of mean seasonal lengths of dry spell for Governor's station**

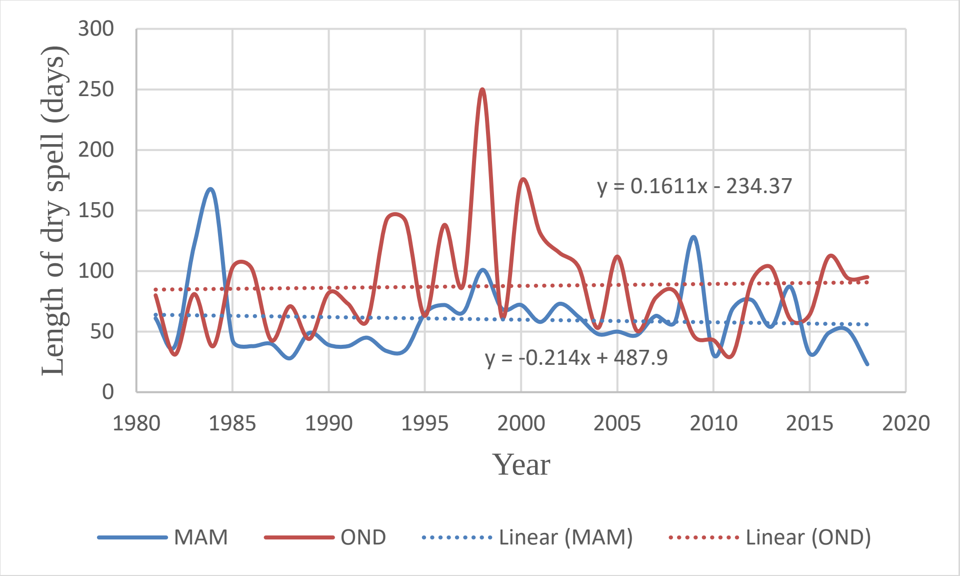

**Figure 69: Time series plots of mean seasonal lengths of dry spell for Loita station**

Kilgoris, Mosiro and Oloololo stations depicted decreasing trends in seasonal lengths of dry spell in both MAM and OND season, signifying reduced lengths of dry spell and therefore greater prospects for crop agriculture around Kilgoris, Mosiro and Oloololo stations. On the contrary, Elementaita, Nyangores and Olchorro stations depicted increasing trends in dry spell lengths in both MAM and OND season over the study period, signifying longer lengths of dry spell. The projected increase in lengths of dry spell indicate the increasing vulnerability of maize crop to water stress and consequently decreased growth and productivity of maize. Narok station depicted an increasing trend in lengths of dry spell in MAM rainy season and a corresponding decreasing trend in the length of dry spell in OND rainy season, signifying an increased duration of dry spell in MAM and a reduced duration of dry spell in OND season. Decreasing durations of dry spell in OND presents an opportunity for increased crop agriculture around Narok station during OND season. Governor’s and Loita stations depicted decreasing trends in lengths of dry spell during MAM season and increasing trends in OND season lengths of dry spell, implying shorter dry spell lengths in MAM and longer lengths of dry spell during OND season.

### 4.3.8 Coefficients of variation (CV) in Intra-seasonal Rainfall characteristics

Table 11 presents the coefficients of variation of the intra-seasonal rainfall characteristics for Kilgoris station.

**Table 11: Coefficient of variation of intra-seasonal rainfall characteristics at Kilgoris station**

| Rainfall Characteristics | MAM | | | OND | | |
|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Coefficient of Variation (%) | Mean | Standard Deviation | Coefficient of Variation (%) |
| Onset dates (Days) | 69 | 9.79 | 14.1 | 282 | 9.59 | 3.4 |
| Cessation dates (Days) | 156 | 28.02 | 18.0 | 340 | 6.81 | 2.0 |
| Season Length (Days) | 87 | 30.59 | 35.2 | 58 | 11.75 | 20.1 |
| Number of rainy days | 43 | 9.58 | 22.2 | 38 | 9.83 | 25.9 |
| Season total rainfall | 465 | 208.62 | 44.8 | 347 | 136.92 | 39.5 |
| Length of wet spell (Days) | 20 | 8.15 | 40.4 | 18 | 8.27 | 47.1 |
| Length of dry spell (Days) | 25 | 9.20 | 36.3 | 27 | 7.43 | 27.9 |

The table indicates that, the largest coefficient of variation (44.8%) in seasonal total rainfall and the least coefficient of variation (14.1%) in onset dates during MAM season. During OND season, lengths of wet spells had the largest coefficient of variation (47.1%), while the rainy season cessation dates had the least coefficient of variation (2%). Table 12 presents the coefficients of variation of rainfall characteristics for Elementaita station.

**Table 12: Coefficients of variation of intra-seasonal rainfall characteristics at Elementaita station**

| Rainfall Characteristics | MAM | | | OND | | |
|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Coefficient of Variation (%) | Mean | Standard Deviation | Coefficient of Variation (%) |
| Onset dates (Days) | 83 | 15.43 | 18.7 | 282 | 7.64 | 2.7 |
| Cessation dates (Days) | 135 | 16.68 | 12.4 | 337 | 3.72 | 1.1 |
| Season Length (Days) | 47 | 26.06 | 55.5 | 45 | 14.25 | 31.8 |
| Number of rainy days | 33 | 15.43 | 18.7 | 282 | 7.64 | 2.7 |
| Season total rainfall | 240 | 112.94 | 47.1 | 136 | 74.68 | 54.9 |
| Length of wet spell (Days) | 18 | 9.23 | 51.4 | 13 | 7.69 | 60.3 |
| Length of dry spell (Days) | 50 | 22.41 | 44.5 | 47 | 15.08 | 32.2 |

At Elementaita station, lengths of growing season and lengths of wet spell had the highest coefficients of variation (55.5% and 51.4%) during MAM season respectively. Rainy season cessation dates had the least coefficients of variation (12.4%). On the other hand, lengths of wet spell had the largest coefficients of variation (60.3%), while cessation dates had the least coefficient of variation (1.1%) during OND rainy season. Table 13 presents the Coefficient of variation of intra-seasonal rainfall characteristics for Narok station.

**Table 13: Coefficients of variation of intra-seasonal rainfall characteristics at Narok station**

| **Rainfall Characteristics** | **MAM** | | | **OND** | | |
|---|---|---|---|---|---|---|
| | **Mean** | **Standard Deviation** | **Coefficient of Variation (%)** | **Mean** | **Standard Deviation** | **Coefficient of Variation (%)** |
| Onset dates (Days) | 76.2 | 14.7 | 19.3 | 297.2 | 15.1 | 5.0 |
| Cessation dates (Days) | 138.9 | 15.5 | 11.1 | 339.2 | 7.5 | 2.0 |
| Season Length (Days) | 61.3 | 23.0 | 37.5 | 42.6 | 15.5 | 36.2 |
| Number of rainy days | 32.5 | 7.7 | 23.7 | 23.5 | 9.0 | 38.2 |
| Seasonal total rainfall | 328.4 | 111.5 | 33.9 | 188.8 | 124.8 | 66.1 |
| Length of wet spell (Days) | 14.8 | 4.74 | 32.0 | 10.6 | 5.3 | 49.7 |
| Length of dry spell (Days) | 34.9 | 9.9 | 28.4 | 44.7 | 16.2 | 36.2 |

At Narok station, seasonal total rainfall and lengths of wet spell had the largest coefficients of variation (66.1% and 49.7%) during OND season respectively. During MAM rainy season, growing season length and seasonal total rainfall had the largest coefficients of variation (37.5% and 33.9%) respectively. Onset and cessation dates had the least coefficient of variation of 5% and 2% respectively.

## 4.4 Intra- seasonal Temperature Characteristics

Table 14 presents the results for temperature characteristics considered in this study.

**Table 14: Mean maximum temperature, minimum temperature, temperature range and GDD**

| **Station Name** | **Mean Tmax** | | **Mean Tmin** | | **Temp Range** | | **GDD** | |
|---|---|---|---|---|---|---|---|---|
| | **MAM** | **OND** | **MAM** | **OND** | **MAM** | **OND** | **MAM** | **OND** |
| Elementaita | 20.5 | 20.3 | 8.2 | 7.4 | 12.3 | 12.9 | 537 | 400 |
| Narok | 25.0 | 25.8 | 11.5 | 9.8 | 13.5 | 16.0 | 744 | 708 |
| Abossi | 24.5 | 24.9 | 14.9 | 14.7 | 9.6 | 10.2 | 896 | 903 |
| Kilgoris | 24.5 | 24.9 | 14.8 | 14.7 | 9.7 | 10.2 | 882 | 905 |
| Loita | 23.1 | 24.1 | 12.4 | 11.8 | 10.7 | 12.3 | 710 | 731 |
| Nyangores | 22.0 | 22.1 | 11.5 | 10.8 | 10.5 | 11.3 | 623 | 592 |
| Olchorro | 21.1 | 21.3 | 8.3 | 7.3 | 12.8 | 14.0 | 432 | 395 |
| Oloololo | 26.0 | 27.1 | 15.0 | 14.7 | 11.0 | 12.4 | 965 | 999 |
| Mosiro | 25.3 | 26.0 | 14.7 | 13.7 | 10.6 | 12.3 | 1104 | 1093 |
| Cottar’s Camp | 27.0 | 28.3 | 15.0 | 14.2 | 12.0 | 14.1 | 1010 | 1037 |
| Governor’s Camp | 27.6 | 28.8 | 16.2 | 15.7 | 11.4 | 13.1 | 1097 | 1122 |
| **Mean** | 24.3 | 24.9 | 12.9 | 12.3 | 11.3 | 12.6 | 818 | 808 |

The highest observed maximum temperature was 27.6 $^{0}$C and 28.8 $^{0}$C in MAM and OND seasons respectively, and were recorded in Governor’s station (Narok West). Olchorro station recorded the least maximum temperature of 21.1 $^{0}$C in MAM and 21.3 $^{0}$C in OND seasons respectively. Governor’s station recorded the highest minimum temperature of 16.2 $^{0}$C in MAM and 15.7 $^{0}$C in OND seasons respectively. The temperature range during OND season was greater than the temperature range in MAM season, implying higher temperatures recorded in OND compared to MAM season. Mosiro station had the highest GDD value of 1104 in MAM rainy season, whereas Governor’s station recorded the highest GDD value of 1122 in OND season.

### 4.4.1 Temporal variability in Temperature characteristics

Figures 70 to 78 present time series plots of mean maximum temperature for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor’s and Loita stations respectively

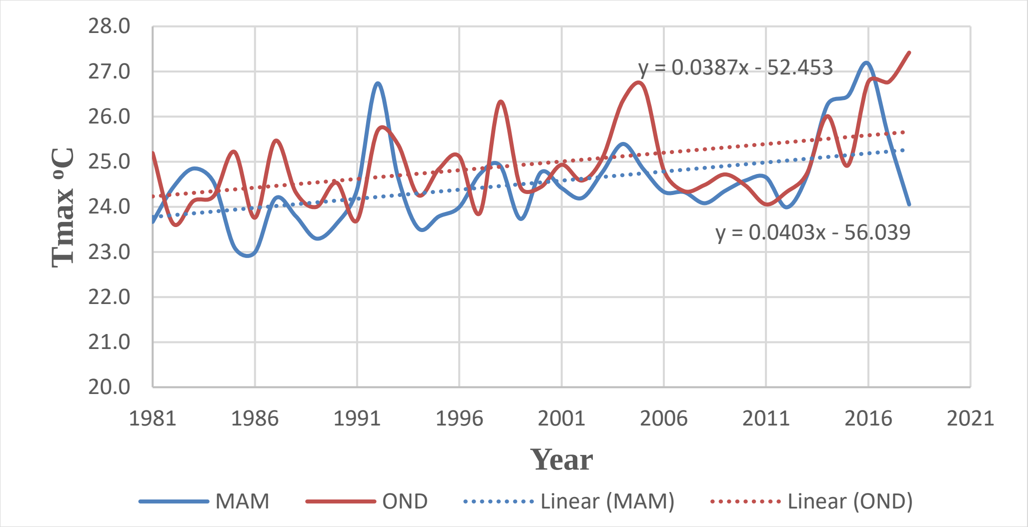

Figure 70: Time series of mean maximum temperature for Kilgoris station

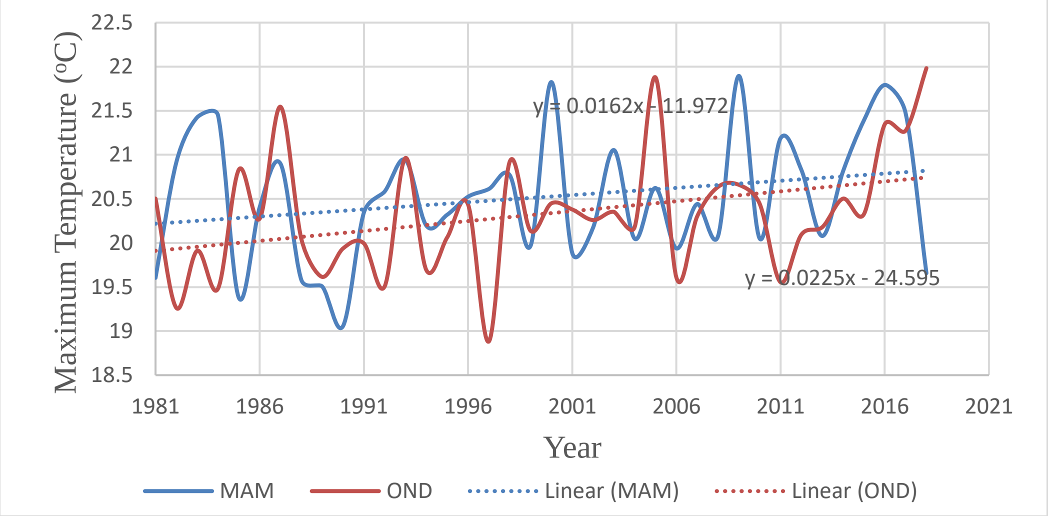

Figure 71: Time series of mean maximum temperature for Elementaita station

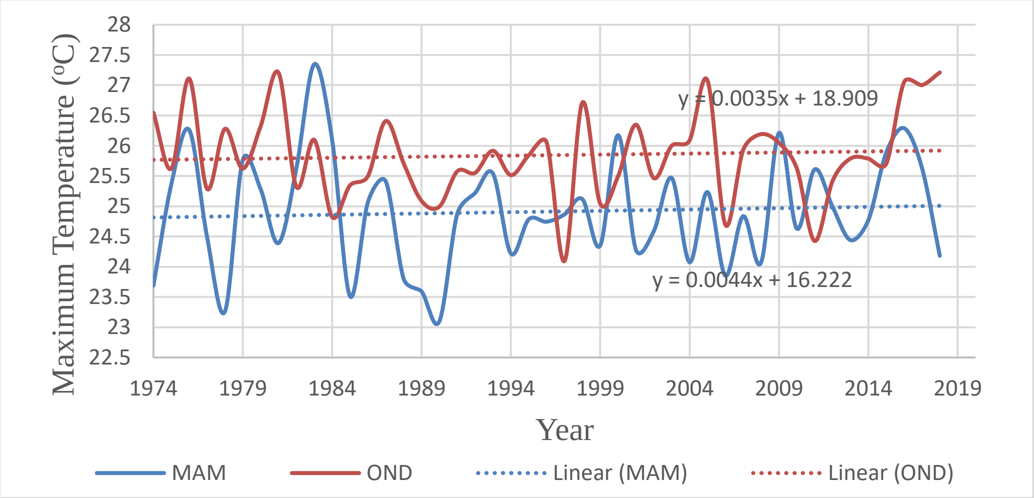

Figure 72: Time series of mean maximum temperature for Narok station

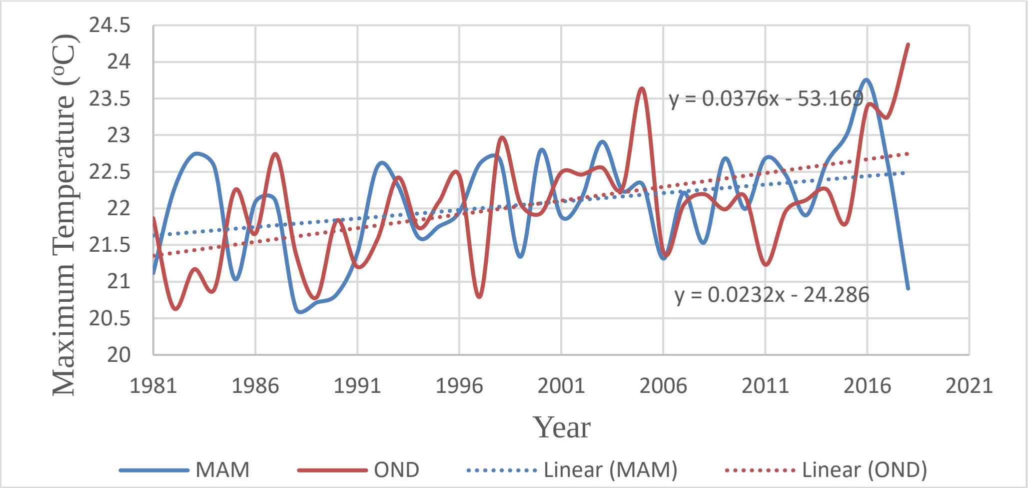

**Figure 73: Time series of mean maximum temperature for Nyangores station**

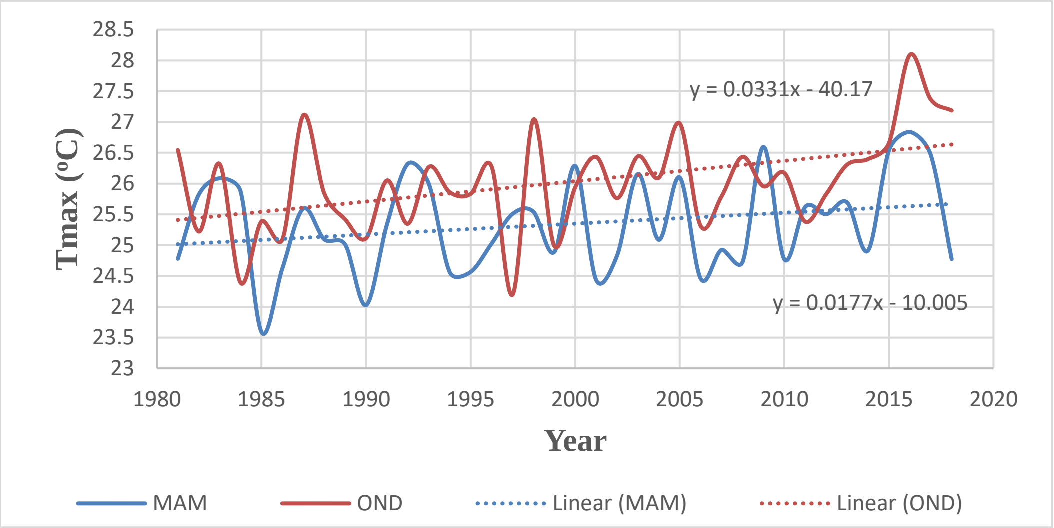

**Figure 74: Time series of mean maximum temperature for Mosiro station**

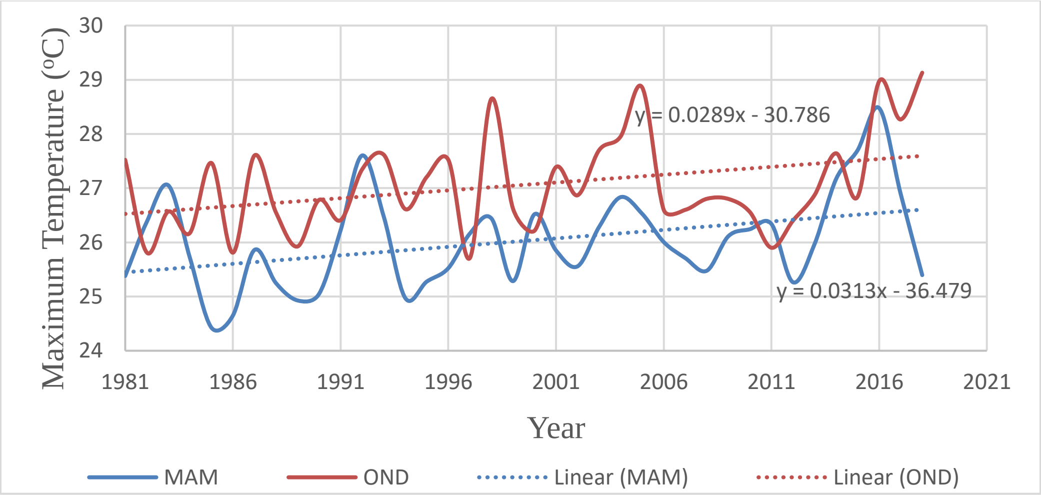

**Figure 75: Time series of mean maximum temperature for Oloololo station**

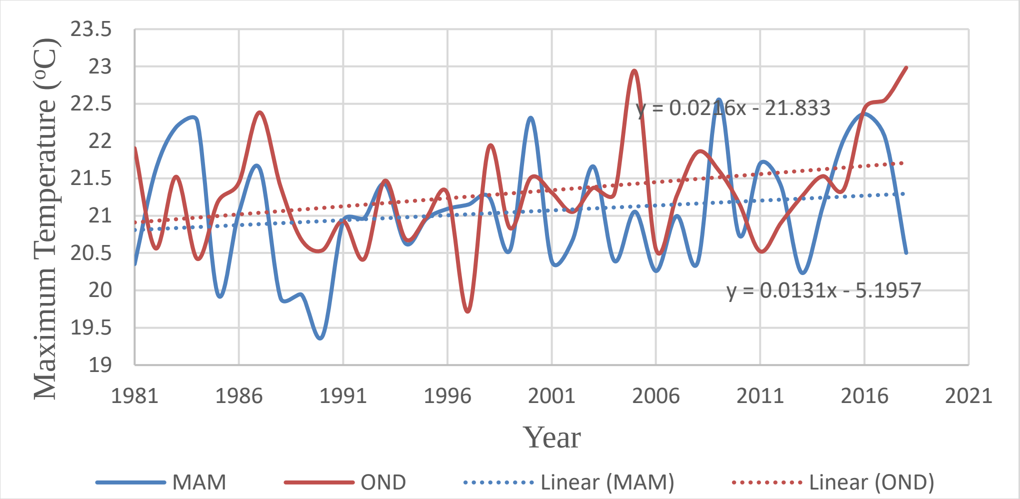

Figure 76: Time series of mean maximum temperature for Olchorro station

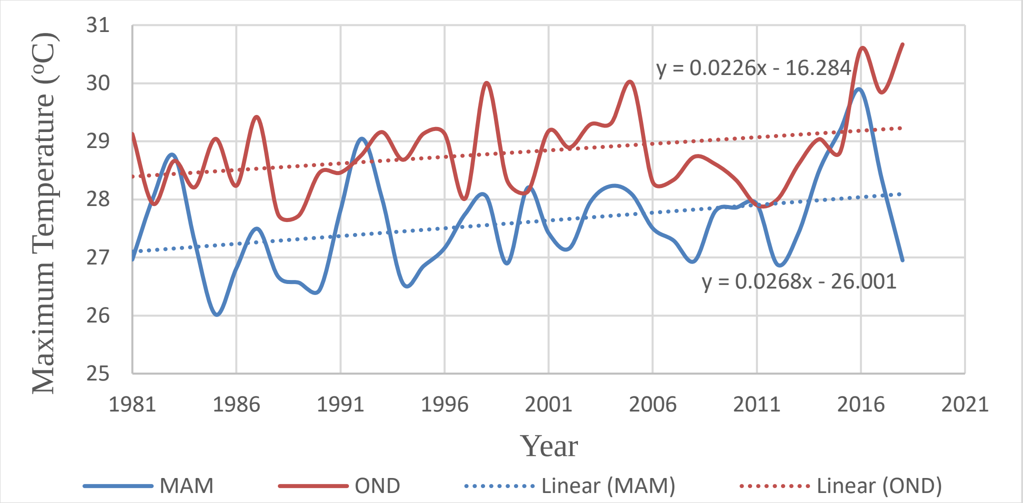

Figure 77: Time series of mean maximum temperature for Governor's station

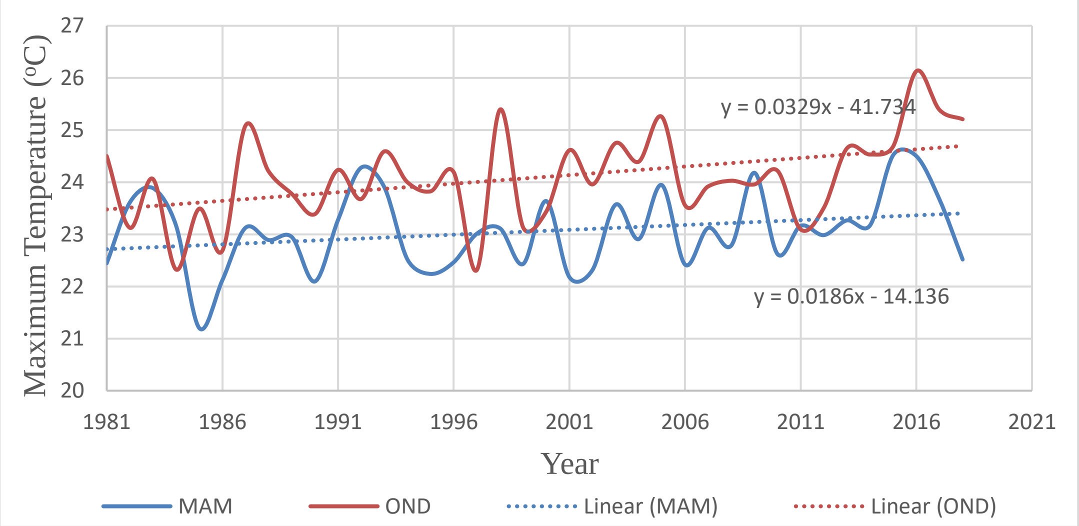

Figure 78: Time series of mean maximum temperature for Loita station

From these figures, all the study stations depicted increasing trends in the mean maximum temperature, during both MAM and OND seasons, implying increasing mean maximum temperatures. The rising maximum temperatures could have negative implications on the water balance parameters, thereby adversely affecting maize growth, development and eventual yield.

Figures 79 to 87 present the time series plots of mean minimum temperature for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations respectively.

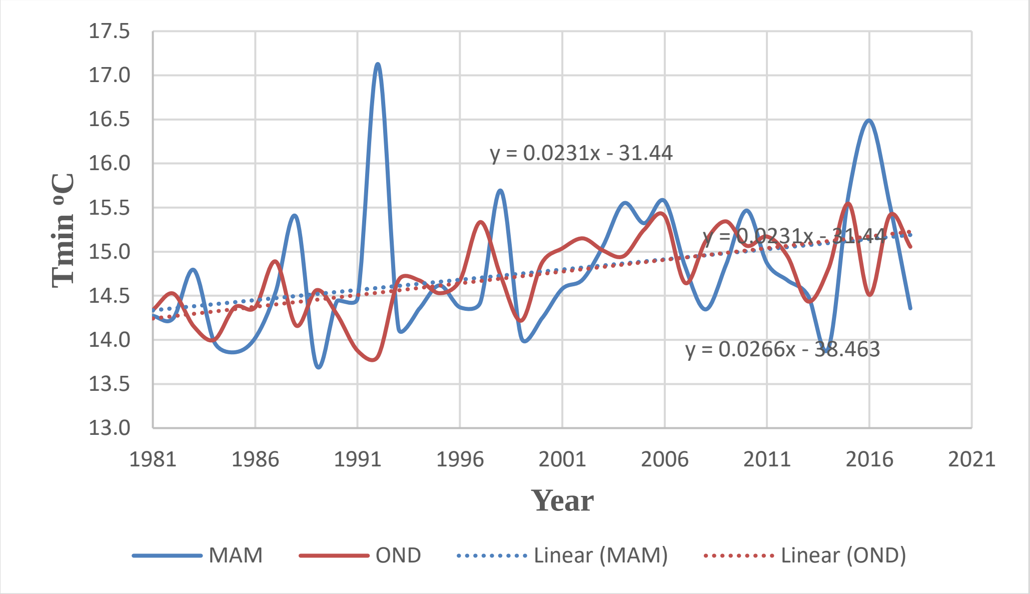

**Figure 79: Time series of mean minimum temperature for Kilgoris station**

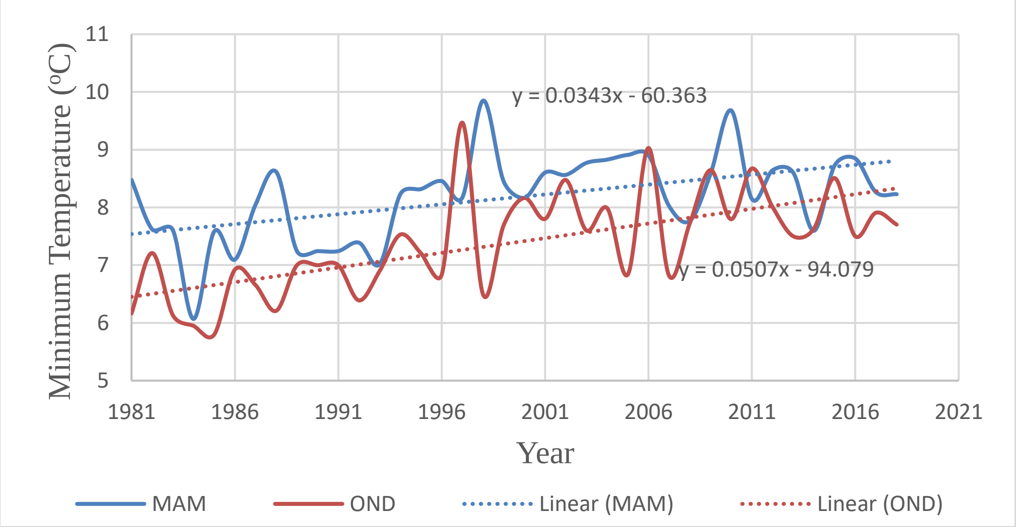

**Figure 80: Time series of mean minimum temperature for Elementaita station**

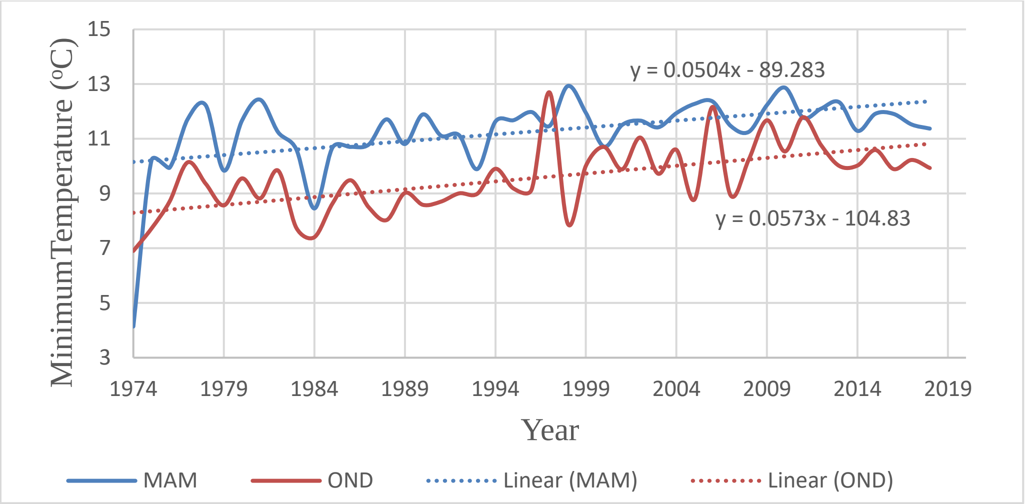

Figure 81: Time series of mean minimum temperature for Narok station

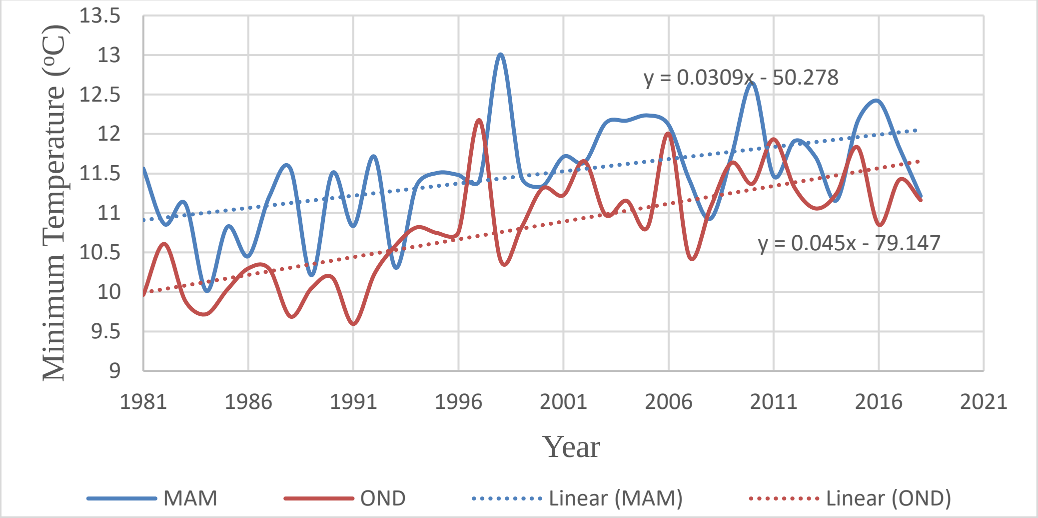

Figure 82: Time series of mean minimum temperature for Nyangores station

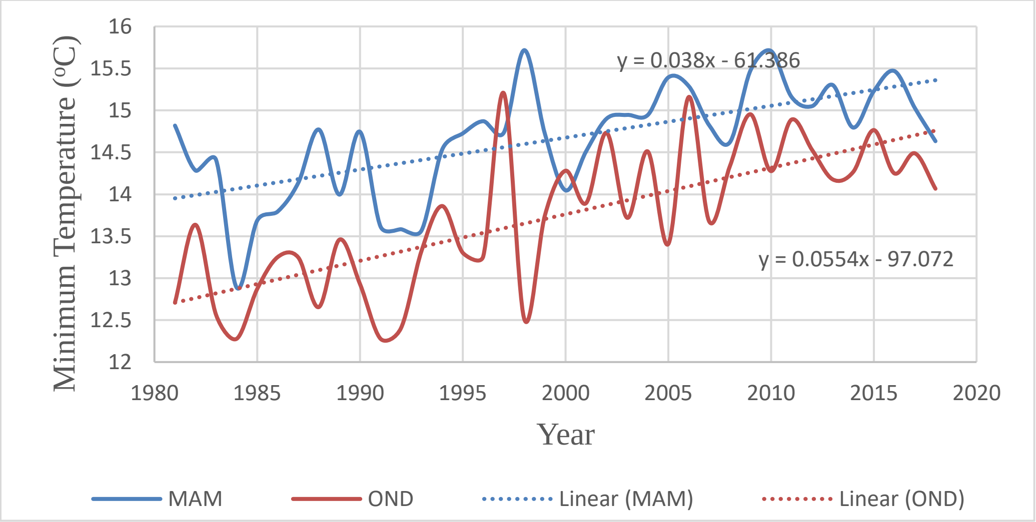

Figure 83: Time series of mean minimum temperature for Mosiro station

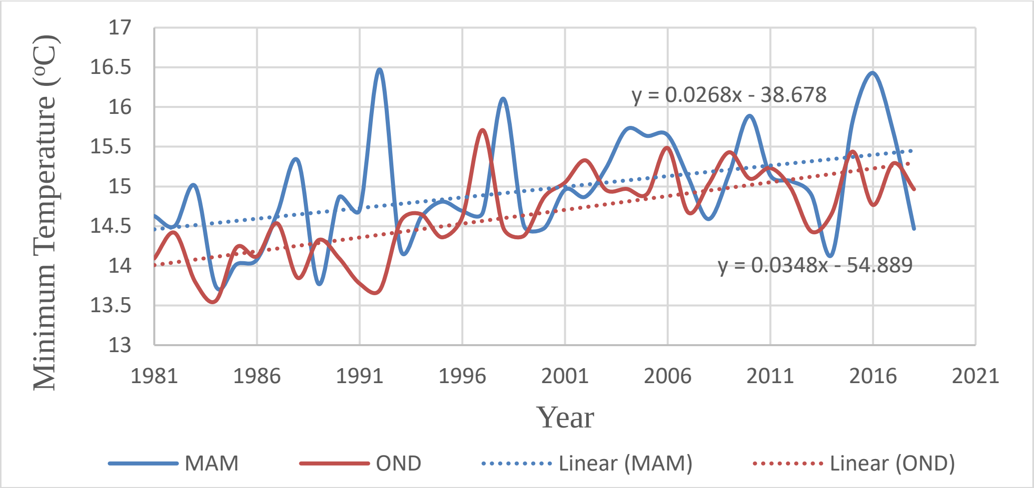

Figure 84: Time series of mean minimum temperature for Oloololo station

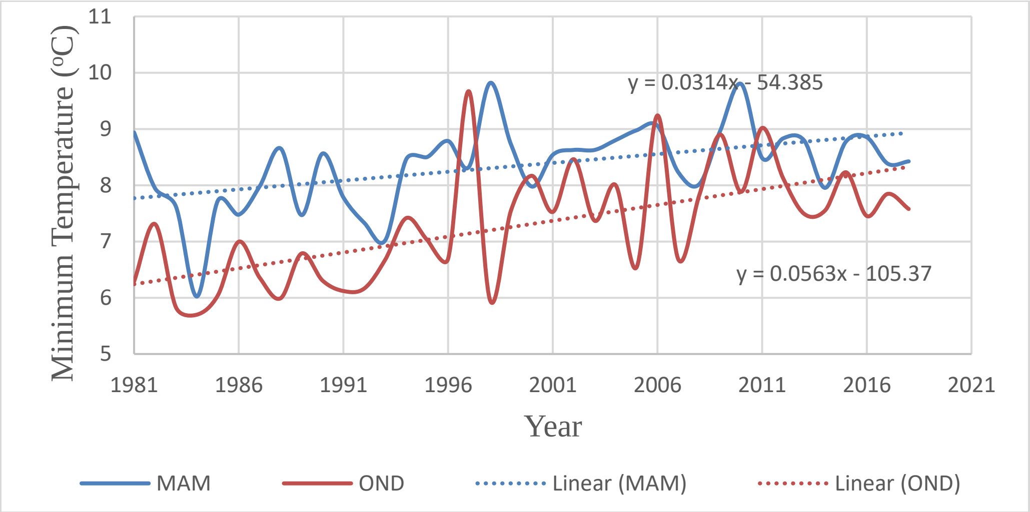

Figure 85: Time series of mean minimum temperature for Olchorro station

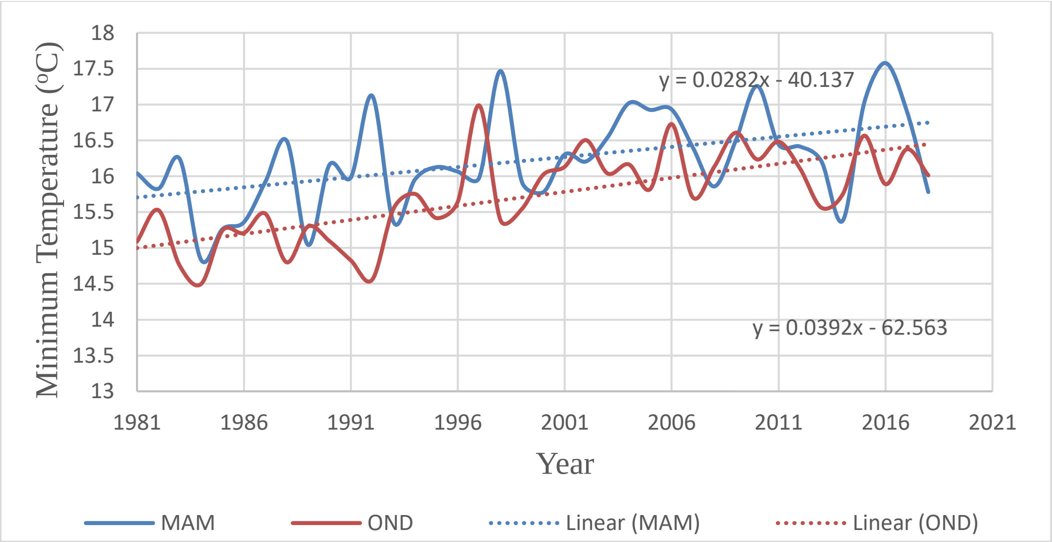

Figure 86: Time series of mean minimum temperature for Governor's station

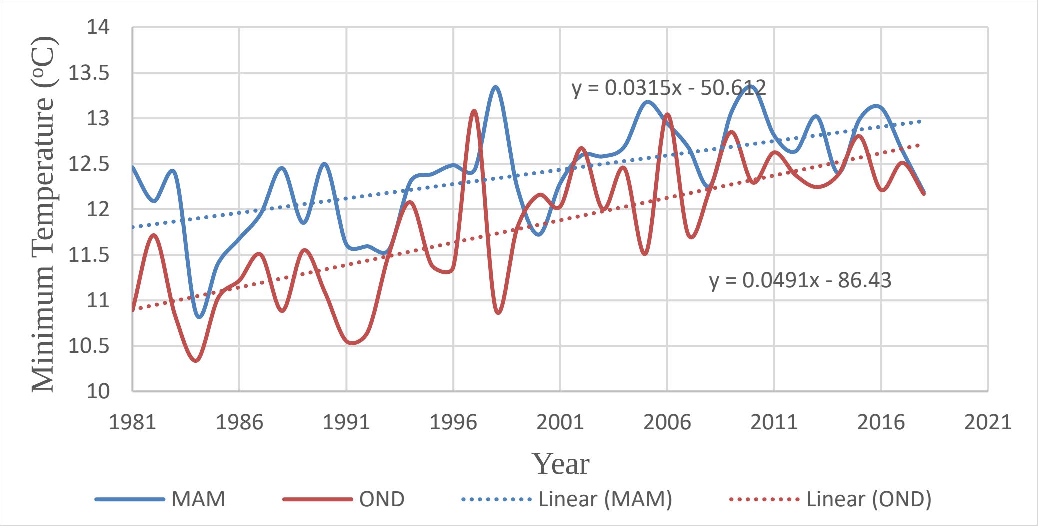

**Figure 87: Time series of mean minimum temperature for Loita station**

From these figures, it is readily seen that mean minimum temperature depicted increasing trends across the study stations during both MAM and OND seasons, implying warming conditions in Narok County. This reduces diurnal temperature range, presenting favorable conditions for maize growth and development leading to increased productivity.

Figures 88 to 96 present mean temperature range for Kilgoris, Elementaita, Narok, Nyangores, Oloololo, Olchorro, Governor's and Loita stations respectively.

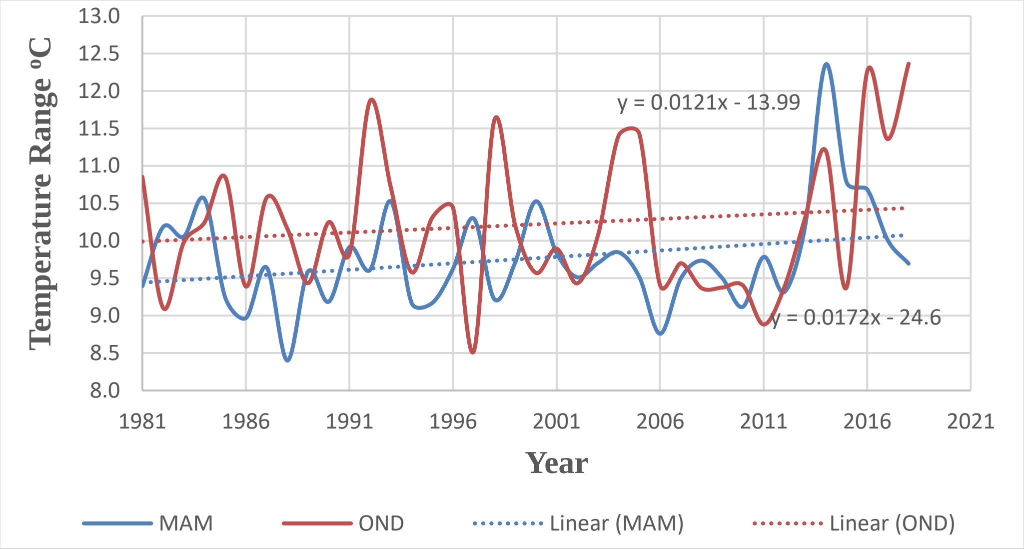

**Figure 88: Time series of mean temperature range for Kilgoris station**

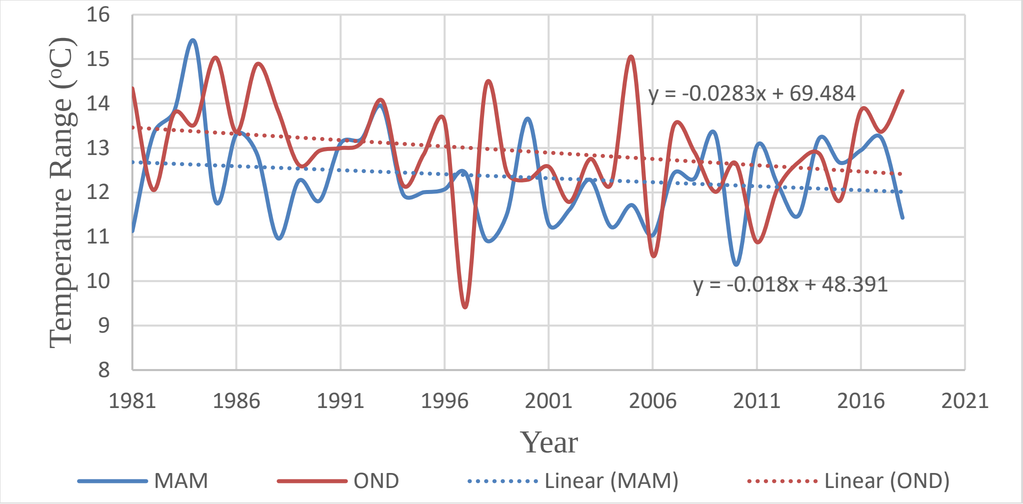

Figure 89: Time series of mean temperature range for Elementaita station

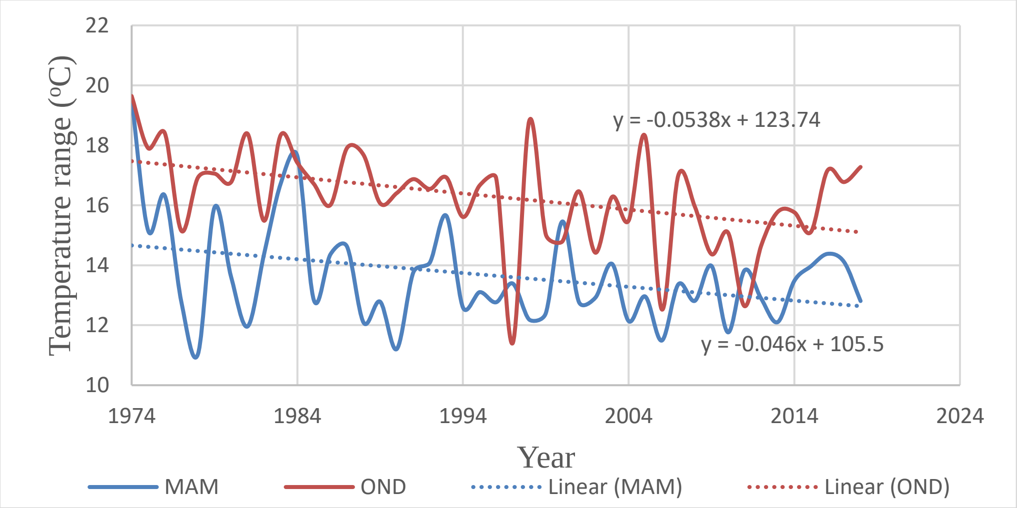

Figure 90: Time series of mean temperature range for Narok station

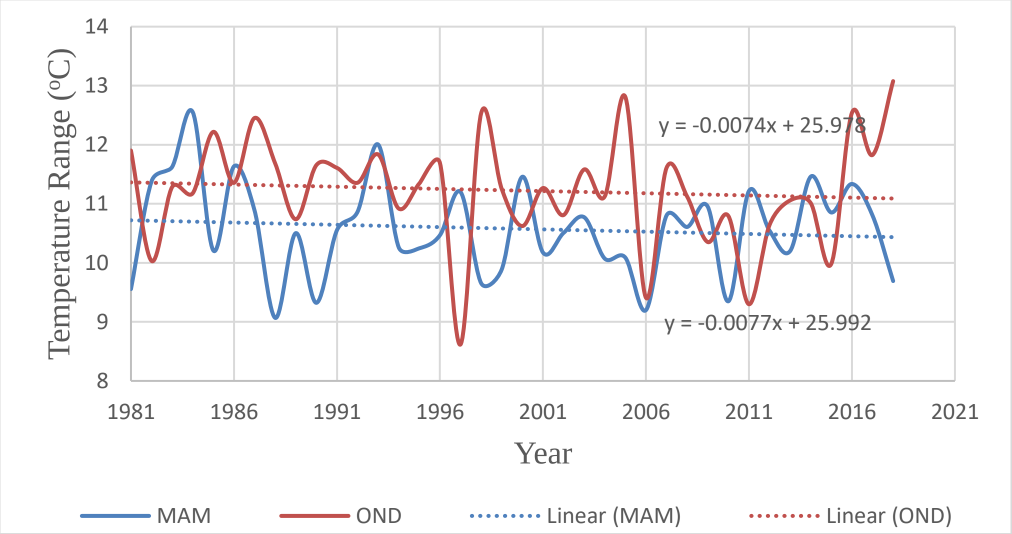

Figure 91: Time series of mean temperature range for Nyangores station

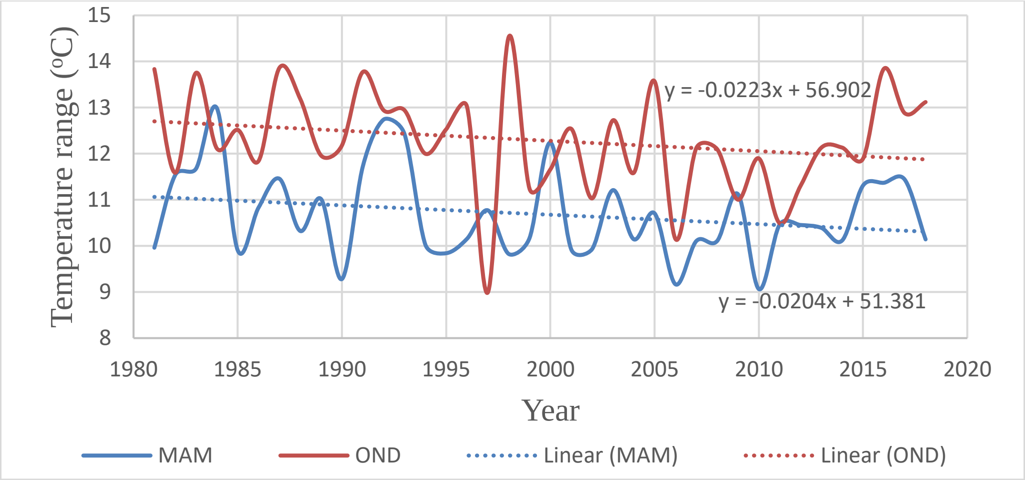

Figure 92: Time series of mean temperature range for Mosiro station

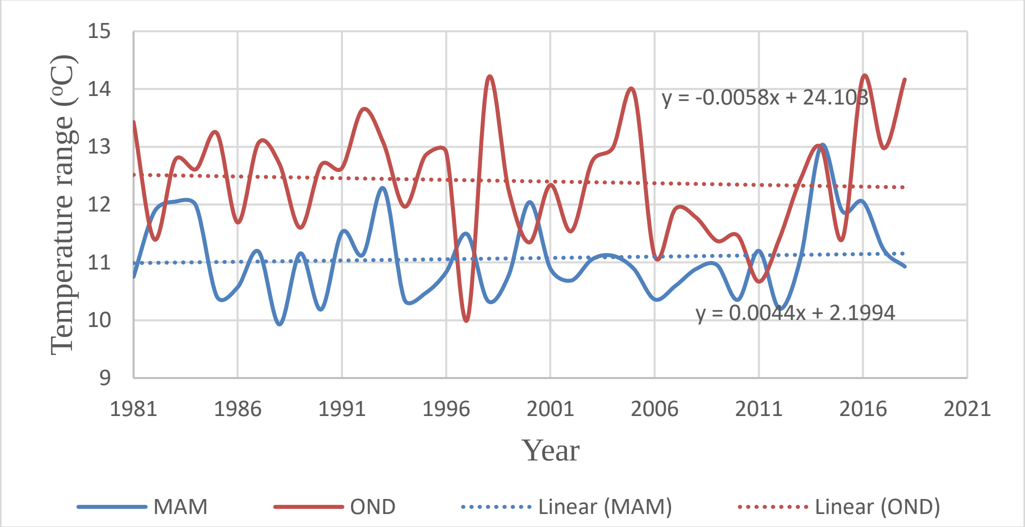

Figure 93: Time series of mean temperature range for Oloololo station

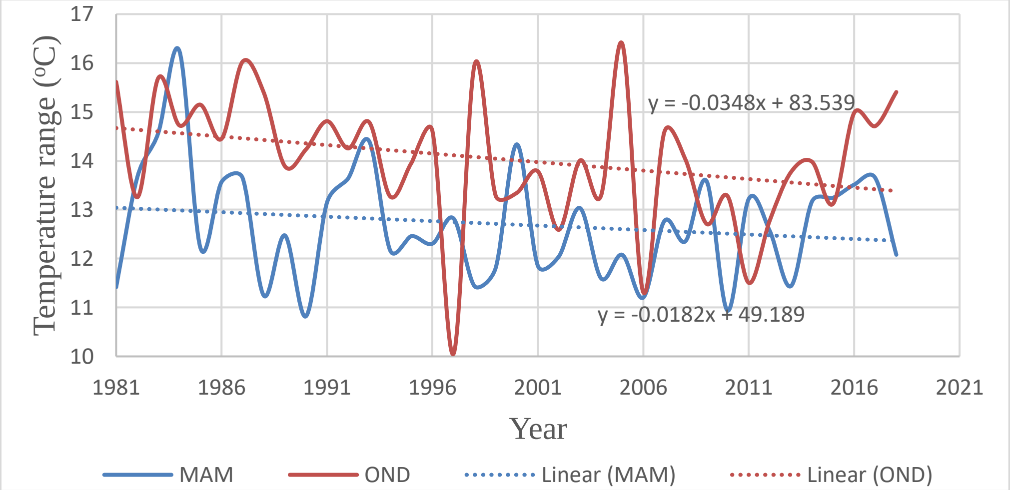

Figure 94: Time series of mean temperature range for Olchorro station

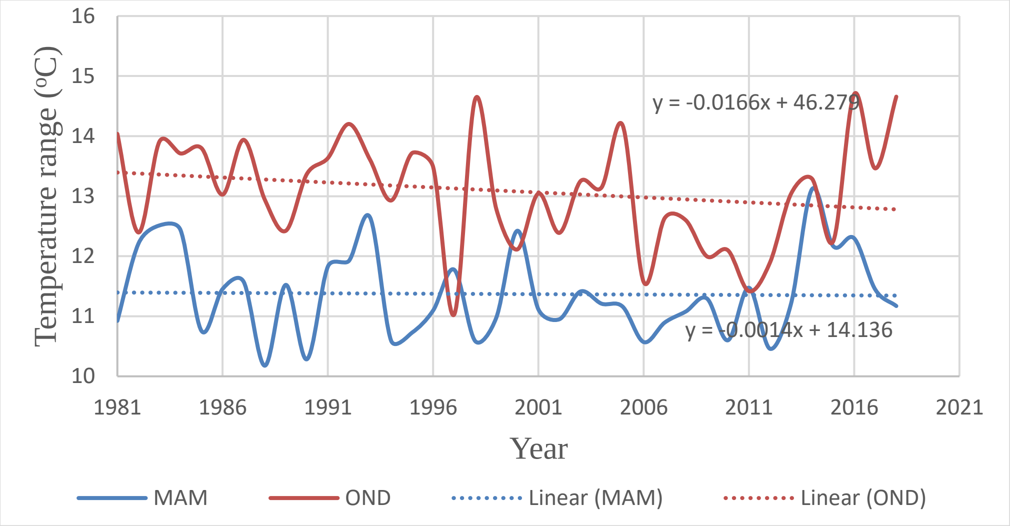

**Figure 95: Time series of mean temperature range for Governor's station**

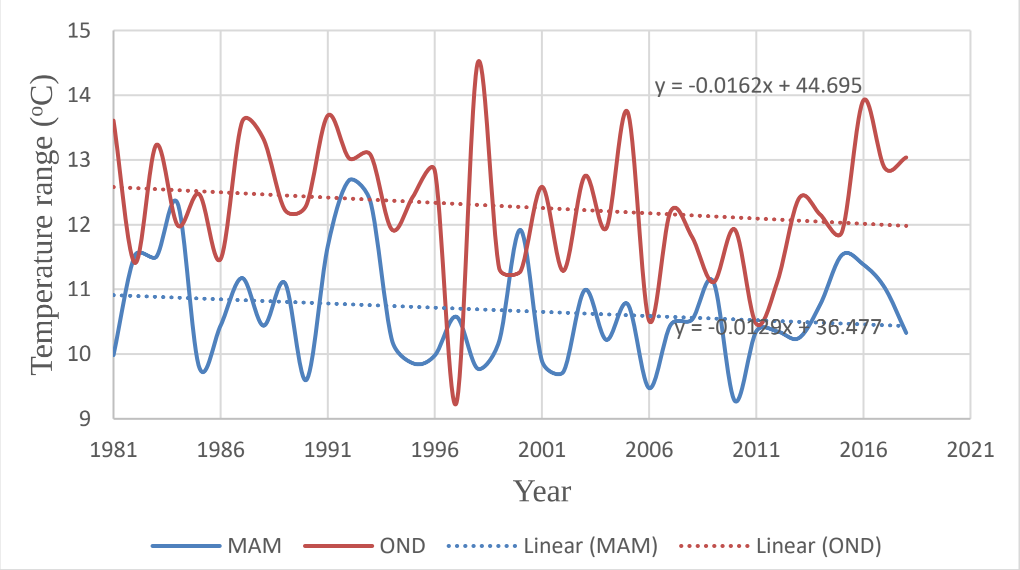

**Figure 96: Time series of mean temperature range for Loita station**

Kilgoris station depicted increasing trend in the mean temperature range during both MAM and OND seasons. On the contrary, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's and Loita stations depicted decreasing trends in mean temperature range during both MAM and OND seasons. This implies that in Kilgoris, the increase in minimum temperature was smaller than the warming in the mean maximum temperature. For the rest of the stations, mean minimum temperature experienced much higher warming, thereby narrowing the gap between minimum and maximum temperature.

Figures 97 to 105 present time series plots of GDD for Kilgoris, Elementaita, Narok, Nyangores, Mosiro, Oloololo, Olchorro, Governor's, and Loita stations respectively.

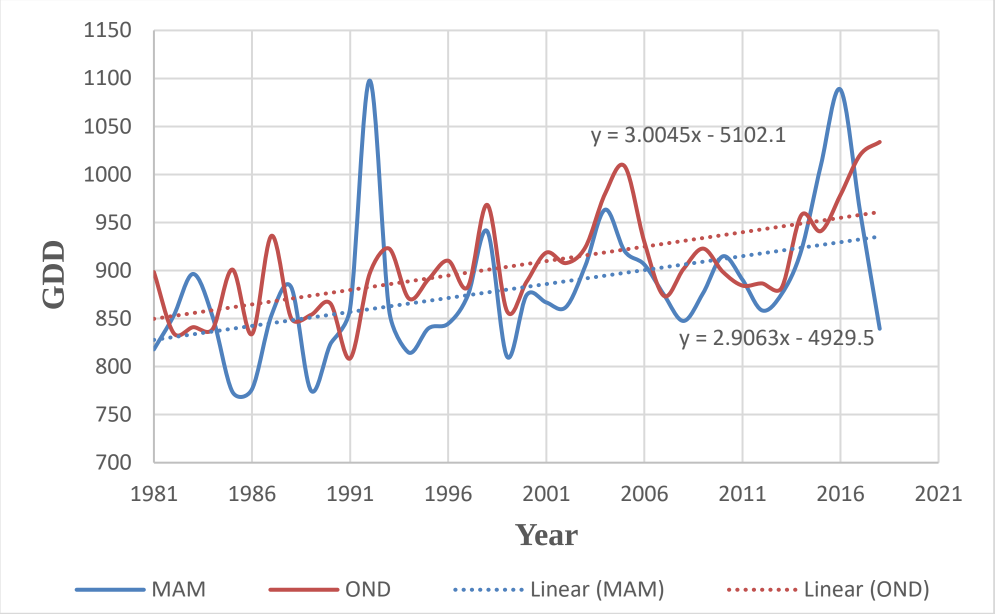

**Figure 97:Time series of mean GDD for Kilgoris station**

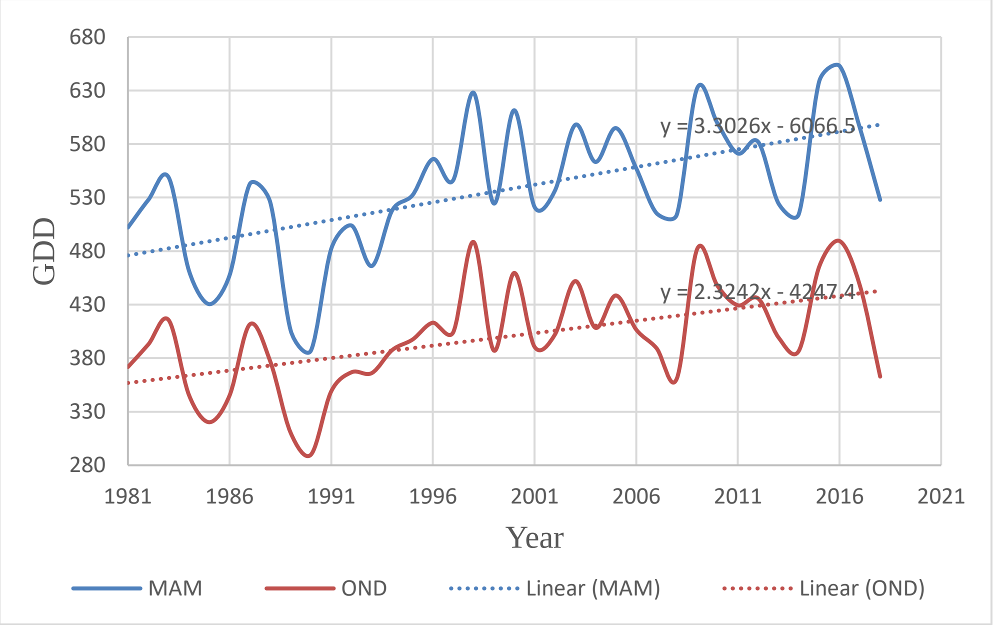

**Figure 98:Time series of mean GDD for Elementaita station**

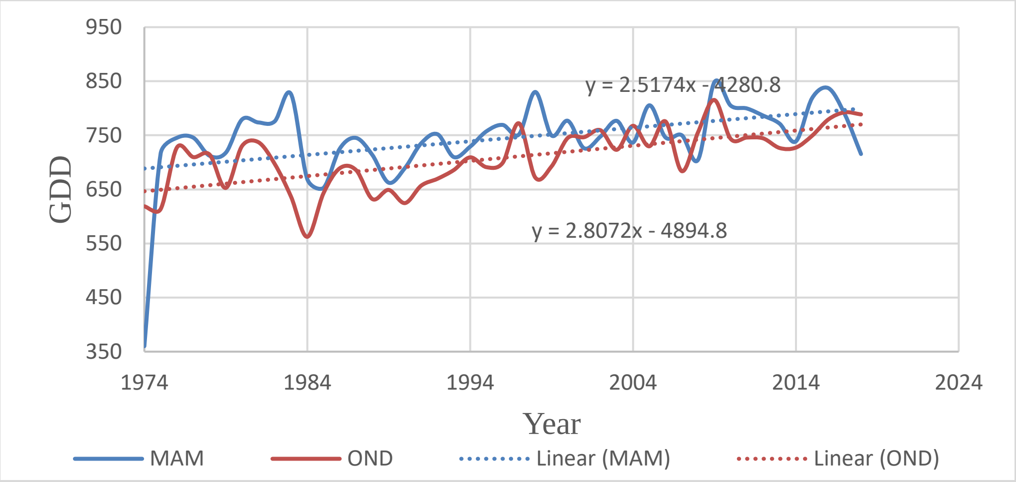

**Figure 99:**Time series of mean GDD for Narok station

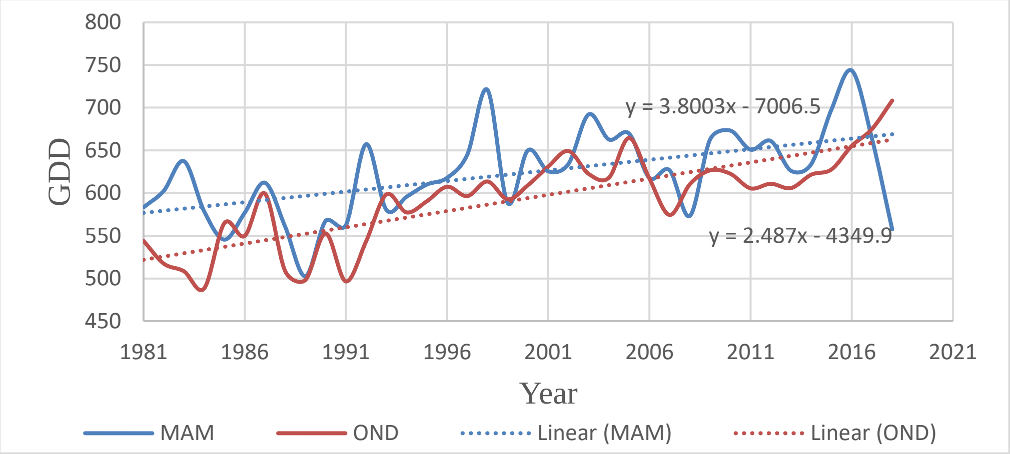

**Figure 100:**Time series of mean GDD for Nyangores station

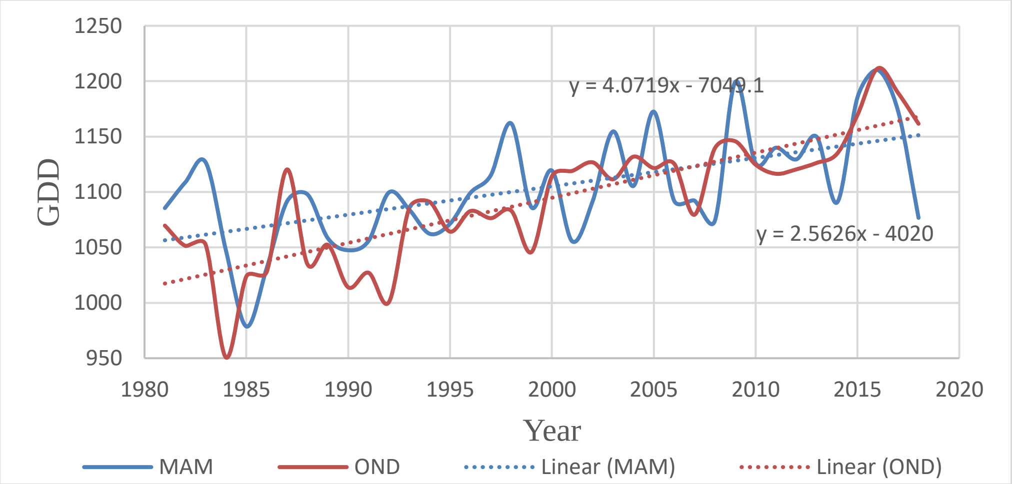

**Figure 101:**Time series of mean GDD for Mosiro station

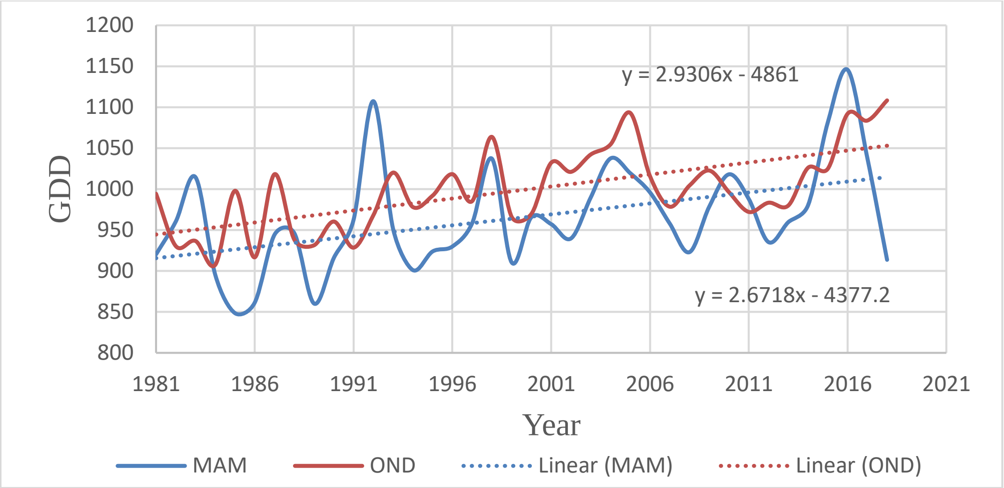

Figure 102: Time series of mean GDD for Oloololo station

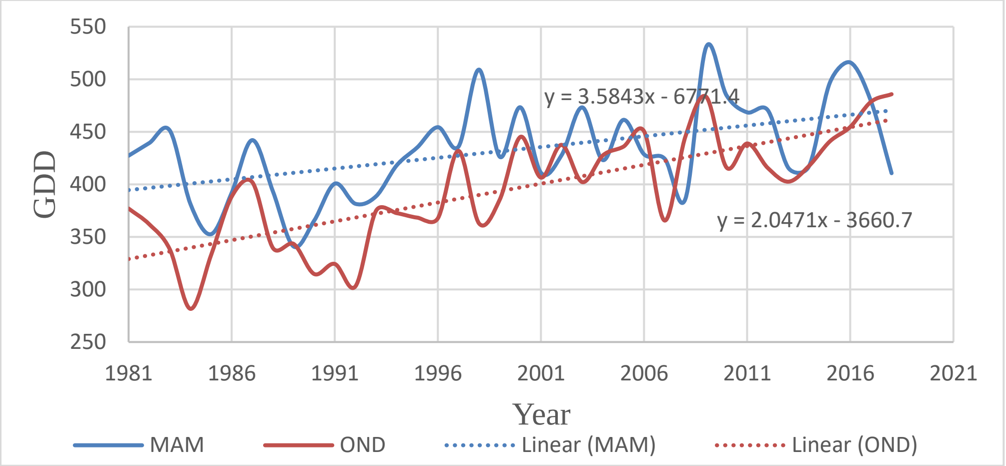

Figure 103: Time series of mean GDD for Olchorro station

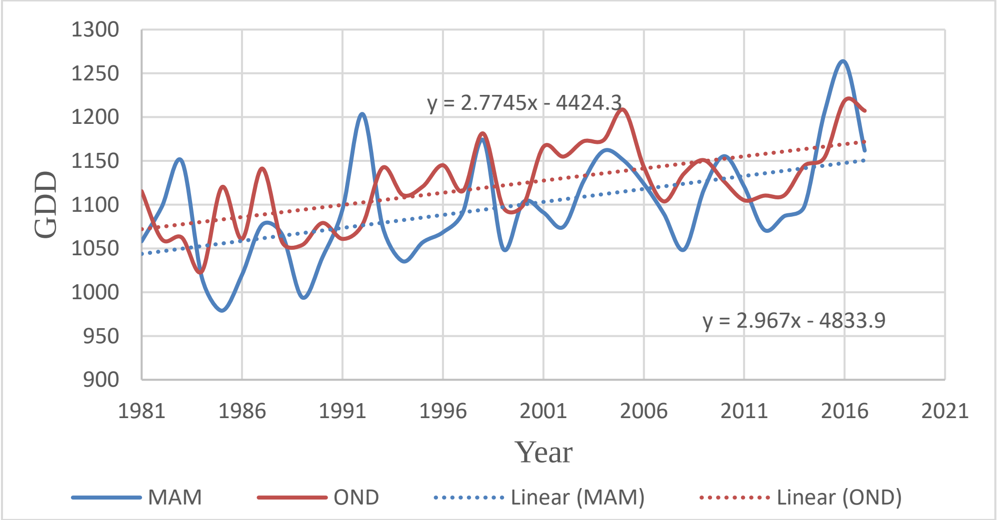

Figure 104: Time series plot of mean GDD for Governor's station

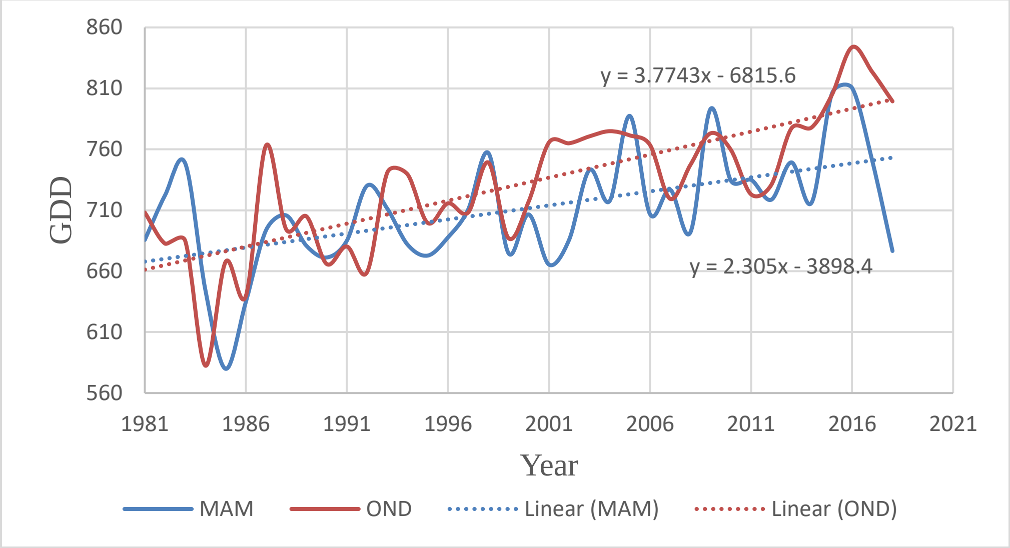

**Figure 105:Time series of mean GDD for Loita station**

All the study stations depicted increasing trends in the mean GDD during both MAM and OND seasons, implying increasing GDD in both seasons. Increasing mean GDD, occasioned by rising daily mean temperature besides enhancing maize growth and development, will also provide a favorable environment for development of weeds, pests and diseases which could severely affect crop growth and development, thereby reducing crop yields (Mumo, 2018; Hatfield, 2015). These observations are proof enough of increasing temperatures over Narok County of Kenya, as a result of climate variability and change.

### 4.4.2 Coefficient of variation of temperature characteristics

Table 15 presents the coefficients of variation in temperature characteristics including GDD for Kilgoris station.

**Table 15: Coefficients of variation of temperature characteristics for Kilgoris station**

| Temperature Characteristics | Mean | | Standard Deviation | | Coefficient of variation (%) | |
|---|---|---|---|---|---|---|
| | MAM | OND | MAM | OND | MAM | OND |
| Seasonal average maximum temperature | 24.5 | 24.9 | 0.94 | 0.95 | 3.8 | 3.8 |
| Seasonal average minimum temperature | 14.8 | 14.7 | 0.73 | 0.45 | 5.0 | 3.1 |
| Seasonal temperature range | 9.8 | 10.2 | 0.7 | 0.9 | 7.0 | 9.2 |
| GDD | 882 | 905 | 71.6 | 53.1 | 8.1 | 5.9 |

During MAM season, GDD had the highest coefficient of variation (8.1%), whereas maximum temperature had the least coefficient of variation (3.8%). On the other hand, during OND season, temperature range had the highest coefficient of variation (9.2%) while, maximum temperature had the least coefficient of variation (3.8%). These coefficients of variation of temperature characteristics indicate smaller levels of dispersion of maximum temperature, minimum temperature, temperature range and GDD around the mean during both MAM and OND seasons.

### 4.5 Inter-annual variability in observed yields of maize

Table 16 presents the coefficients of variation in maize yields for Narok County.

**Table 16: Coefficient of variation of maize yields.**

| **Parameter** | **Mean of maize yields (MT/ha)** | **Standard Deviation of maize yields** | **Coefficient of variation (CV) (%)** |
|---|---|---|---|
| Observed Maize Yields | 2.24 | 0.76 | 34.27 |

The coefficient of variation (CV) of maize yields in Narok County was 34. 27%. The variability in maize yields could be attributed to the variability in climate and other non-climatic factors, which could include pests (fall armyworms) and diseases such as the Maize Lethal Necrosis Disease (MLND), limited access to farm inputs such as fertilizer and certified seeds, and poor agronomic practices among other factors (KFFSG, 2016).

Figure 106 presents the inter-annual variability in maize yields for the period 1982-2015.

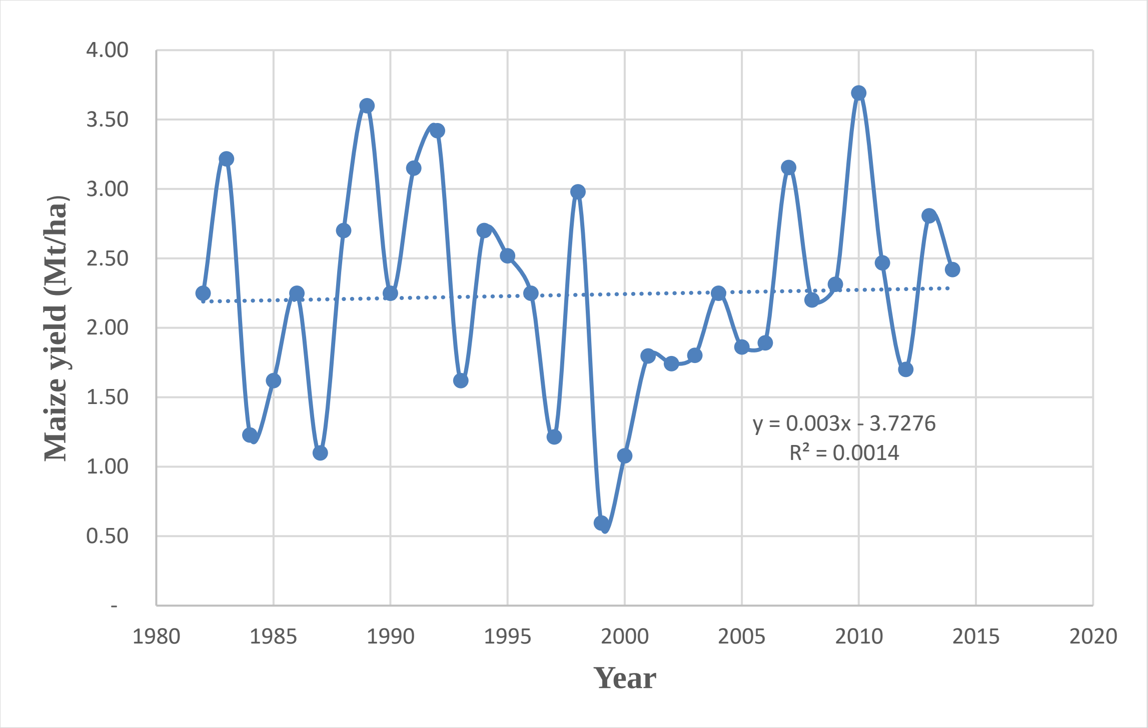

**Figure 106: Inter-annual variability in maize yields in Narok County from 1982 to 2014**

Though marked with the highest inter-annual variability of maize yields, Narok County generally experienced an increasing, though insignificant trend. The highest maize yields over Narok County were recorded in the year 2010 (3.69 MT/ha) while the least yields were recorded in 1999 (0.59 MT/ha). There was a decline in maize yields for the period 1994 to 1997. The decline in maize yields is attributed to the decrease in seasonal total rainfall, increased lengths of dry spell, reduced number of rainy days, delayed onset dates, early cessation dates and increased maximum temperatures recorded in most of the study stations during the same period (1994-1997). Generally, the observed fluctuations in maize yields can be attributed to the variability in intra-seasonal rainfall and temperature characteristics in Narok County and non-climatic factors.

## 4.6 Relationship between maize yields and intra-seasonal climate characteristics

This section presents the results of correlation and regression analyses between intra-seasonal climate characteristics and maize yields in Narok County.

### 4.6.1 Correlation analysis between intra-seasonal climate characteristics and maize yield

Table 17 presents correlation coefficients between intra-seasonal climate characteristics analyzed in this study and maize yields for MAM season for Mosiro station.

**Table 17: Correlation coefficients between climate characteristics and maize yield for MAM season (2000-2014)**

| **Intra- seasonal climate characteristics** | **MAM season** | | | |
|---|---|---|---|---|
| | **Correlation coefficient** | **Computed t** | **Tabulated t** | **Significance at α = 0.05** |
| Season Onset date | 0.3907 | 1.5303 | 2.179 | Not Significant |
| Season cessation date | -0.0681 | 0.2461 | 2.179 | Not Significant |
| Length of season | 0.4860 | 2.005 | 2.179 | Not Significant |
| Season Rainy days | 0.1528 | 0.5574 | 2.179 | Not Significant |
| Season rainfall total | 0.1112 | 0.4034 | 2.179 | Not Significant |
| Wet spell | 0.017 | 0.0160 | 2.179 | Not Significant |
| Dry spell | -0.5742 | 2.5287 | 2.179 | Significant |
| Tmax | -0.2754 | 1.0330 | 2.179 | Not Significant |
| Tmin | 0.5637 | 2.4606 | 2.179 | Significant |
| T Range | -0.5510 | 2.3806 | 2.179 | Significant |
| GDD | 0.0559 | 0.2019 | 2.179 | Not Significant |

Statistically significant correlation coefficients were found between each of the dry spell length, minimum temperature, temperature range and maize yields. There was strong negative correlation between dry spell lengths and maize yields (-0.5742), implying increased lengths of dry spells decrease maize yields and therefore exacerbate the vulnerability of maize crop to water stress.

Minimum temperature had a significant positive correlation (0.5637) with maize yields. Rising minimum temperatures would yield positive effects on maize yield through enhanced seed germination, dry matter accumulation and enhanced overall maize plant development. Temperature range had significant negative correlation (-0.55) with maize yields, signifying that increased temperature range would significantly reduce maize yields as a result of high fluctuations between minimum and maximum temperatures thereby disrupting the diurnal rhythms associated with the maize plant physiological processes. Table 18 presents correlation coefficients between maize yields and climatic characteristics for OND season at Kilgoris station.

**Table 18: Correlation coefficients between climate characteristics and maize yields for OND season for Kilgoris station (2000-2014)**

| **Intra- seasonal climate characteristics** | **OND season** | | | |
|---|---|---|---|---|
| | **Correlation coefficient** | **Computed t** | **Tabulated t** | **Significance at α = 0.05** |
| Season Onset date | -0.158 | 0.876 | 2.179 | Not Significant |
| Season cessation date | -0.141 | 0.787 | 2.179 | Not Significant |
| Length of season | 0.044 | 0.245 | 2.179 | Not Significant |
| Season Rainy days | -0.049 | 0.275 | 2.179 | Not Significant |
| Season rainfall total | -0.047 | 0.263 | 2.179 | Not Significant |
| Wet spell | 0.287 | 1.559 | 2.179 | Not Significant |
| Dry spell | -0.447 | 2.786 | 2.179 | Significant |
| Tmax | -0.066 | 0.369 | 2.179 | Not Significant |
| Tmin | 0.258 | 1.441 | 2.179 | Not Significant |
| T Range | -0.074 | 0.828 | 2.179 | Not Significant |
| GDD | 0.169 | 0.585 | 2.179 | Not Significant |

During OND season, the correlation coefficient between length of dry spells and maize yields was found to be statistically significant. The length of dry spell had strong negative relationship with maize yields (-0.447). Increased lengths of dry spell will reduce maize yields in Kilgoris during OND season due to deprivation of water required by the maize crop for growth, development and productivity.

Generally, most of the study stations exhibited positive correlation coefficients between the intra-seasonal rainfall characteristics and maize yields. However, negative correlation coefficients were presented between intra-seasonal temperature characteristics and maize yields. These results are in agreement with some past studies by Adamgbe & Ujoh (2013).

### 4.6.2 Multiple Linear Regression Analysis

Since onset and cessation dates were used to compute length of the growing season, they were excluded from the multiple linear regression model to avoid the inherent multicollinearity. The resultant multiple linear regression equations linking maize yields and intra-seasonal climate characteristics that were found to have statistically significant correlation coefficients with maize yields, together with the proportion of the yield variation explained by the equations are presented in Table 19.

**Table 19: Multiple Regression equations between Intra- seasonal climate characteristics and maize yield in Narok County.**

| Meteorological Station | Regression equation for MAM Season | Coefficient of Determination ($R^2$) (%) |
|---|---|---|
| Nyangores | Yield = 3.1471 – 0.04* Dry spell length | 19 |
| Narok | Yield = -4.924 + 0.6037* $T_{min}$ | 27 |
| Kilgoris | Yield = -4.043 + 0.4277* $T_{min}$ | 15 |
| Mosiro | Yield = -3.2013 + 0.4958* $T_{min}$ – 0.249* $T_{range}$ – 0.003* Dry spell | 33 |

The coefficient of determination ($R^2$) values ranged between (19%) and (33%) in Narok County. The highest variance explained ($R^2$) in maize yields was (33%) in Mosiro station by minimum temperature, temperature range and dry spell length. The rest of the variability in maize yields could be ascribed to other factors not directly considered in the study such as changes in farm management practices, pests and diseases among other factors.

The developed multiple linear regression model for OND season is given by equation 11.

Y = 3.297 – 0.044* DSL (20%) ……………………………… (11)

Where Y is maize yield in MT/Ha and DSL is the dry spell length.

This implies that during the OND rainy season, it is only the dry spell length that influenced maize yields in Narok County. Dry spell length explains about 20% of the variability in maize yields in Narok.

### 4.7 Impact of future climate variability and change on maize yield

This section presents the results for the impact of climate variability and change on maize yields in Narok County based on the projected future climate characteristics derived from the outputs of the CORDEX model under RCP4.5 and RCP8.5 emission scenarios.

### 4.7.1 Skill of the CORDEX model in simulating future climate

Table 20 presents the correlation and mean absolute error (MAE) for the RCA4 driven GCMs in projecting maximum and minimum temperature.

**Table 20: Validation of RCA4 driven GCMs in projecting maximum temperature**

| **MODEL** | **Maximum Temperature** | |
|---|---|---|
| | **Correlation coefficient (r)** | **MAE** |
| MOHC | 0.48 | 1.67 |
| CNRM | 0.58 | 1.41 |
| MPI | 0.52 | 1.95 |
| MIROC | 0.17 | 1.80 |
| ICHEC | 0.42 | 1.35 |
| NOAA | 0.21 | 1.87 |
| CCCma | 0.37 | 1.85 |
| CSIRO | 0.34 | 1.65 |

From Table 20, the CNRM model had the best skill in simulating maximum temperature in Narok, with a correlation coefficient value of 0.58 and MAE value of 0.41. Table 21 presents the correlation and Mean Absolute Error (MAE) results associated with minimum temperature in Narok County.

**Table 21: Validation of RCA4 driven GCMs in projecting minimum temperature**

| **Station Name** | **Minimum Temperature** | |
|---|---|---|
| | **Correlation coefficient (r)** | **MAE** |
| MOHC | 0.25 | 2.68 |
| CNRM | 0.32 | 1.60 |
| MPI | 0.27 | 1.91 |
| MIROC | 0.20 | 2.76 |
| ICHEC | 0.16 | 2.74 |
| NOAA | 0.24 | 2.56 |
| CCCma | 0.26 | 3.92 |
| CSIRO | 0.23 | 2.95 |

Similarly, the CNRM model had the best skill in projecting minimum temperature over Narok compared to the other models, with an average correlation coefficient value of 0.32 and an average MAE value of 1.62.

The correlation coefficients and MAE associated with total seasonal rainfall are presented in Table 22.

**Table 22: Validation of RCA4 driven GCMs in simulating Rainfall**

| **Station Name** | **Rainfall** | |
|---|---|---|
| | **Correlation Coefficient (r)** | **MAE** |
| MOHC | 0.21 | 100.7 |
| CNRM | 0.31 | 79.3 |
| MPI | 0.30 | 99.8 |
| MIROC | 0.17 | 85.6 |
| ICHEC | 0.31 | 88.9 |
| NOAA | 0.08 | 109.7 |
| CCCma | 0.15 | 108.9 |
| CSIRO | 0.19 | 90.9 |

Like for maximum and minimum temperatures, the CNRM model had the best skill in projecting rainfall over Narok with a correlation coefficient value of 0.31 and MAE value of 79.3. Based on these observations, the study utilized rainfall, minimum and maximum temperature projection outputs from CNRM model.

### 4.7.2 The skill of the AquaCrop Model

Table 23 presents a comparison between the projected maize yields by the AquaCrop model and the observed maize yields in Narok County for the period 1982-2014.

**Table 23: Comparison between projected and observed maize yields for Narok**

| Year | Simulated Maize Yield (MT/Ha) | Observed Maize Yield (MT/Ha) |
|---|---|---|
| 1982 | 2.77 | 2.25 |
| 1983 | 2.63 | 3.22 |
| 1984 | 1.50 | 1.23 |
| 1985 | 2.10 | 1.62 |
| 1986 | 2.25 | 2.25 |
| 1987 | 2.87 | 1.25 |
| 1988 | 2.73 | 2.70 |
| 1989 | 3.07 | 3.60 |
| 1990 | 2.40 | 2.25 |
| 1991 | 3.38 | 3.00 |
| 1992 | 3.07 | 3.42 |
| 1993 | 2.84 | 1.62 |
| 1994 | 3.15 | 2.23 |
| 1995 | 2.89 | 2.44 |
| 1996 | 3.41 | 1.63 |
| 1997 | 2.80 | 1.22 |
| 1998 | 3.30 | 2.70 |
| 1999 | 1.61 | 0.59 |
| 2000 | 1.55 | 1.08 |
| 2001 | 2.89 | 1.80 |
| 2002 | 2.15 | 3.02 |
| 2003 | 2.79 | 3.13 |
| 2004 | 1.99 | 4.57 |
| 2005 | 3.10 | 4.50 |
| 2006 | 2.64 | 4.75 |
| 2007 | 3.71 | 3.15 |
| 2008 | 2.20 | 2.20 |
| 2009 | 2.99 | 2.31 |
| 2010 | 3.09 | 3.69 |
| 2011 | 2.95 | 2.47 |
| 2012 | 2.66 | 1.70 |
| 2013 | 2.66 | 2.81 |
| 2014 | 3.29 | 2.42 |

The projected maize yields by the AquaCrop model were higher than the observed maize yields. The average observed maize yields was 2.24 MT/Ha, whereas the average simulated maize yields by the AquaCrop model for the baseline period was 2.71 MT/Ha. The analysis of the mean error between simulated and observed maize yields indicated a Mean error value of 0.47, implying that AquaCrop model overestimated maize yields by 0.47 MT/Ha in Narok County. Overall, the AquaCrop model could explain 38.25% of the variability in the maize yields in Narok County.

Figure 107 presents time series plots of observed and projected maize yields for the baseline period (1982-2014).

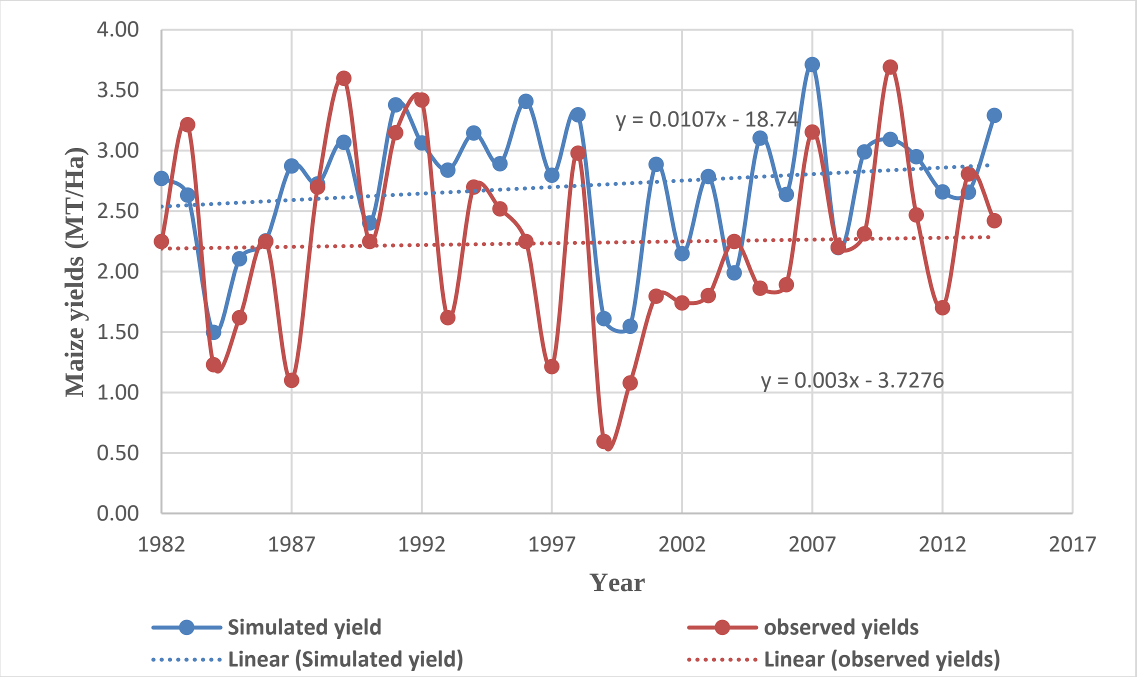

**Figure 107: Time series of observed and projected maize yields for Narok for the period 1982- 2014.**

From Figure 107, the projected maize yields were higher than the observed maize yields for most of the years.

Table 24 presents the projected maize yields under RCP4.5 and RCP8.5 emission scenarios for the period 2021-2050.

**Table 24: Projected Maize yields in Narok under RCPs 4.5 and 8.5 for 2021-2050**

| YEAR | RCP4.5 | RCP8.5 | YEAR | RCP4.5 | RCP8.5 |
|---|---|---|---|---|---|
| | Maize yield (MT/ha) | Maize Yield (MT/ha) | | Maize yield (MT/ha) | Maize Yield (MT/ha) |
| 2021 | 2.72 | 1.23 | 2039 | 2.30 | 2.56 |
| 2022 | 2.57 | 2.82 | 2040 | 1.13 | 1.38 |
| 2023 | 2.50 | 3.19 | 2041 | 2.31 | 2.48 |
| 2024 | 2.98 | 3.42 | 2042 | 2.13 | 2.86 |
| 2025 | 2.87 | 1.16 | 2043 | 1.54 | 1.94 |
| 2026 | 2.82 | 1.48 | 2044 | 2.81 | 2.34 |
| 2027 | 3.18 | 2.97 | 2045 | 3.40 | 1.84 |
| 2028 | 2.28 | 2.88 | 2046 | 2.63 | 1.68 |
| 2029 | 2.92 | 2.50 | 2047 | 2.54 | 2.62 |
| 2030 | 3.50 | 3.25 | 2048 | 3.40 | 2.56 |
| 2031 | 2.72 | 3.19 | 2049 | 2.81 | 2.23 |
| 2032 | 3.08 | 2.54 | 2050 | 2.07 | 2.95 |
| 2033 | 2.76 | 2.65 | | | |
| 2034 | 2.34 | 2.91 | | | |
| 2035 | 2.07 | 3.22 | | | |
| 2036 | 2.86 | 3.40 | | | |
| 2037 | 2.94 | 2.39 | | | |
| 2038 | 3.20 | 3.26 | | | |

The projected maize yields under RCP4.5 were higher than those under RCP8.5 by 0.11 MT/ha. Comparing the projected maize yields (2021-2050) to the observed maize yields (1982-2014), the future maize yields will decline by 0.07 MT/Ha (2.5%) under RCP4.5 and 0.28MT/Ha (10.3%) under RCP8.5 emission scenario by the year 2050. The decline in maize yields will be greater under RCP8.5 emission scenario due to increased temperatures and rainfall variability under the emission scenarios in the future.

### 4.8 Variability in future rainfall and temperature over Narok County

Table 25 presents a comparison between the projected average rainfall, maximum and minimum temperature in Narok under RCP4.5 and RCP8.5 emission scenarios for the period 2021-2050.

**Table 25: Differences between the Averages of projected rainfall and temperature**

| Station | RCP4.5 | RCP8.5 | Difference | Percentage (%) |
|---|---|---|---|---|
| **Average Rainfall (mm)** | | | | |
| Mosiro | 324 | 312 | -12 | -3.7 |
| Loita | 2353 | 2317 | -36 | -1.5 |
| Olchorro | 1376 | 1325 | -51 | -3.7 |
| Kilgoris | 1414 | 1337 | -77 | -5.4 |
| Narok | 1286 | 1241 | -45 | -3.5 |
| Cottar's | 690 | 669 | -21 | -3.0 |
| **Average Maximum Temperature ($^oC$)** | | | | |
| Mosiro | 26.4 | 26.7 | 0.3 | 1.1 |
| Loita | 24.6 | 24.9 | 0.3 | 1.2 |
| Olchorro | 21.7 | 22.0 | 0.3 | 1.3 |
| Kilgoris | 26.1 | 26.4 | 0.3 | 1.1 |
| Narok | 22.9 | 23.1 | 0.3 | 1.3 |
| Elementaita | 20.9 | 21.2 | 0.3 | 1.4 |
| **Average Minimum Temperature ($^oC$)** | | | | |
| Mosiro | 13.5 | 13.8 | 0.3 | 2.2 |
| Loita | 13.8 | 13.6 | 0.2 | 1.4 |
| Olchorro | 11.8 | 12.1 | 0.3 | 2.5 |
| Kilgoris | 14.8 | 15.3 | 0.3 | 2.0 |
| Narok | 11.8 | 12.1 | 0.3 | 2.5 |
| Elementaita | 11.5 | 11.7 | 0.2 | 1.7 |

Model outputs for RCP4.5 emission scenario indicate that, average rainfall for the period 2021 - 2050 is projected to be higher compared to average rainfall under RCP8.5 emission scenario. The greatest difference is projected for Kilgoris station (-5.4%) while the least difference is projected for Loita station (-1.5%). Higher maximum and minimum temperatures as would be expected are projected under RCP 8.5 compared to RCP4.5. The largest difference in maximum temperature is projected for Elementaita station (1.4%). The largest difference in minimum temperature is projected for both Narok and Olchorro stations amounting to 2.5%.

### 4.8.1 Trends in projected climate under RCP4.5 Emission Scenario

#### 4.8.1.1 Rainfall Patterns

Figures 108 to 110 present the trends in projected rainfall for Narok, Kilgoris and Loita stations under RCP4.5 emission scenario.

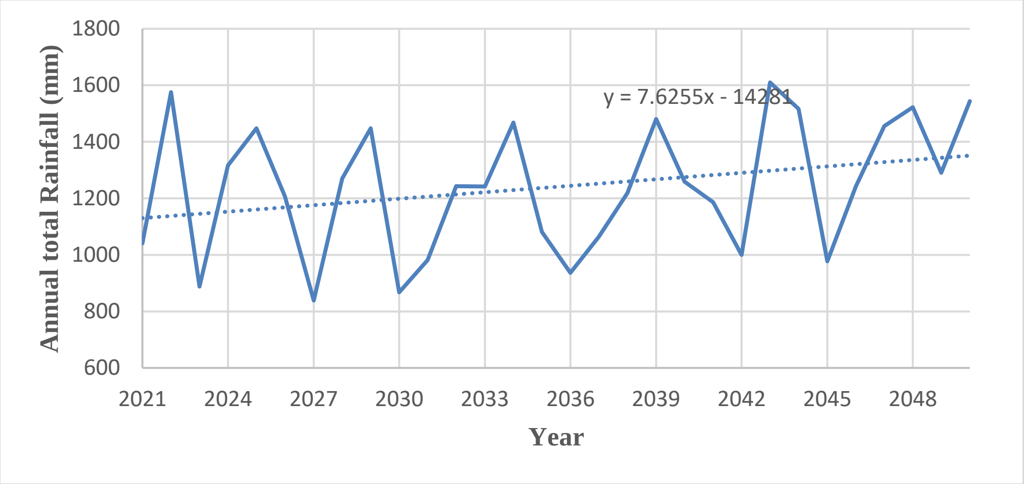

**Figure 108: Projected total annual rainfall trend under RCP4.5 emission scenario for Narok station**

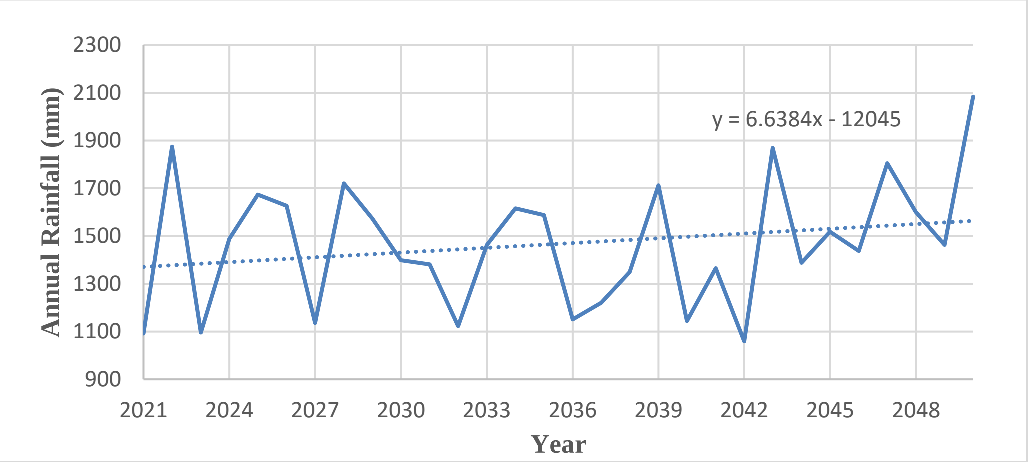

**Figure 109: Projected total annual rainfall trend under RCP4.5 for Kilgoris station**

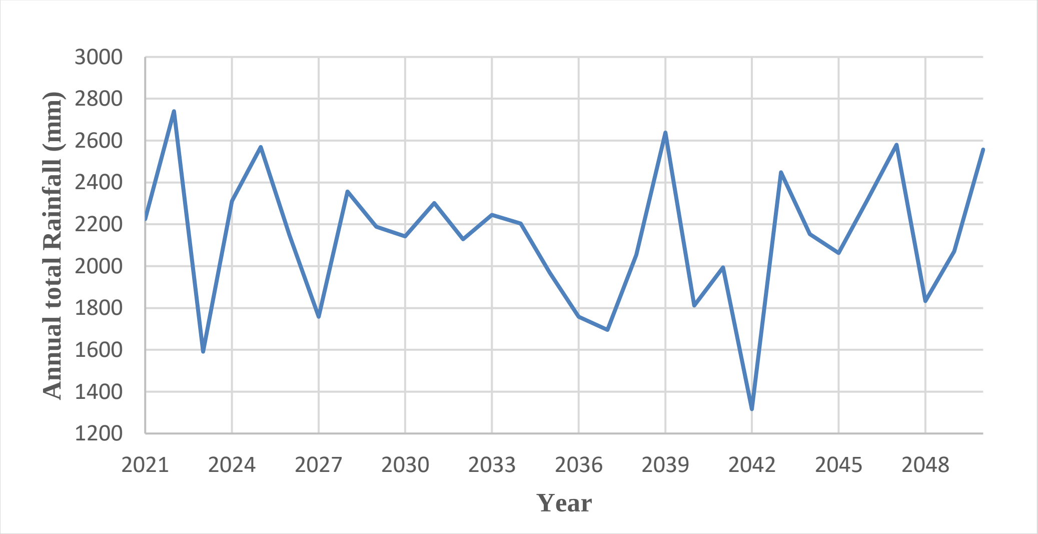

**Figure 110: Projected total annual rainfall trend under RCP4.5 for Loita station**

Under the RCP4.5 emission scenario model outputs, rainfall is projected to increase in the study county during the period 2021 to 2050. Increased rainfall could increase prospects for crop agriculture in Narok County.

#### 4.8.1.2 Trends in Maximum temperature

Figures 111 to 113 indicate the projected maximum temperature under RCP4.5 emission scenario for Narok, Kilgoris and Loita stations respectively.

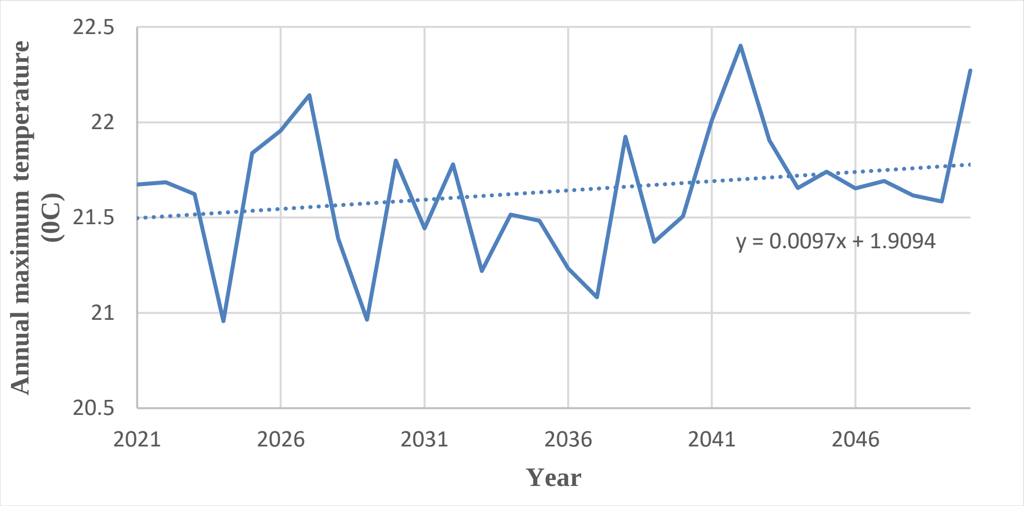

**Figure 111: Trend of projected maximum temperature under RCP 4.5 emission scenario for Narok station.**

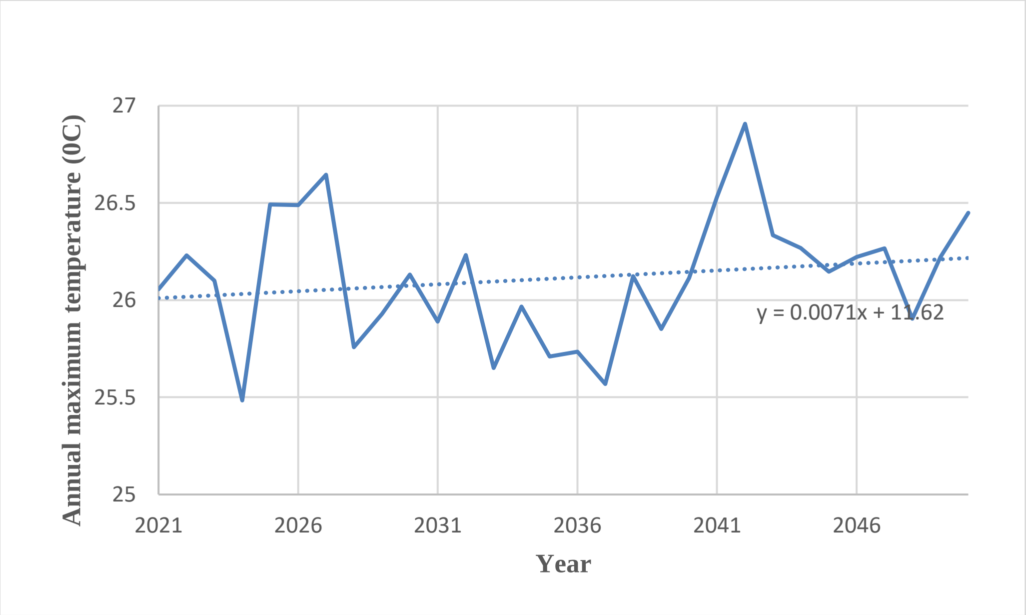

**Figure 112:Trend of projected maximum temperature under RCP 4.5 emission scenario for Kilgoris**

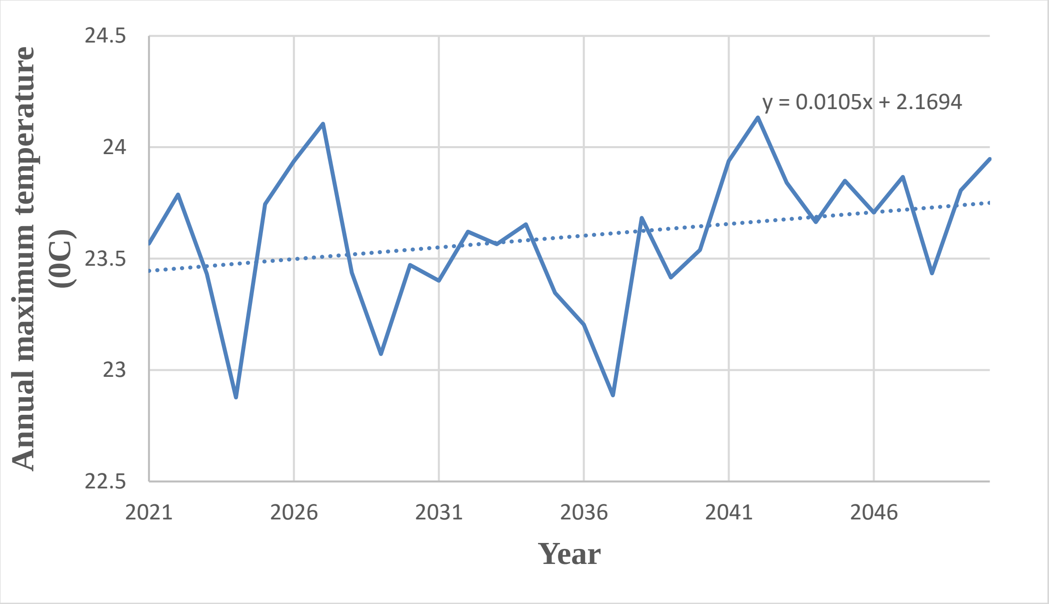

**Figure 113:Trend of projected maximum temperature under RCP 4.5 emission scenario for Loita**

Under RCP 4.5, maximum temperatures are projected to increase over the three study stations for the period 2021 to 2050. This would increase rates of evapotranspiration and exacerbate vulnerability of maize crop to water stress and consequently lead to decreased growth and productivity of the crop.

### 4.8.1.3 Trends in the projected minimum temperature

Figures 114 to 116 presents trends of minimum temperature under RCP4.5 emission scenario for Narok, Kilgoris and Loita stations respectively.

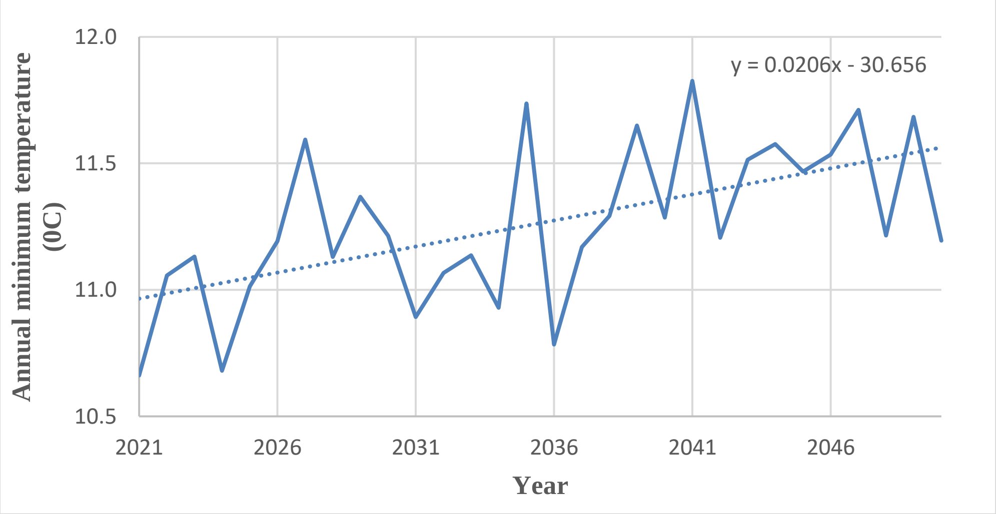

**Figure 114:Trend of projected annual minimum temperature under RCP4.5 for Narok station**

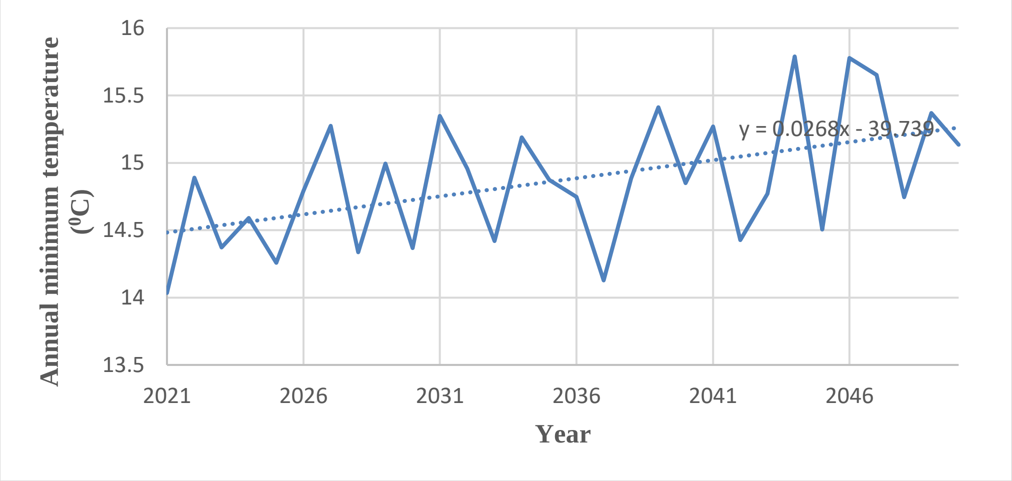

**Figure 115: Trend of projected annual minimum temperature under RCP4.5 for Kilgoris**

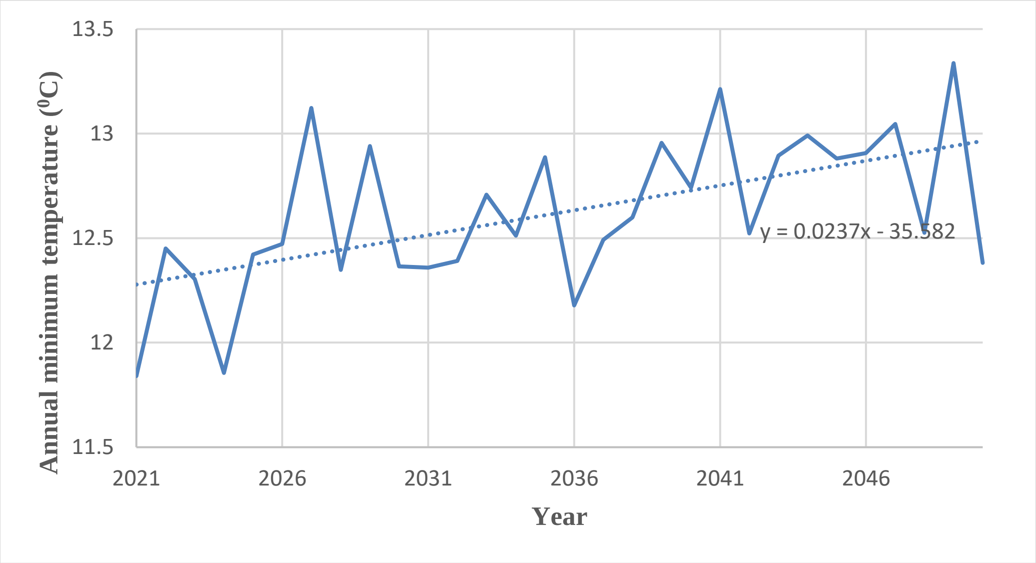

**Figure 116: Trend of projected annual minimum temperature under RCP 4.5 emission scenario for Loita**

Under RCP4.5 emission scenario, minimum temperatures are projected to increase over Narok, Kilgoris and Loita stations for the period 2021 to 2050. While the projected increase in minimum temperature may be beneficial for a short period during germination stage, higher minimum temperatures will increase the daily mean temperatures and the likelihood of extreme events and therefore decrease maize yields by severely affecting maize development during the critical stages of flowering and grain filling (Hatfield, 2015). Increasing mean daily temperatures equally provides favorable conditions for development of weeds, pests and diseases which would negatively affect maize crop growth, development and eventual yield.

### 4.8.2 Trends in projected climate under RCP8.5 Emission Scenario

This section presents the trends of projected rainfall, maximum temperature and minimum temperature under RCP8.5 emission scenario.

#### 4.8.2.1 Rainfall trends

Figures 117 to 119 present the trends in projected rainfall for Narok, Kilgoris and Loita stations for the period 2021-2050 respectively.

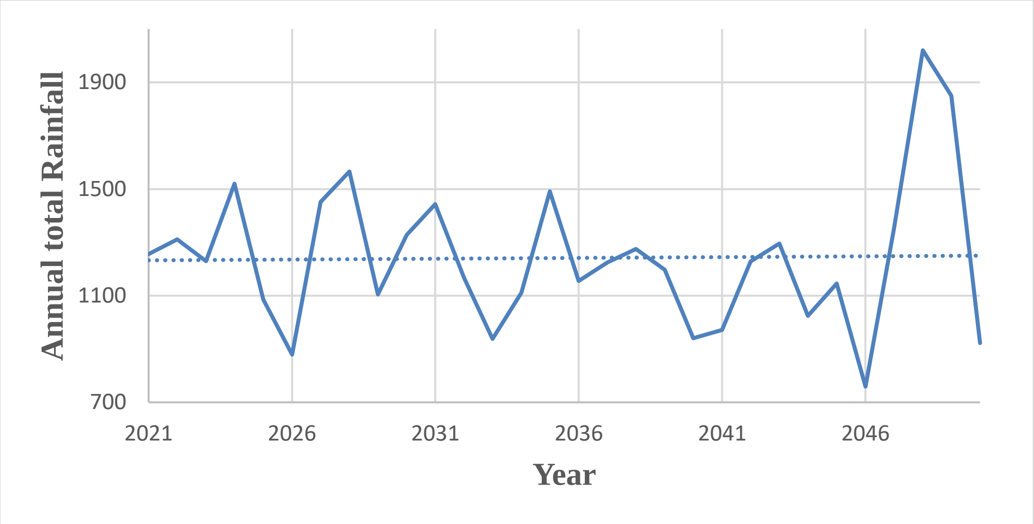

**Figure 117: Projected annual rainfall trend under the RCP8.5 emission scenario for Narok station**

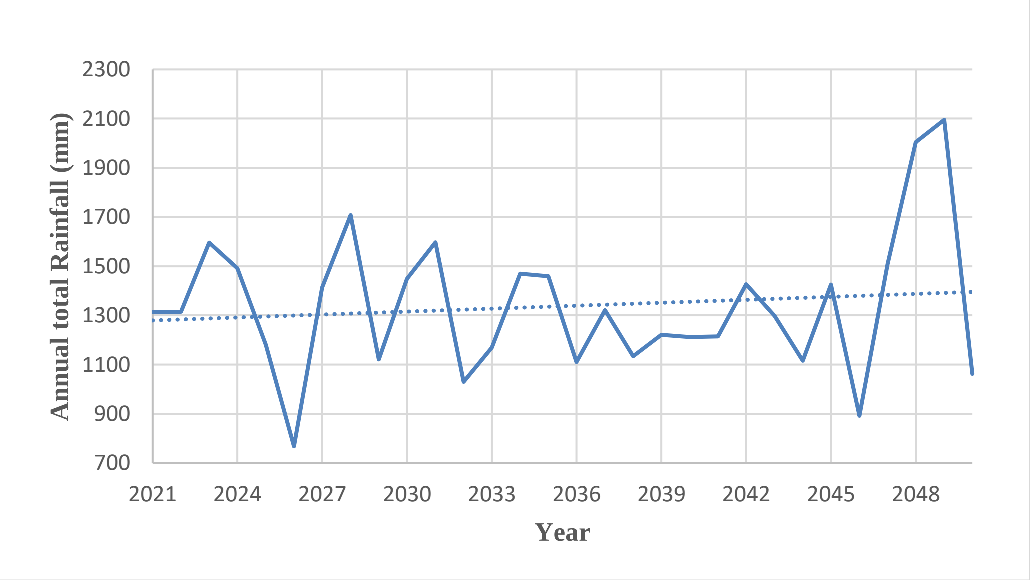

**Figure 118: Projected annual rainfall trend under the RCP8.5 emission scenario for Kilgoris**

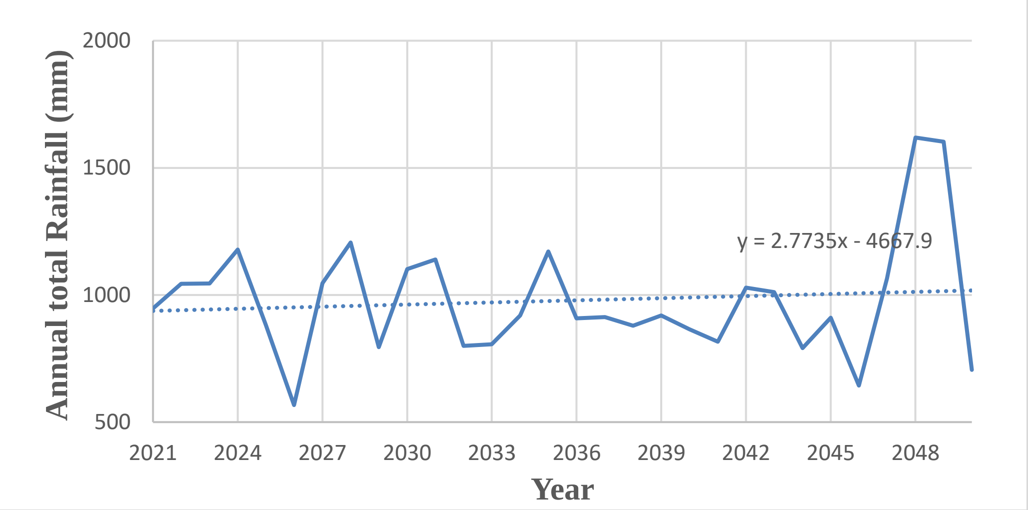

**Figure 119: Projected annual rainfall trend under RCP8.5 emission scenario for Loita**

Rainfall is projected to increase under the RCP8.5 emission scenario. The projected increase in rainfall is likely to increase extreme rainfall events in the form of floods and flashfloods, increasing waterlogging and soil erosion with severe consequences on maize crop growth and development, resulting in mediocre yields and/or crop failure.

### 4.8.2.2 Trends of Maximum temperature

Figures 120 to 122 present the trends in the projected maximum temperature under the RCP8.5 emission scenario for Kilgoris, Loita and Narok stations respectively.

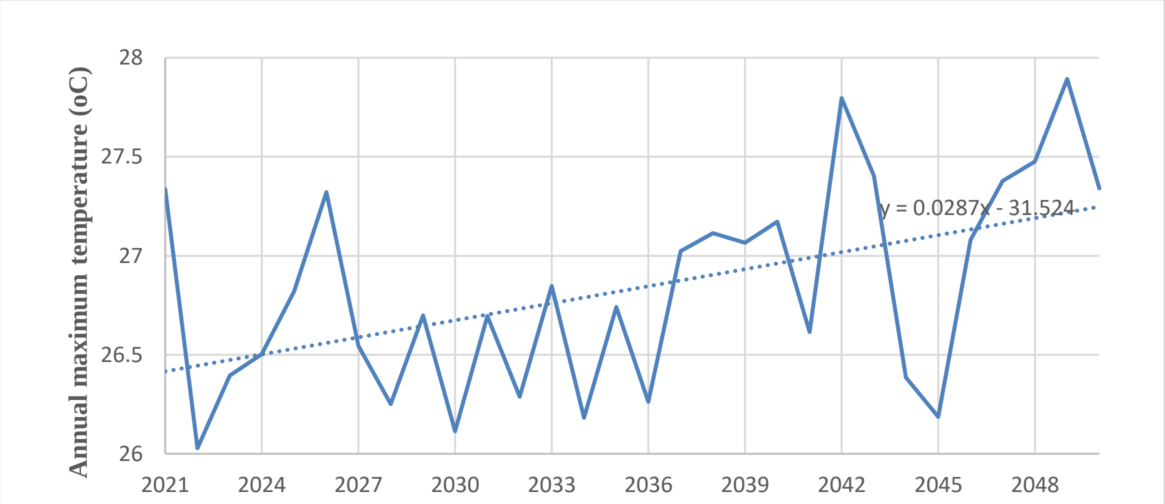

**Figure 120: Trend of projected annual maximum temperature under RCP8.5 emission scenario for Kilgoris station**

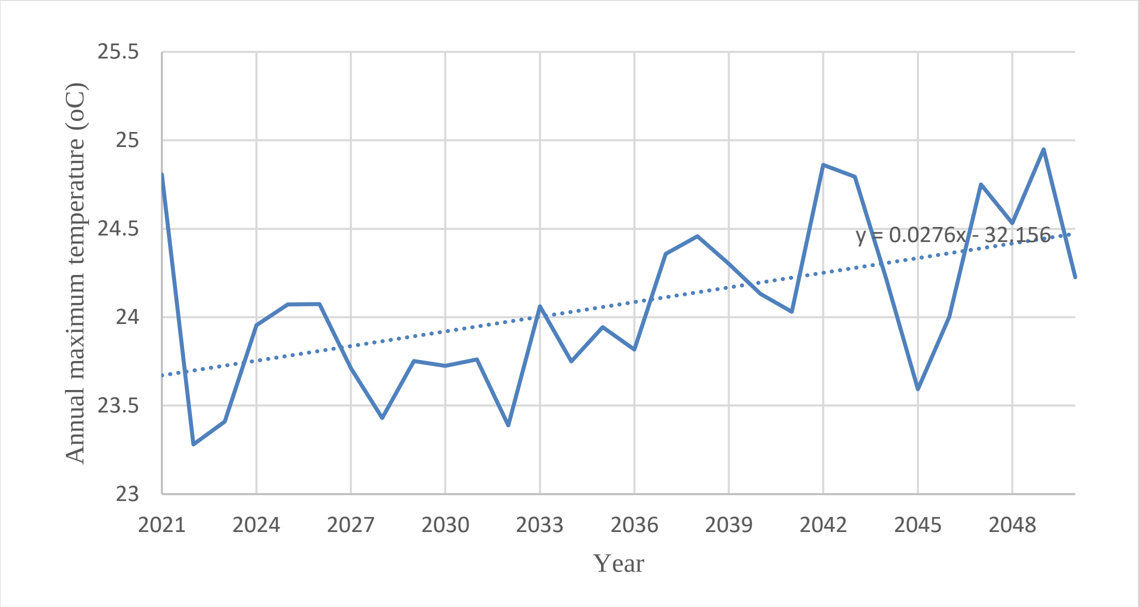

**Figure 121: Trend of projected annual maximum temperature under RCP8.5 emission scenario for Loita station.**

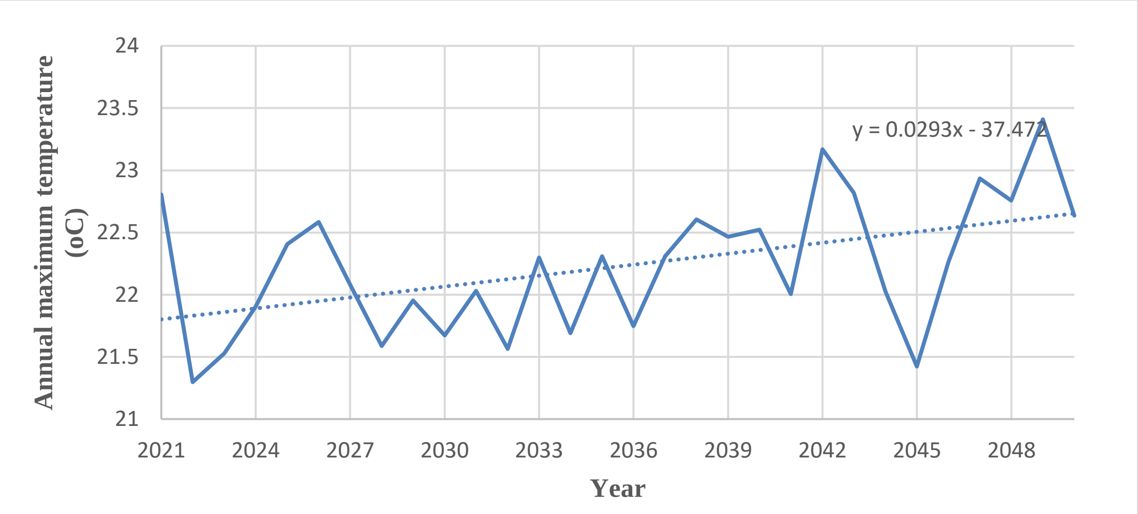

**Figure 122: Trend of projected annual maximum temperature under RCP8.5 emission scenario for Narok station**

Maximum temperatures are projected to increase, signifying higher rates of warming. High temperatures will result in high rates of evapotranspiration, thereby increasing vulnerability of maize crop to water stress. Extremely high temperatures during the reproductive phase, will affect pollen viability and also adversely affect maize crop during the critical stages of fertilization and grain filling (Hatfield, 2015).

#### 4.8.2.3 Trends in projected minimum temperature

Figures 123 to 125 present the trends in the projected minimum temperature under RCP8.5 emission scenario for Kilgoris, Narok and Loita stations respectively.

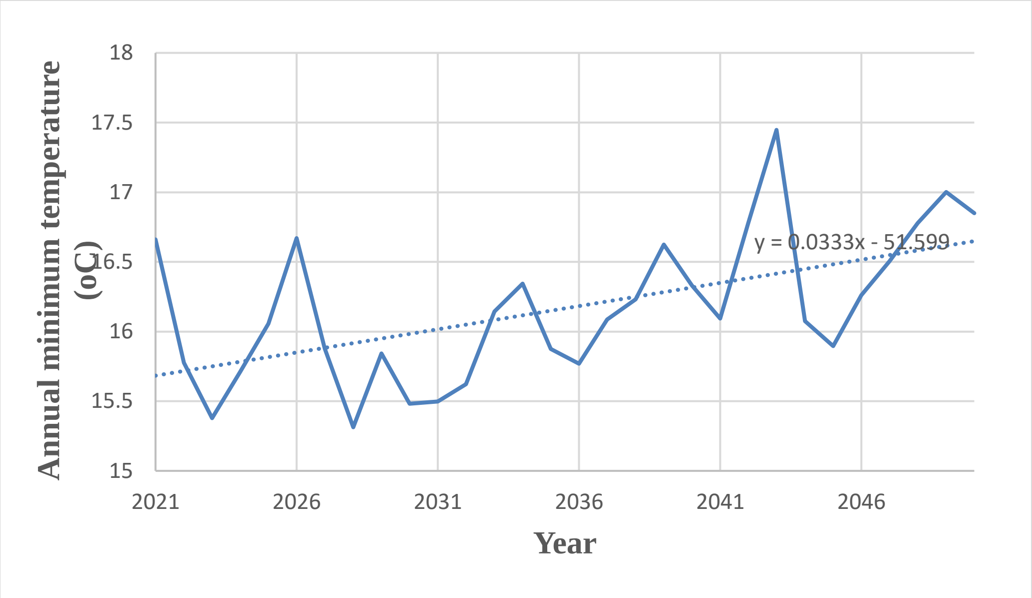

**Figure 123: Projected annual minimum temperature trend under RCP8.5 emission scenario for Kilgoris**

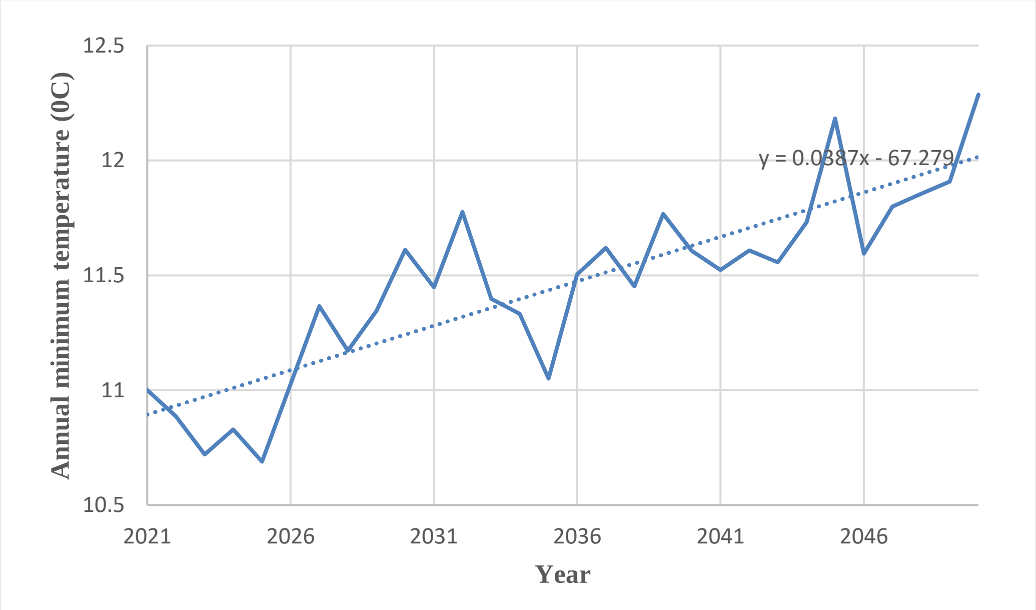

**Figure 124: Projected annual minimum temperature trend based on RCP8.5 emission scenario for Narok station.**

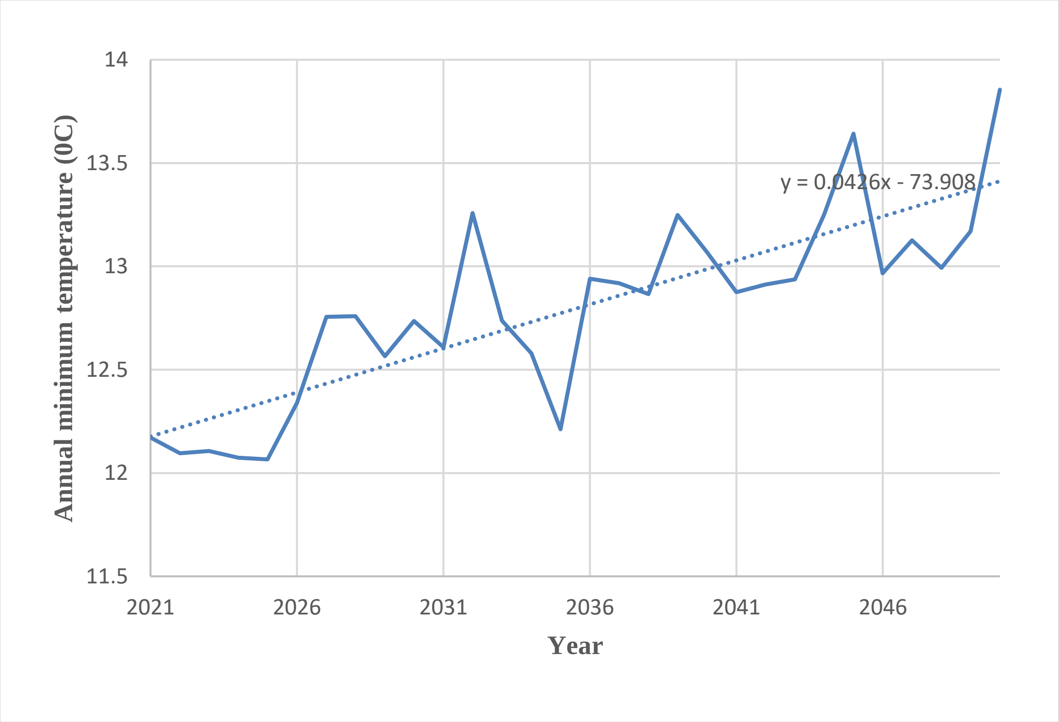

**Figure 125: Projected annual minimum temperature trend under the RCP8.5 emission scenario for Loita station.**

Minimum temperatures are projected to increase across the three study stations, thereby increasing the mean daily temperatures. Increased mean daily temperatures and associated temperature extremes would negatively affect pollen viability, flowering, reproductive and grain filling stages, and consequently reduce maize yields (Hatfield, 2015).

# CHAPTER FIVE

# 5.0: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Narok County has been, and will continue experiencing climate variability and change effects through rising temperature and disruptions of intra-seasonal rainfall characteristics including delayed onset dates, increased lengths of dry spells, and occasional increases in number of rainy days and length of growing season.

The marked variability in intra-seasonal climate characteristics including length of dry spells, minimum temperature and temperature range are responsible for the observed increase in inter-annual variability of maize yields over Narok County.

Maize yields in Narok County are strongly influenced by the intra-seasonal climate characteristics, notably, temperature range, minimum temperature and lengths of dry spell that together explain 33% of the variance in maize yield.

The projected increase in maximum temperature and minimum temperature, and decline in rainfall over Narok County under RCP4.5 and RCP8.5 will trigger maize yield reductions in 2021-2050 of 2.5% and 10.3% respectively.

## 5.2 Recommendations

- Rain-fed maize farmers within Narok County should adopt early-maturing maize cultivars that tolerate low moisture levels associated with the shortening lengths of growing seasons in order to ensure sustainable and enhanced maize productivity and food security.
- Relay cropping of maize should be adopted in stations such as Kilgoris and Mosiro with increasing lengths of growing seasons.
- Narok County government should formulate and implement agricultural policies that promote adoption of drought tolerant early maturation maize varieties by maize farmers.

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# APPENDIX I

## Double mass curves

This section presents a summary of the results for homogeneity for Narok, Elementaita, Nyangores, Mosiro, Loita, Abossi, Governor's, Olchorro. Oloololo, and Cottar's stations.

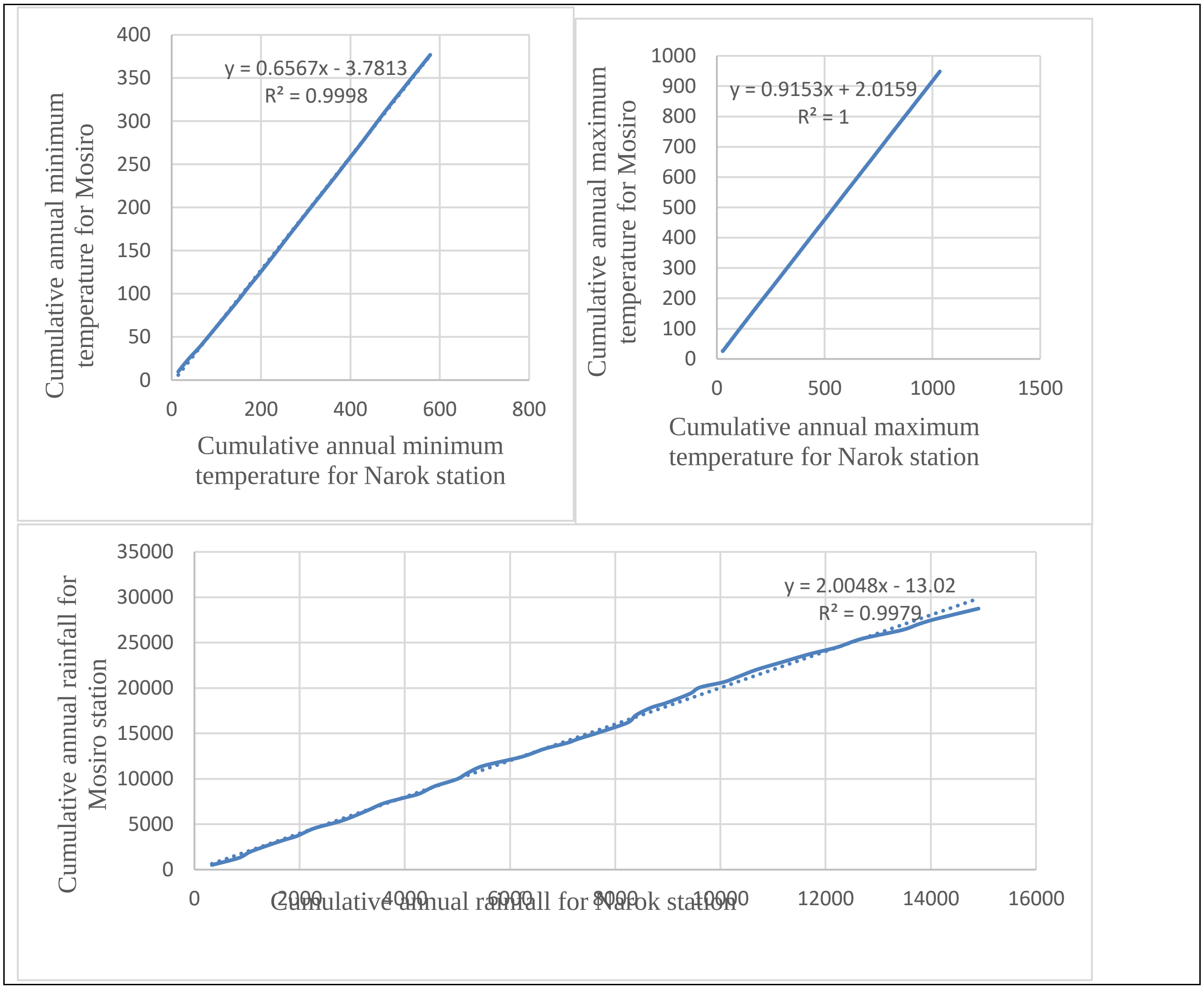

**Figure 126: Double mass curves Mosiro station**

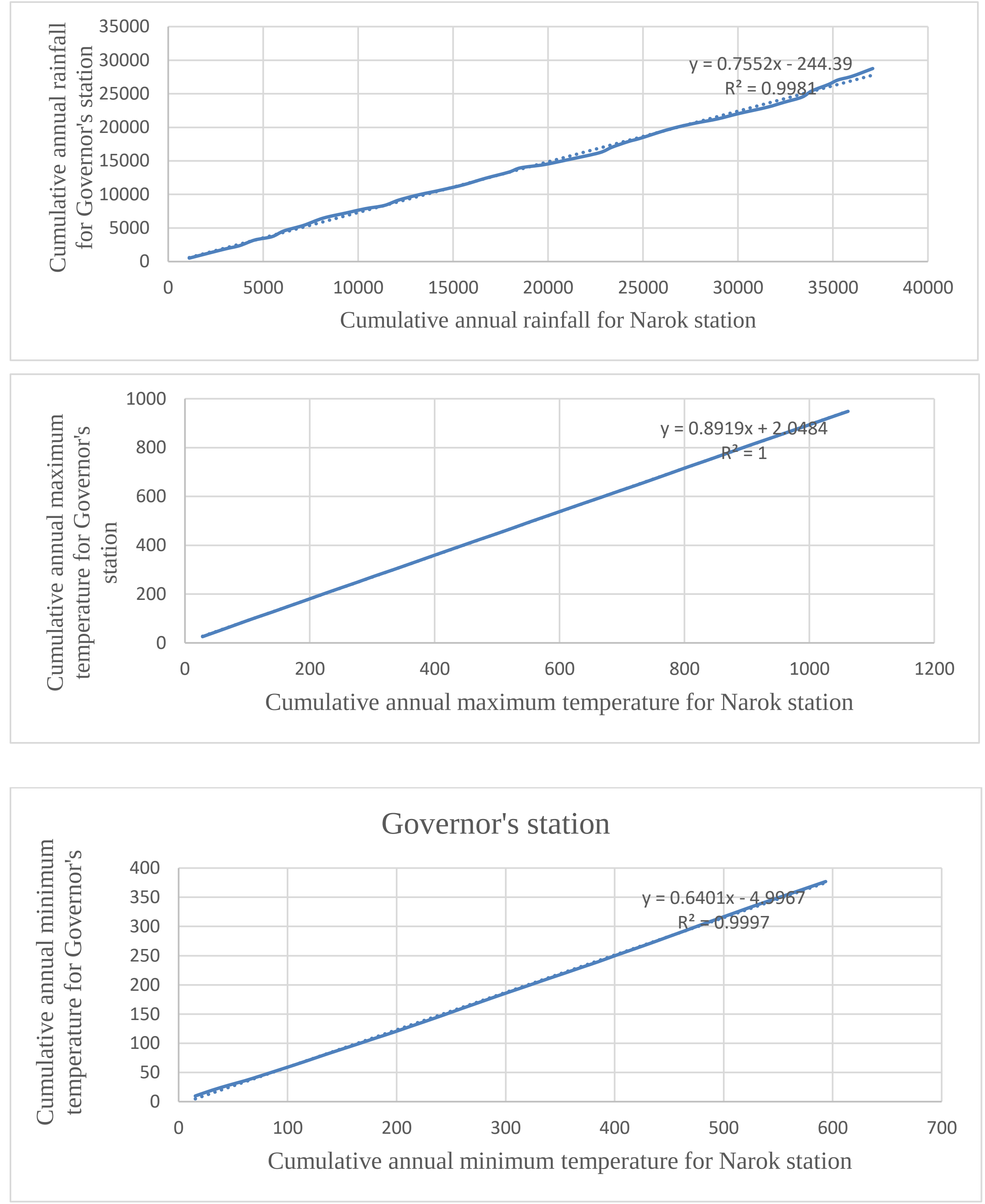

**Figure 127: Double mass curves Governors' station**

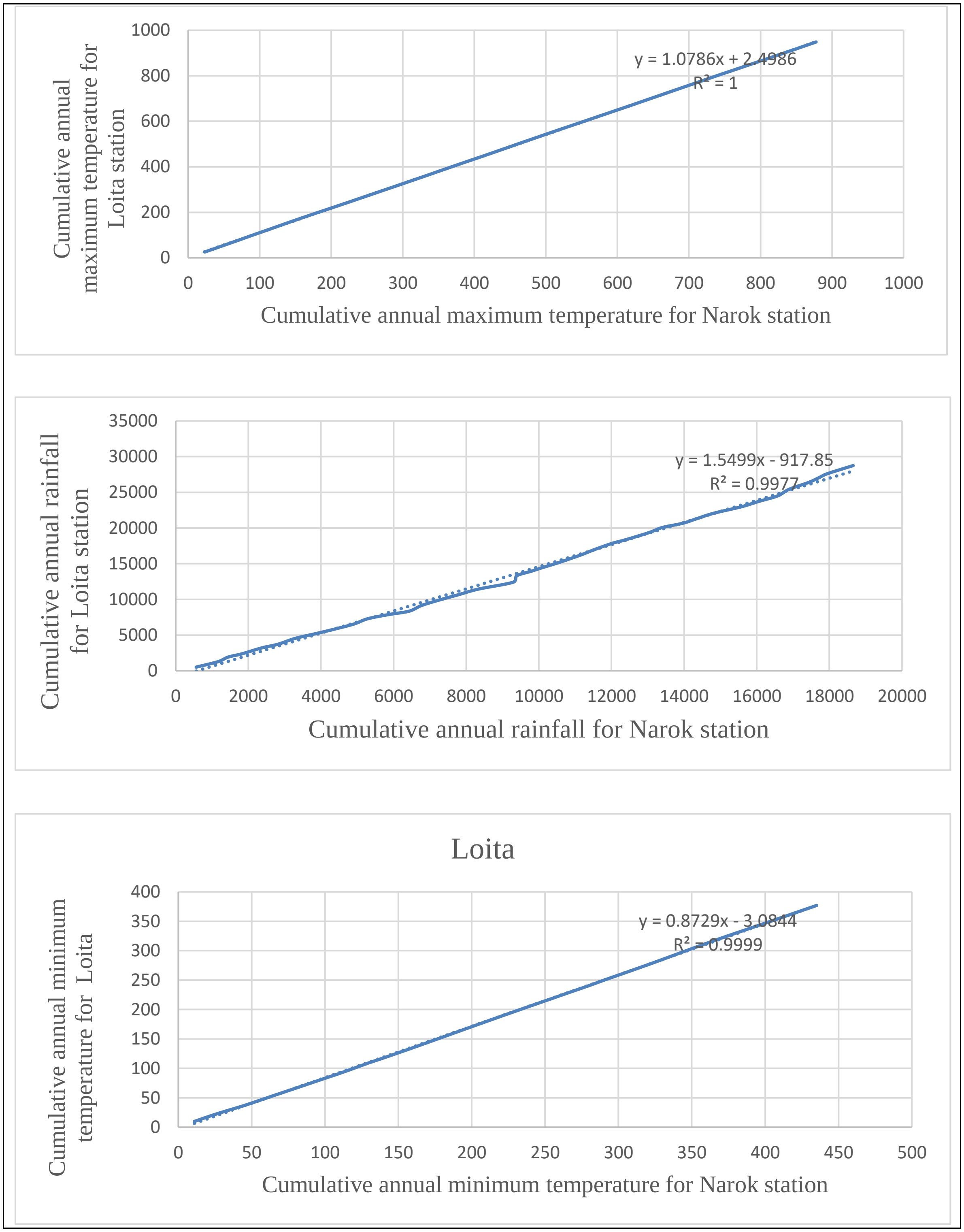

**Figure 128: Double mass curves for Loita station**

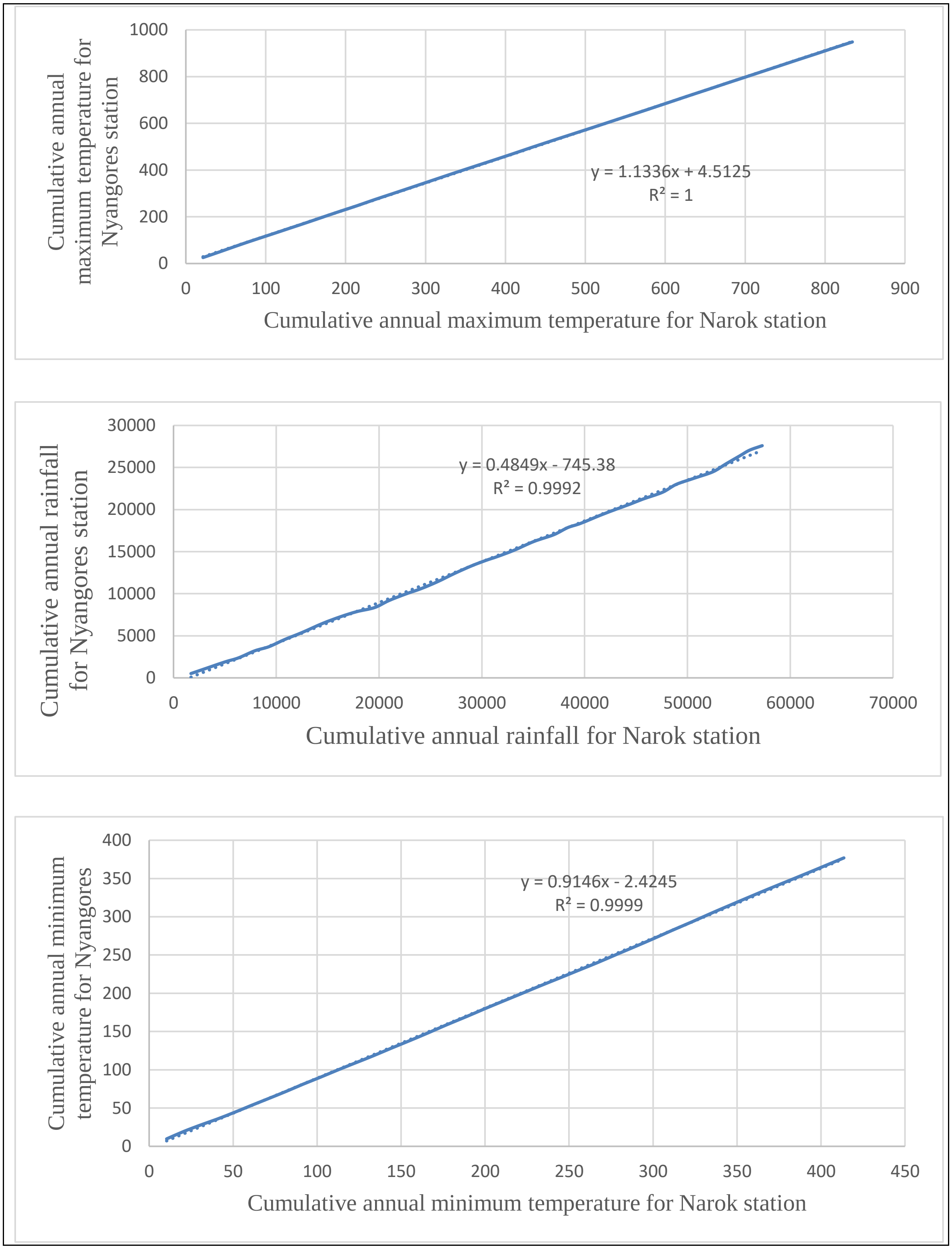

**Figure 129: Double mass curves for Nyangores station**

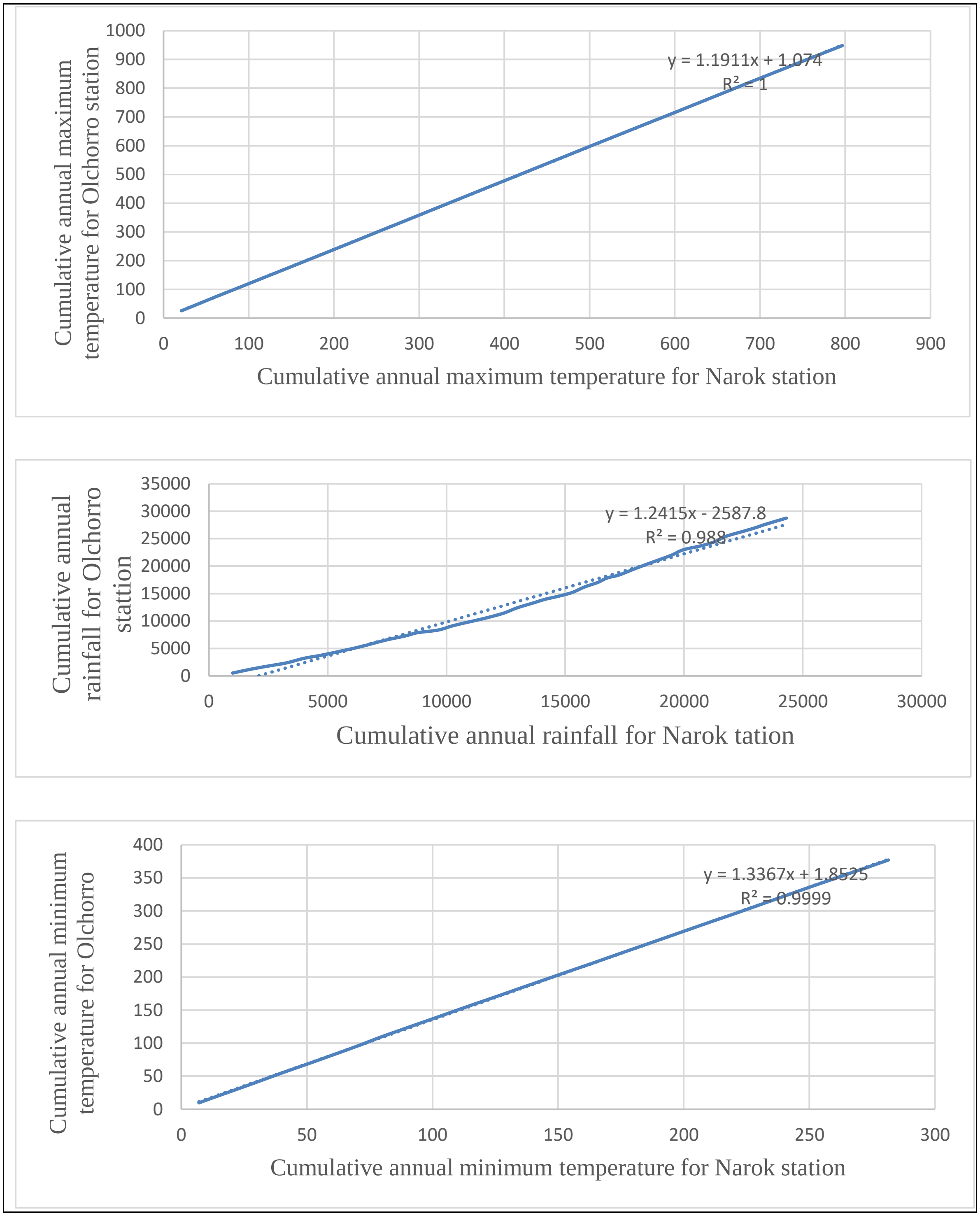

**Figure 130: Double mass curves for Olchorro station**

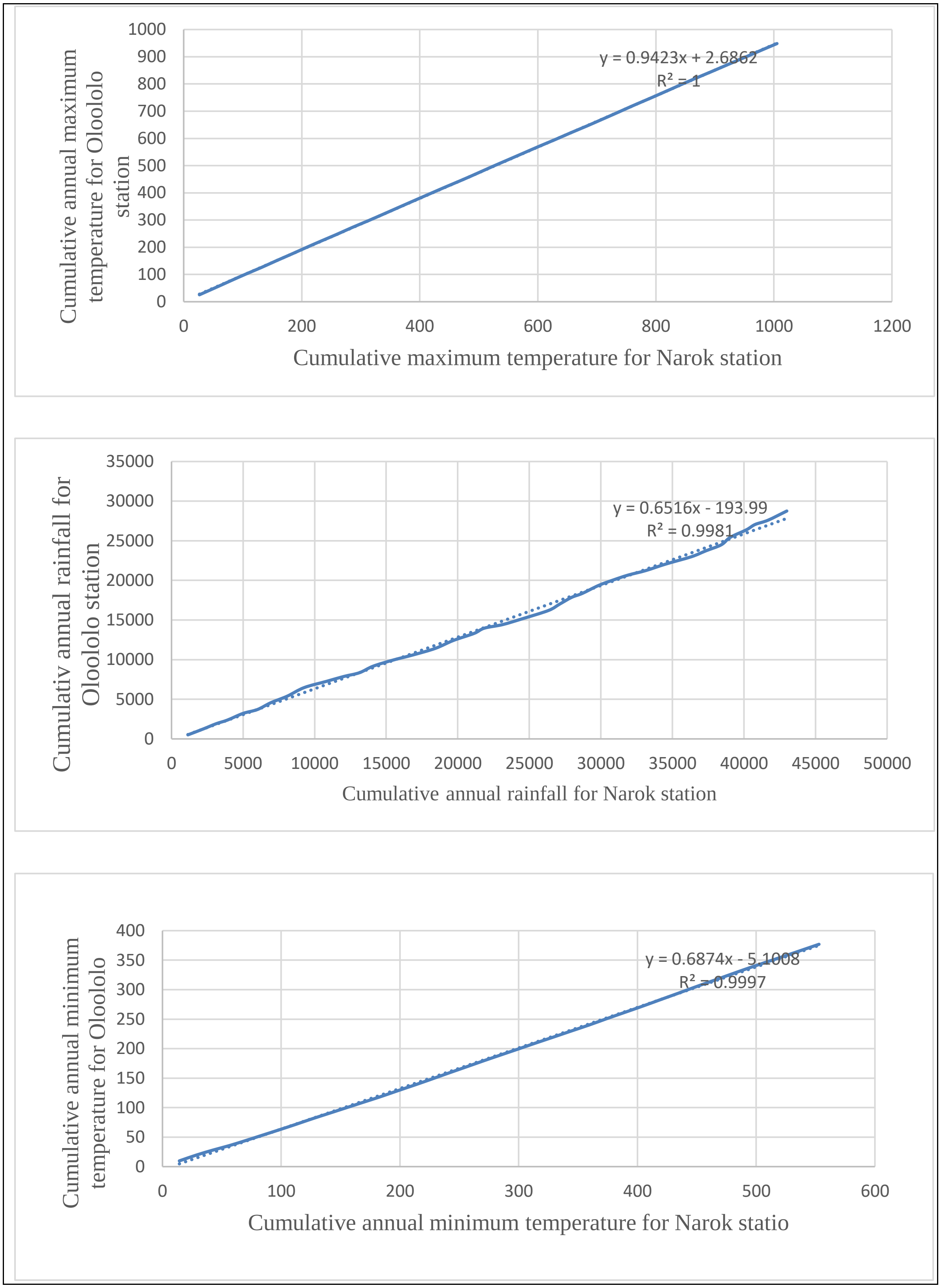

**Figure 131: Double mass curves for Oloololo station**

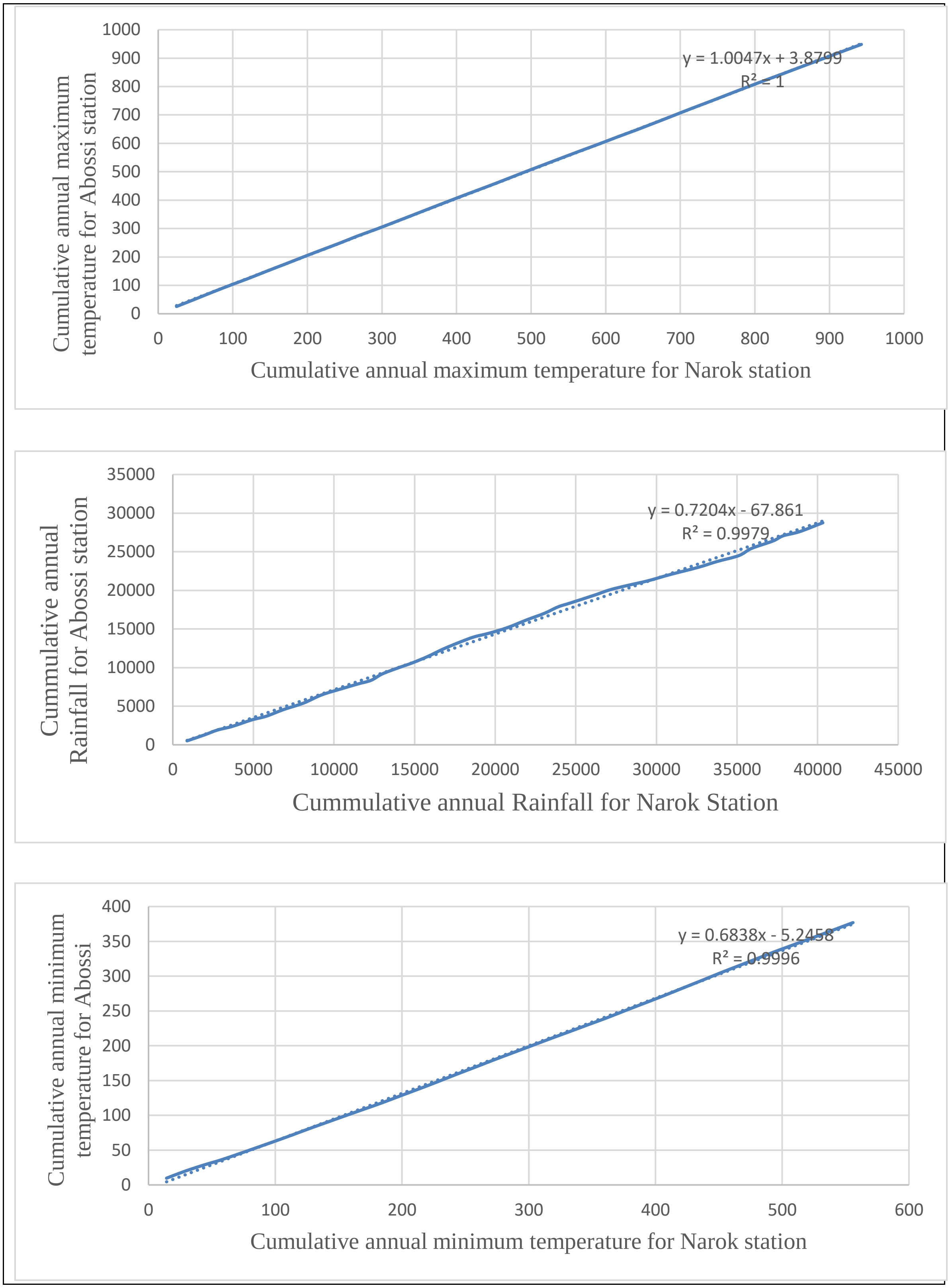

**Figure 132: Double mass curves for Abossi station**

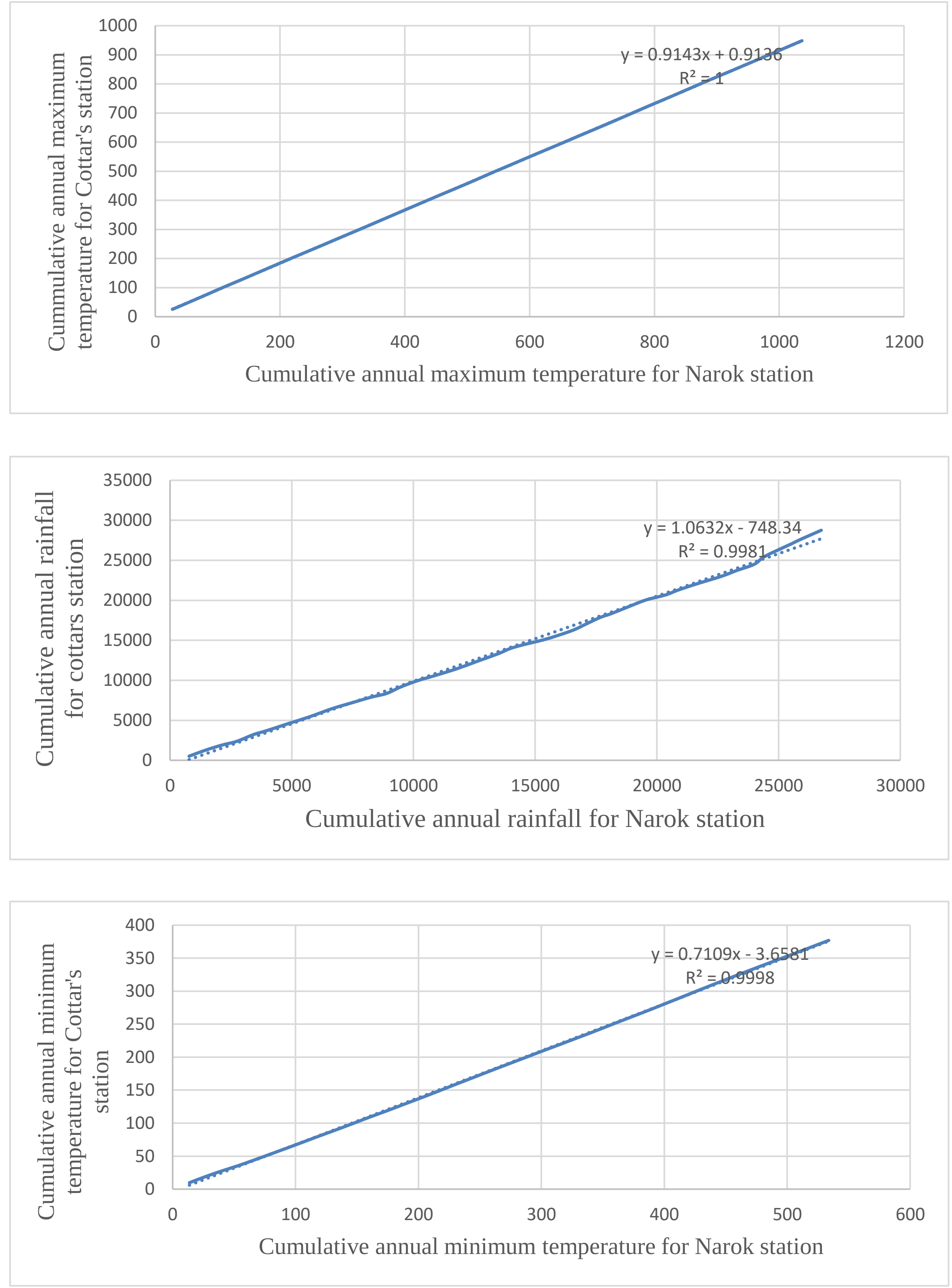

**Figure 133: Double mass curves for Cottars' stati**