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ASSESSMENT OF METEOROLOGICAL DROUGHT CHARACTERISTICS IN NORTH EASTERN COUNTIES OF KENYA

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DECLARATION

I hereby declare that this is my original work and has not been presented in part or whole for any degree in this or any other University

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DEDICATION

This dissertation is dedicated to my family for their resilient prayers.

ABSTRACT

Climate has an influence on the day-to-day socio-economic development. Agriculture is a vital socio-economic sector in the North Eastern region of Kenya. In this study, the trend of past, present and future rainfall characteristics and severity of drought conditions over North Eastern Region Counties were assessed. Observed data included total monthly precipitations over the three synoptic stations spread in North Eastern counties of Wajir, Garissa, and Mandera and obtained from the Kenya Meteorological Department. Downscaled rainfall ensemble data from 8 Coordinated Regional Climate Downscaling Experiment (CORDEX) Regional Climate Models (RCMs)were also used.The spatial and temporal characteristics of rainfall were assessed based on time series analysis through determination of the trend and seasonality components of the time series. Drought severity was analyzed using Standardized Precipitation Index (SPI) for both past (1971-2015) and future (2015-2045) period. The frequency, probability and persistence of drought occurrence were also analyzed. The periodicity analysis to determine drought recurrence was done using the Single Series Fourier (Spectral) Analysis

Rainfall was noted to be bi-modal marked by March to May (MAM) and October to December (OND). Based on the observed and ensemble CORDEX models, rainfall was noted to have the highest temporal variability and affirmed by the coefficient of variability values ranging from 1.96 to 3.02 indicating variability increases significantly in RCP 8.5 to values more than the past and RCP 4.5 Wm^{-2}. Projected precipitation variability was higher in RCP 8.5Wm^{-2}, compared to the past and RCP 4.5 Wm^{-2}. SPI analysis indicated two prevailing drought conditions, namely, the mild drought with values ranging from -0.01 to – 0.99 and moderately dry condition with SPI values ranging from -1.0 to -1.49. There was a high probability of mild drought both in MAM and OND seasons in the three selected stations in the North-eastern region with Wajir recording the highest probability while the Probability for moderate drought was low at all stations. The individual drought category had a low probability for higher runs In both seasons, the probability of occurrence of a given drought characteristic decreased as the number of runs increased. The probability of occurrence of a mild drought of only a single run recorded the highest frequency in the MAM season in Wajir. In Mandera, the probability of occurrence of a mild drought of a single run recorded the highest frequency in OND season. Moderate drought conditions only recorded a single run for MAM season and no runs recorded for OND season except in Mandera. In Garissa, the probability of occurrence of a mild drought of a single run recorded the highest

frequency in OND season. The cycle observed from the spectral analysis could be grouped into 2-3 years, 2.5-3.5years, 4.5-7years, and 8-12years

SPI analysis of projected seasonal rainfall indicated drought of varying intensity based on RCPs scenarios. There was a high probability of moderate drought both in MAM and OND seasons based on RCP 4.5 and RCP 8.5 scenarios. However, Wajir recorded higher probability of moderate drought compared to the other two stations. Projected (2015-2045) drought persistence indicated that individual drought category had a low probability for higher runs. Computed conditional probability of drought occurrence indicated higher probability values based on lower run values during the MAM season compared to OND for both RCP 4.5 and RCP 4.5 scenario with the higher runs indicating lower conditional probability values. The periodicity of projected drought conditions based on RCP 4.5 could be grouped into 2 to 3 years, 4.5 to 7 years and 8 to 12 years in Garissa, Wajir and Mandera. For lower periodicity (< 3 years), Garissa and Wajir indicated a higher magnitude of the drought conditions compared to Mandera, which showed higher magnitudes for drought conditions for the periodicity of between 4 and seven years. The periodicity of projected drought conditions based on RCP 8.5 could be grouped into 2.5 to 4 years, 6 to 10 years and 10 to 15 years. Higher magnitudes were recorded for periodicity values of between 3.5 and 6 years. In general, spectral analysis based on RCP 4.5 and 8.5 indicated distinct groups of 2-3 years, 4.5-7years, and 8-12 years and thus could be attributed to a different scale of motions.

The drought analyses over the area of study varied between mild drought and moderately dry condition. Given that these are rainfall seasons and as such the conditions might worsen during other dry seasons, reducing the risks and therefore the impacts of drought are of utmost importance.

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ACRONYMS

ASAL	Arid and Semi-Arid Land
AU	Africa Union
CORDEX	Coordinated Regional Climate Downscaling experiment
CV	Coefficient of Variation
EA	East Africa
EAC	East African Community
ECMWF	European Centre for Medium-Range Weather Forecasts
ENS	Ensemble
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
GCM	Global Climate Model
GDP	Gross Domestic Product
GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
KMD	Kenya Meteorological Department
KRCS	Kenya Red Cross Society
MAM	March-April-May
NCCAP	National Climate Change Action plan
NDMC	National Drought Mitigation Centre

NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
OBS	Observations
OND	October-November-December
PDNA	Post Disaster Needs Assessment
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
QBO	Quasi Biennial Oscillation
RCM	Regional Climate Models
RCP	Representative Concentration Pathway/ Radiation Convection Pathway
SEI	Stockholm Environment Institute
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SWE	Snow Water equivalent
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
USA	United States of America
WMO	World Meteorological Organization

CHAPTER ONE
INTRODUCTION

1.0 Background of the Study

Climate has an influence on social and economic development especially in the developing countries (IPCC, 2007). Droughts and floods are significantly affected by modes of variability, small- and large-scale weather patterns, thermodynamic processes, antecedent conditions and land–atmosphere feedbacks (Ngaina and Mutai, 2013). In assessing changes in climate extremes, challenges that exist are not only as a result of invariably disruptive conditions but also the intrinsically unusual nature of these events, especially in the main sectors such as agriculture (IPCC, 2007; IPCC, 2013).

The agricultural sector in Kenya contributed to 36.6% of Gross Domestic Product (GDP), 33.2%, 29.8%, 26.5% and 24.5% in 1964-1974, 1974-1979, 1980-1989 and 1990-1995 periods respectively (FAO, 2005). Further, the FAO report indicates that the livestock sector accounted for 90% of employment and more than 95% of family incomes in Arid and Semi-Arid Lands (ASALs). Vulnerabilities of communities to impacts of climate change are made worse by very low access to basic social services such as education facilities and infrastructure and the highest incidence of poverty (about 65%). It has become increasingly hard for the livestock sector to sustain production to cope with increased demand for products due to increased fragility of the ASALs. In Kenya, the annual growth rate of livestock production (value of animals) estimates based on Food and Agriculture Organisation (FAO) reduced from 3.5% to -1.3% between 1980s and 2000s (FAO, 2005). These could be attributable to factors such as lack of farm credit and high costs of agricultural inputs, inadequate and inefficient infrastructure, insufficient funding for research and extension and inappropriate technology (FAO, 2005).

Livestock can be affected by climate either indirectly or directly with its shocks leading to devastating effects on the poor (Mcpeak, 2006). For example, indirectly influences the quality and quantity of feedstuffs such as forage, pasture, grain and the distribution and severity of livestock diseases and parasites (Seo and Mendelsohn, 2006). Direct effects of climate (humidity, air temperature, and wind speed) include the influence on animal performance regarding milk production, growth, reproduction and wool production (Houghton *et al.* 2001). A decrease in mean annual precipitation may be expected to have an adverse impact on the grassland while an increase in temperature could have a positive effect on the amount of pasture (Kabubo-Mariara, 2008). For example, the shift of forests to grassland which may lead to increased livestock products.

Droughts have significant economic and humanitarian impacts because rain-fed agriculture is the backbone of most economies in East Africa (Mwangi *et al*., 2014). Assessment of drought impacts requires the understanding of regional historical droughts as well as the behaviours on human activities during their occurrences (Naumann *et al*., 2014). Commonly used techniques in drought assessment are based on water supply indices derived from rainfall data. Currently, the planning for drought mitigation has shifted to drought risk management from disaster management because the characteristic, behaviour and expected losses due to droughts remains highly uncertain.

1.1 Statementof the Problem

Agriculture is a vital socio-economic sector in the North Eastern region of Kenya. The water deficit is often the most limiting factor for both livestock and crop production. Droughts continue to affect millions of people in Africa through their socio-economic impacts on affected areas. Droughts are recognized when they become natural disasters (Maybank *et al.*, 1995). It is different from other natural disasters mainly because of their inevitable recurrence in prone areas after every few years. They also differ by lacking sudden and quickly identified onsets and termination. Droughts vary widely in the degree of severity, duration, and aerial extent. It is worth noting that Arid and Semi-Arid Lands (ASALs) of Kenya make up more than 80% of the Country's landmass. However, it continues to be prone to harsh weather leading to the highest number of people affected by natural disasters for the last two decades (Deely *et al.,* 2010; Masinde and Bagula, 2011). In North Eastern region, the livestock sector accounts for over 60% of incomes earned through pastoral livelihoods with a total population of 1.12 million (Lewis and Sema, 2011). Notably, in Mandera and Wajir, between 40% and 70% livestock in the communities have died due to drought. Moreover, during the same period (2011), market prices for cattle decreased dramatically by up to 38% within six months (Lewis and Sema, 2011).

1.2 Objectives of the study

The main aim of the study was to assess the characteristics of meteorological droughts in North Eastern Countiesof Kenya (Wajir, Garissa, and Mandera). The following are the specific objectives;

i. To determine the spatial-temporal characteristics of rainfall in North Eastern Counties of Kenya

ii. To determine the past drought characteristics in North Eastern Counties of Kenya

iii. To determine the future drought characteristics in North Eastern Counties of Kenya

1.3 Significance of the study

Most of North Eastern Kenya lies in arid and semi-arid land making it more vulnerable to climate sensitivity due to the dependence of the communities' pastoralism. As a result, their frequent mobility, the entrenchment of land management policies, service delivery, and support to cope with weather-related disaster tends to be difficult (Onyango, 2014). Consequently, the region has experienced a weak coping mechanism towards droughts and water-related stress and thus, aggravating their vulnerability to the projected climate change. The area has experienced constant conflicts for pasture and water among clans during long periods of drought when their traditional coping strategies are rendered insufficient (Campbell, 1999; Oba, 2001). Although the primary response to mitigate drought impacts in the region involves short-term emergency relief aid (Oba, 2001, Onyango, 2014), non-food interventions to reduce vulnerability to the meteorological disasters have been noted to be more sustainable.

In planning for drought mitigation, it is important to understand the drought characteristics through drought analysis. It consists of reliable information as the primary factor in the decision-making process. Analysis of drought based only on rainfall data has been frequently utilized since, in many areas, rainfall data are more available than other meteorological or remote sensing data. There is a shift from disaster management to drought risk management (Wilhite, 2000). Notably, drought indicators characterize drought conditions and help to guide appropriate responses to reduce impacts (Steinemann and Cavalcanti, 2006). An effective drought monitoring system can deliver an early warning in a case of the drought's onset, successfully measure drought severity and spatial extent, and communicate facts to decision-making groups promptly (Hayes, 2011). The experiences of regional drought management programs can thus be used to inform the development of National Programs

1.4 Area of Study

The North-eastern Kenya lies between latitude 4^0 16’N and 0^0 29’S and between Longitude 39^0 38’E and 40^0 6’E (Figure 1-1). According to Ogallo and Anyamba (1983), falls within homogeneous rainfall zones in Kenya as they have similar temporal characteristics and receive rainfall of the same magnitude. Most of the area in this study is either arid or semi-arid rangeland with little, if any, agricultural activity.

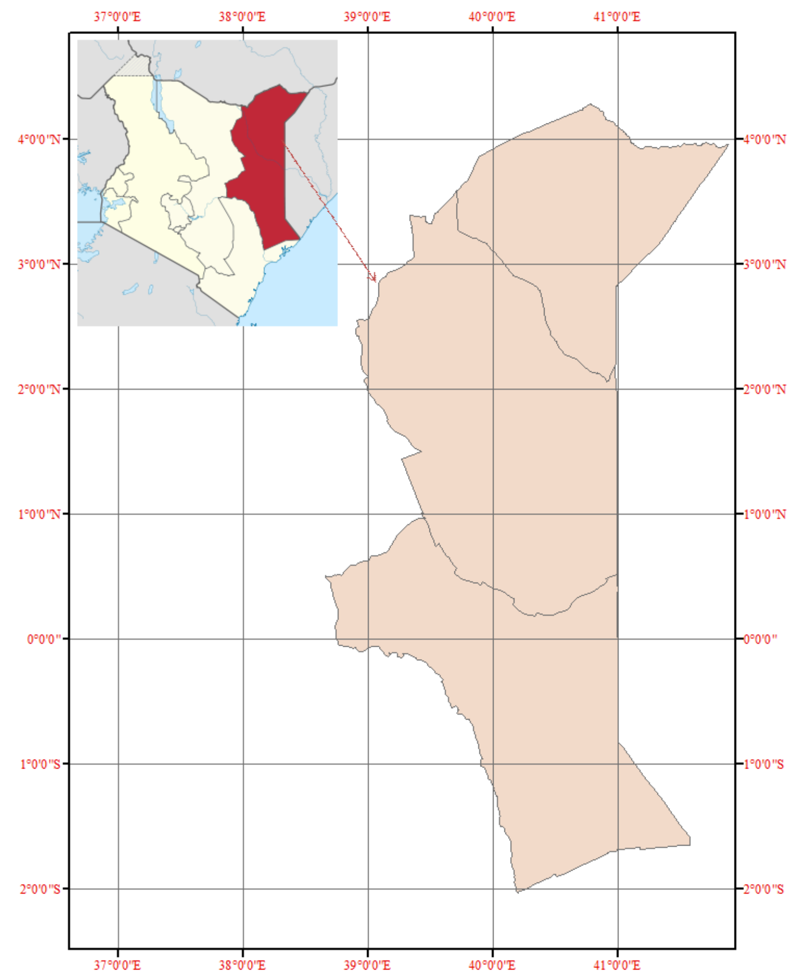

Figure 1-1: **The Location of North Eastern Region in Kenya**

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Several studies have been carried out in an effort to understand the characteristics of droughts. This section provides review of literature that are relevant to the current study.

2.1 Types of Drought

Drought is a condition on land characterized by recurring scarcity of water that falls below normal average or defined threshold levels (Wambua *et al.* 2014 a). It is a naturally reoccurring climatic variability (Altman, 2013) yet an unambiguous and precise definition of drought remains elusive (Karavitis, 1998). Due to its accumulating impacts over time and slow onset, drought remains the most devastating but least understood weather phenomena, (Opiyo et al., 2015). Moreover, drought lasts for extended periods of time and distresses large areas. Presently, droughts are expected to increase in severity and frequency and thus to impact environmental, social and economic sectors of vulnerable populations (IPCC, 2012).

Droughts are classified as either hydrological (insufficient surface and subsurface water resources), meteorological (lack of precipitation) or agricultural (declining soil moisture) (Hounam *et al*. 1975). The Figure 2.1 presents commonly accepted drought types occurrence and impacts sequence (NDMC, 2007). Opiyo *et al.* (2015) attribute crop failure in the North-Eastern region to lack of surface water resources, or failure of water resources systems to meet demands. Other studies define normal meteorological drought as a condition where observed rainfall is less than 75% of the climatological normal (KMD, 2010, Opiyo *et al.*, 2015). This definition is extremely crude as it gives little information about the temporal distribution of rainfall (Wilhite and Glantz, 1985). On the other hand, one could define optimal rainfall as sufficient rainfall in amount and distribution over time and space to meet the needs of specific livelihoods.

(Karavitis 1999) defines drought as “the state of adverse and widespread hydrological, environmental, social and economic impacts due to less than anticipated water quantities. Droughts are likely to increase in severity and frequency with the changing climate. In contrast to aridity, droughts affect almost all climates in the world (WMO, 2006). Although there is no universal definition of drought (Heim, 2002), the common factor is a deficit in normal precipitation over an extended period sufficient to cause adverse impacts.

Drought characteristics are critical in design, planning, and management of water resources (Kyambia *et al.*, 2014). The term "drought" and its features have been defined differently in numerous applications (Wambua *et al.*, 2014a, 2014b). However, it is a challenge to define the term quantitatively. Drought proxies include the use of indices involving precipitation deficit, soil-water deficit, low stream flow, low reservoir levels and low groundwater level. Different sectors use the terminology for various scenarios. For example, a hydrological drought occurs whenever the river or groundwater levels are relatively low. Besides, water resources drought happens when basins experience low streamflow, reduced water reservoir volume, and groundwater levels.

Impacts are the primary ways to measure drought severity. Based on the implications, the WMO defines four major drought types: agricultural, meteorological, socio-economic and hydrological. Notably, all droughts result from a deficiency of precipitation and begin as meteorological drought. Other types of drought and their impacts cascade from meteorological drought to other forms (WMO, 2006).

The ability of societies to reduce drought effects and build resilience is a significant grave concern on a global level. The WMO and other United Nations agencies promote an implementation of National Development Plan (NDP) that will provide insight into science-based actions useful to address key drought issues (WMO and UNCCD, 2012). Such policies are intended to engender cooperation and coordination at all levels of government to enhance their capacity in coping with extended periods of water scarcity (Sivakumar *et al.*, 2011).

An effective drought monitoring and early warning system is a way to prevent or reduce drought impacts. An effective drought tracking system can deliver an early warning in a case of the drought's onset, successfully measure drought severity and spatial extent, and communicate facts to decision-making groups promptly (Hayes, 2011). The experiences of regional drought management programs can thus inform the development of National programs.

According to Wondie and Terefe (2016), drought index is a variable which characterizes droughts on their intensity, duration, and severity at a given location and time. An index should, therefore, be able to quantify drought for a variety of time scales to address different kinds of drought phenomena, e.g. meteorological and hydrological drought

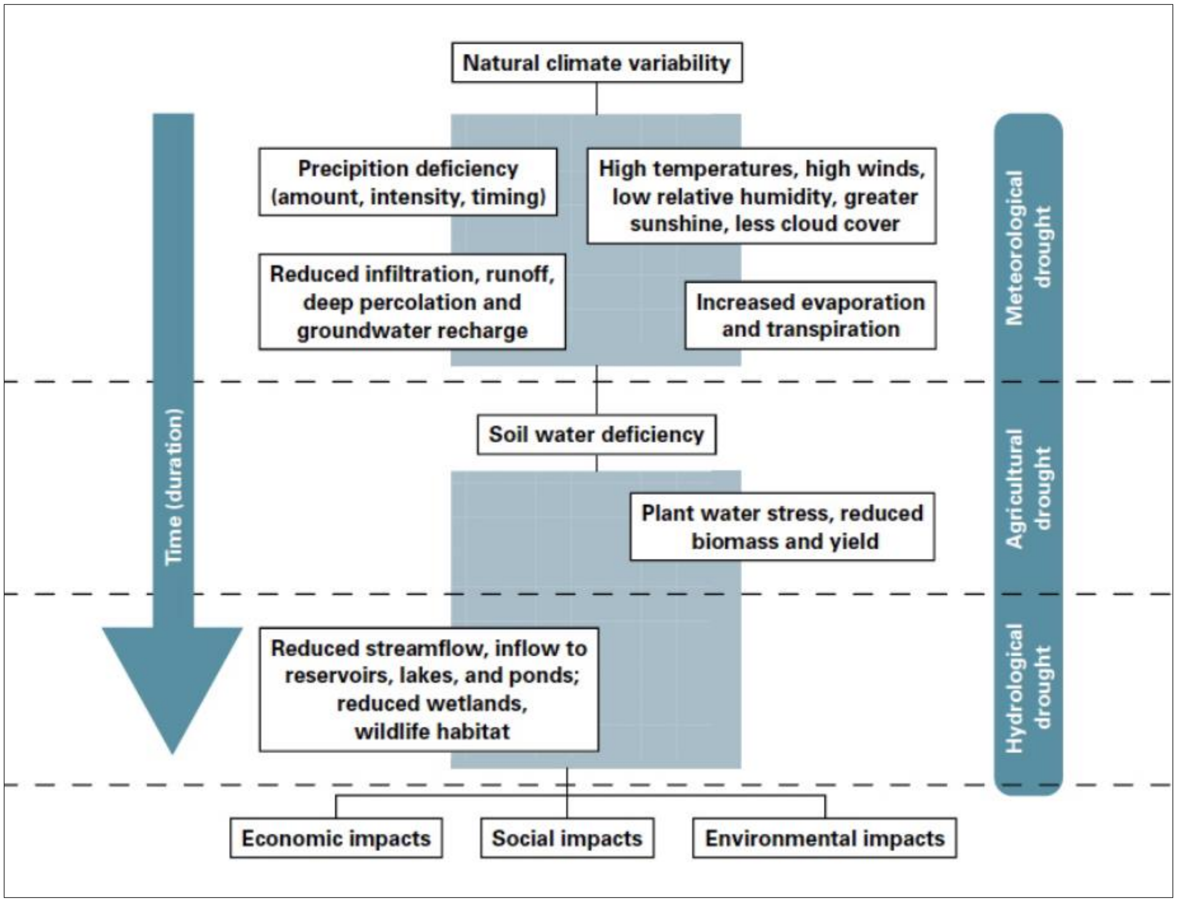

Figure 2-1: Commonly accepted drought types occurrence and impacts sequence (NDMC, 2007)

2.2 Drought Monitoring and Prediction

Various drought indicators are used as a proxy for different types of drought (Aghrab *et al.*, 2008). Droughts can develop quickly in some climatic regimes, but usually require a minimum of two to three months to become established. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity and the duration of the event. There are many tools to identify drought characteristics. The choice depends on the hydro-climatology of the region, the type of drought, the vulnerability of the society, the purpose of the study and the available data. The lack of a standard definition, making this choice is subjective (Hisdal *et al.,* 2004). The primary attributes that determine drought and surface water supply include snow water equivalent (SWE), precipitation (P), soil moisture and potential evapotranspiration (PET) (Wolf, 2012). Not only do the timing and duration associated with drought matter but also the amount of rainfall associated with them.

Among other things, drought prediction plays a critical role in the planning and management of the now scarce water resource. Drought indicators commonly computed include severity, duration, the location of the drought in absolute time (initial and termination time points), magnitude/density of the drought calculated by getting the ratio of severity to duration and area of affected by drought (Panu, 2002). According to Byun and Wilhite (1999), studies on drought are aimed at understanding the causes of droughts, describing and understanding of the impacts of droughts, looking at the frequencies and severity of droughts, looking at responses, appropriate mitigation, and preparedness strategies. Notably, this research focuses on a reduction of the impacts associated with drought. Therefore, the current study puts more focus on severity, duration, frequency, persistence and probability of occurrence.

The impact of drought on society and agriculture is a real issue, but it is not easily quantified (Shukla, 2007). Reliable indices to detect the spatial and temporal dimensions of drought occurrences and its intensity are necessary to assess the impact and also for decision-making and crop research priorities for alleviation (Seiler *et al.,* 1998). The development and advancements in space technology, to address issues like drought detection, monitoring and assessment have been dealt with very successfully and helped in the formulation of plans to deal with this slow onset disaster. Drought can be detected four (4) to six (6) weeks earlier than before with the help of environmental satellite, and delineated more accurately. Therefore, its impact on agriculture can be diagnosed far in advance of harvest in support of operational decision in global food security and trade (Kogan, 1990).

There is no uniform method to characterize drought conditions, and there are a variety of drought indices used as tools to monitor meteorological drought (Quiring 2009). The input variables required for the calculation of meteorological drought indices vary depending on the drought index in question but include precipitation, temperature, available water-holding capacity of the soil and others that are representative of the moisture in the system. Drought indices such as

Standardized Precipitation-Evapotranspiration Index (SPEI) (Vicente-Serrano *et al.* 2010) and Standardized Precipitation Index (SPI) (McKee *et al.,* 1993) have been developed to accommodate the multi-scalar properties of drought that are applicable and temporally flexible to different types of drought.

Numerous previous studies have evaluated the utility of drought indices to track measured hydrological, agricultural, ecological indicators (Ellis et al., 2010; van der Schrier *et al.*, 2007). A study by Altman (2013) has also reviewed numerous studies on drought indices. This study adopts SPI to assess the drought severity, duration, frequency, persistence, and the probability of occurrence.

The use of SPI to monitor the 1996 drought in the United States of America showed that the onset of the drought could have been detected one month in advance of the Palmer Drought Severity Index (PSDI) (Hayes *et al.*, 1999; Rouault and Richard, 2003). Using SPI index one can develop the climatology of the spatial extension and intensity of droughts which provides a further understanding of its characteristics and an indication of the probability of recurrence of drought at various levels of severity.

Ji and Peters (2003) undertook a study relating to assessing vegetation response in the northern Great Plains using vegetation and drought indices. The study focused on the relationship between NDVI and SPI at different time scales, the response of NDVI to SPI during different time periods within a growing season and regional characteristics of the NDVI-SPI relationship. It was found that the 3- month SPI has the highest correlation to the NDVI because the 3- month SPI is best for determining drought severity and duration. Also, it was found that seasonality has a very significant effect on the relationship between the NDVI and SPI.

Recent research has shown that the SPI has many advantages over the PDSI and other indices in that it is relatively straightforward, spatially consistent, and temporally flexible, thus allowing for observation of water deficits at different scales (Hayes *et al.*, 1999). Therefore, SPI can be used as the reliable agent for detecting emerging drought and valuable tool for assessing moisture condition and initiating mitigation and response actions.

Despite the advancements in computer technology (for example, availability of powerful computers) and simulation algorithms/models, scientists are only able to provide indications of drought trends and never the actual values. (Me-Bar 2003) argue that droughts be random events (not deterministic) and compare them to ancient cultures which consider drought as an 'acts-of-gods'. Models for predicting drought duration are more developed; however, those for predicting drought severity are still fraught with great difficulty and yet the latter is of paramount importance.

2.3 Overview of Drought Indices

Several studies have reviewed the use of drought indices as proxies for drought. These include Alley (1984), Wu *et al.* (2005), Hayes (1999), Heim (2002), Wilhite and Glantz (1985), Friedman (1957), Palmer and Denny (1971) and the WMO (1975a,b, 1985). Other Initial studies include Hasemeier (1977), Wilhite and Hoffman (1980), Wilhite and Wood (1983), NOAA (1989) and Frick *et al.* (1990). This subsection reviews basic uses, advantages, and disadvantages of drought indices

2.3.1 Palmer Drought Severity Index

Palmer developed the PDSI in 1965 and now one of the most widely used drought indicators (Alley, 1984). It is a useful index for meteorological and agricultural drought. This index allows for the comparison of drought with different time and spatial scales. It is a soil moisture drought index that works well with vast areas of uniform topography. Table 2.1 lists categories of the PDI that range from wet conditions in positive values and dry conditions in negative values. According to Alley (1984), the main advantages of this index include its ability to measure the abnormality of recent weather, provision of spatial and temporal representations of historical droughts, comparison of current conditions in historical perspective. Karl and Knight (1985), Alley (1984) and McKee et al. (1993) discussed the weaknesses of the PDSI. These included the fact that it does not give accurate results in winter and spring due to the effects of frozen ground, take into account streamflow, longer-term hydrologic impacts, lake and reservoir levels, and snow. Moreover, it tends to underestimate runoff conditions.

Table 2-1: Palmer Drought Index classes (Source: Altman, 2013)

Palmer Drought Index Classes			
≥ 4.0	Extremely wet	-0.5 to -0.99	Incipient dry spell
3.0 to 3.99	Very wet	-1.0 to -1.99	Mild drought
2.0 to 2.99	Moderately wet	-2.0 to -2.99	Moderate drought
1.0 to 1.99	Slightly wet	-3.0 to -3.99	Severe drought
0.5 to 0.99	Incipient wet spell	≤-4.0	Extreme drought
0.49 to -0.49		Near normal	

2.3.2 Palmer Hydrological Drought Index

The (PHDI) was developed by Palmer and very similar to the PDSI and derived from an additional term of the PDSI calculation (Altman, 2013). The PHDI is a method to calculate hydrological droughts based on evaporation and precipitation. It quantifies the long-term cumulative impact from wet conditions and hydrological drought which accurately reflects reservoir levels and groundwater conditions (Heim, 2002). The PHDI is a slow changing response for drought.

2.3.3 Palmer Z-Index

The Palmer Z-index shows short-term soil moisture droughts and wetness with the soil moisture anomaly on a monthly scale (Alterman *et al*., 2013). The Z-index has the same disadvantages and advantages as the PDSI (Hayes 1999). However, the Z-index responds faster to changes in soil moisture values. This index, in comparison to other analyzed indicators, has a higher frequency of indicating a drought and indicates short duration droughts more often.

2.3.4 Standardized Precipitation Index

The Standard Precipitation index (SPI) (McKee *et al.*, 1993) was designed to quantify precipitation deficits for multiple time scales. Notably, soil moisture conditions respond to precipitation anomalies on a relatively short scale, while reservoir storage, streamflow, and groundwater shows longer- term precipitation anomalies (Hayes 1999). Its standardization allows the SPI to determine the frequency of a current level of drought, as well as the probability of precipitation necessary to end the current drought (McKee *et al.* 1993). The use of different time scales (3-, 6-, 12-, 24-, and 48-month) allows for the assessment of the effects of a precipitation deficit on various water resource components (groundwater, reservoir storage, soil moisture, streamflow) (McKee *et al*., 1993). The index ranges from positive to negative values and measures dry and wet conditions (Table 2.2).

The SPI provides early warning of drought and its severity as it specifies drought conditions for each location and is well suited for risk management. The advantages of SPI are the use of longer timescale to approximate of groundwater and streamflow droughts (Hayes, 1999). However, the limitations of the index include the possibility of trends in precipitation and adequate observed data during this period (Hayes, 1999). The Lincoln Declaration on Drought Indices, the result of WMO's the Inter-Regional Workshop on Indices and Early Warning Systems for Drought, recommends the SPI for widespread use in countries to track meteorological drought (Hayes *et al*. 2011).

Table 2-2: Standard Precipitation Index Categories (Source: Altman, 2013)

SPI Values	
≥2.0	Extremelywet
1.5 to1.99	Verywet
1.0 to1.49	Moderatelywet
-.99 to.99	Nearnormal
-1.0 to-1.49	Moderatelydry
-1.5 to-1.99	Severelydry
≤-2	Extremelydry

2.3.5 Crop Moisture Index

Palmer, (1968) developed the CMI as a short-term soil moisture drought index to monitor week-to-week crop conditions (Table 2.3). It is not intended to assess long-term droughts. This index is calculated similarly to the Palmer Z-index and based total precipitation, the mean temperature for each week as well as the CMI value from the previous week within a climate division (Hayes, 1999). The CMI responds rapidly to changing conditions. It is suited for summer drought predictions and limited only during the growing season. Its main advantage involves early detection of drought than the PDSI and the PHDI. However, the Crop Monitoring Index fast response to changes in the short-term conditions may present a misleading output on long-term conditions (Hayes, 1999).

Table 2-3: Crop Moisture Index Classes (Source:Palmer1968)

CMIClasses	
≥3.0	Excessive wet,some fields flooded
2.0 to2.99	Too wet,standing water in some fields
1.0 to1.99	Prospects good, but fields too wet
0.0 to0.99	Moisture adequate for immediate needs
0.0 to-0.99	Conditions improved but need more rain
-1.00 to-1.99	Prospects improved but still only fair
-2.00 to-2.99	Drought eased,but more rain needed
≤-3.0	Situation serious, rain badly needed

2.3.6 Keetch-Byram Drought Index

Keetch and Byram in 1968 (Melton, 1998) developed the KBDI for use by fire control managers to meteorological drought. The daily index uses precipitation and soil moisture analyzed in a water budget model. The index increases for each day without rain (Table 2.5) and decreases when it rains. Other weather factors, such as atmospheric stability, the wind, relative humidity and temperature, play a major role in determining the actual fire danger.

Table 2-4: Keetch-Byram Drought Index Categories (Source: Melton 1998)

BDI	Class
0 to 150	Upper soil and duff layer are very wet during this stage and do not contribute to the fire very much.
150 to 300	Pine and hardwood stumps can ignite in this stage but the fire hardly goes below ground. Snags may cause escaped fires but can be controlled by standard control tactics. More attention is needed when the KBDI levels are close to 300.
300 to 500	Fire intensity at this stage increases significantly. If the KBDI exceeds 350, all the planned winter and spring understory fire should be cancelled.
500 to 700	In this stage, fire behavior tends to become unpredictable and more urban interface type fire starts to occur. Summer site preparation burns should be cancelled. Severe wind condition aggravates the fire.
≥700	Urban interface fires become a major cause of wildfires. Every burning activity should be prohibited until the KBDI levels go down below 500.

2.4 Strengths and Weaknesses of Drought Indices

Table 2.5 summarizes relative strengths and weaknesses of drought indices. It is important to mention that drought indicators have different temporal variability. Although most of the drought indices are computed on a monthly scale, the CMI and the USDM are calculated weekly and the KBDI daily. The weekly drought indicators respond to wet and dry spells more frequently and can measure strengthening drought conditions faster, than slow-changing indices, such as PDSI and PHDI**.**

Table 2-5: Overview of Major Drought Indices (Source: Altman, 2013)

Drought Index	Who and When	Strengths	Weaknesses
PDSI Monthly	1965 by W.CPalmer	Soil moisture index and good indicator for meteorological and agricultural drought; Places current conditions in historical perspective; Provides spatial and temporal representations of historical droughts	Does not take into account lake and reservoir levels, streamflow, longer-term hydrologic impacts and tends to underestimate runoff conditions
PHDI Monthly	1965 by W.CPalmer	Quantifies the long-term cumulative impact, more accurately reflects ground water conditions, reservoir levels, etc.	Changes slowly than the PDSI and Slow response to drought
Z-Index Monthly	1965 by W.CPalmer	Same advantages and disadvantages as the PDSI	Responds faster to changes in soil moisture values. Drought is declared more often with shorter duration of the
SPI Monthly	1993 by McKeeetal.	Longer time scale sometimes used as an approximation of stream flow and groundwater droughts	Need for along observed time series of data; possibility of trends in precipitation during the period

CMI Weekly	1968 by W.C.Palmer	CMI responds rapidly to changing conditions, can detect drought sooner than the PDSI and the PHDI; Suited for summer drought prediction	Can only be used in the Growing season; Not intended to assess long-term droughts
USDM Weekly	1999 US Agencies	Reflecting the collective best judgment of many experts based on several indicators	Show drought at several temporal scales (from short-term drought to long-term drought) on one map
KBDI Daily	1968 by J.Keechand G. Byram	Forest fire potential assessment for forestfires	Not precise in detecting drought, because more than just deficiency of precipitation influences forest fires

A wide range of available drought indices has their advantages and disadvantages, calculated on different time scales, effective for specific locations (PDSI for areas with uniform topography) or during specific periods (CMI for growing period). No single indicator or index can represent the diversity and complexity of drought effects (Hayes *et al*. 2005; Mizzell 2008), and that is why it is useful to use multiple indicators when monitoring drought conditions to deliver appropriate drought response and to reduce the impacts (Botterill and Hayes, 2012).

Previous research focused on identifying the most suitable drought index to measure drought. Vicente-Serrano *et al*. (2012) compared drought indicators ability to measure drought on a global scale. Keyantash and Dracup (2002) ranked drought indices regarding the usefulness of drought severity assessment. The Lincoln Declaration on Drought Indices aimed to develop standards for drought indices and guidelines for a drought early warning system. The declaration was a result of the Interregional Workshop on Indices and Early Warning Systems of Drought, sponsored by the WMO, other UN agencies with NDMS, NOAA, and other prominent organizations. The workshop came to the consensus that the Standardized Precipitation Index (SPI) should be used to characterize the meteorological droughts around the world. As for agricultural and hydrological drought, no specific index was selected for each of these drought types (Hayes *et al*. 2011). The document emphasized the need for coordination between data monitoring agencies to facilitate effective decision-making.

Drought monitoring system is a “cornerstone” of effective drought management (Wilhite and Buchanan-Smith 2005), information provided by drought index is essential for risk management. It is important to be aware of strengths and weaknesses of each drought index when evaluating drought conditions, especially for drought decision-makers, who often don’t know about specifics of each index (Steinemann and Cavalcanti 2006; Mizzell 2008).

2.5 Impacts of Droughts

Direct impacts of drought include death/malnutrition in animals/humans, decline in food yield, forest and greenbelt; worsening water/air quality and sanitation; and higher fire prevention risk. Indirect effects include price upsurge; reduction of income; loss of jobs; and degradation of living standards among others (Kung et al. 2006). Droughts accounted for 50% of the 2.8 billion people affected by natural disasters between 1967 and 1992 (Mishra, 2006). The study by Mishra, (2010) showed that among all the natural disasters, droughts have the most impact on a country‘s economy.

Drought occurrence has become increasingly severe in the Horn of Africa during the last decade (Opiyo *et al.*, 2015). Notably, total rainfall of at least 50–75 % below normal encountered in most areas remains insufficient to support pasture and crop growth for livelihood security (Nicholson 2014). Kenya has experienced an increase in drought frequency from once in every ten years in the 1960s/70s to once in every five years in the 1980s (Huho and Mugalavai, 2010; Nkedianye *et al*., 2011). Moreover, the frequency of drought increased to once in every two to three years in the 1990s and increasingly unpredictable since 2000.

IPCC (2012) noted that there is likely to be a significant increase in drought risk in Eastern Africa (EA) towards 2050s and ultimately threaten climate-sensitive economic sectors. Populations whose livelihoods depend principally on natural resources are mostly affected by drought (Below *et al.* 2010; Nicholson 2014). Kenya’s ASALs continue to encounter increasingly higher drought intensity and frequency since the 1960s (Nkedianye *et al*. 2011). However, the pastoral economy in the ASALs of Kenya accounts for 95 % of family income and livelihood security and 90 % of all employment opportunities (Kenya ASAL Policy, 2012). Given the changing global climate, coupled with expected increase in evapotranspiration due to increased temperatures, the ASALs are projected to experience frequent climatic extremes, increased aridity, increased water stress, and diminished yields from rain-fed agriculture, and increased malnutrition and food insecurity (Thornton and Lipper, 2014).

In Kenya, the worst drought in the last one hundred years occurred in 1999-2001 resulting in the death of approximately 60-70% of livestock, drying up of water resources, loss of goods and services, massive crop failures, severe environmental degradation (Julius and Kosonei, 2014). Maize yields dropped from 2.5 to 0.5 tons/Ha in Narok County while Kajiado County registered livestock mortality of more than 20% for goats and 50% for cattle. According to UNEP and GoK (2006), a total of US $ 340 million was used to provide assistance to people affected. The 1983-84 droughts severely affected both crop farmers and pastoralists.

In the arid Wajir, West Pokot and Mandera Counties, the 1991-92 extreme droughts resulted in total loss of livestock by 70% of the pastoralists (Ngaira, 1999; Ngaira, 2005). North-eastern Kenya bore the burden of the 2005-2006 drought condition resulted to loss of 30-40% of livestock. Pressure on resources triggered not only conflicts and destitution but also mass migration (Grünewald *et al*., 2009). In 2011, drought in Kenya led to the GoK declaring it a national disaster.

Compared to other natural disasters such as floods, hurricanes, earthquakes and epidemics, droughts are tough to predict; they creep slowly and last longest. The complex nature of droughts onset-termination has made it acquire the title ―the creeping disaster (Mishra, 2010). There is much uncertainty in determining when a drought begins or ends because of this creeping nature. It develops slowly, and its impacts form a complex web that spans all aspects of the life of the affected society. Hypothetically, drought prediction tools could be used to establish precise drought development patterns as early as possible and provide sufficient information to decision-makers to prepare for the droughts long before they happen. This way, the prediction can be used to mitigate effects of droughts. To accurately predict all the dimensions of a drought, one would be required to measure a battery of complex atmospheric and oceanic variables both local (to the location) and global.

Studies show that drought poses serious challenges for populations whose livelihoods depend principally on natural resources (Below *et al.* 2010; Nicholson, 2014). Kenya's ASALs have faced increasing drought intensity and frequency since the 1960s (Nkedianye *et al*. 2011). Given the expected increase in evapotranspiration due to increased temperatures, coupled with the changing global climate, the ASALs are projected to experience frequent climatic extremes, increased water stress, diminished yields from rain-fed agriculture, increased food insecurity, and malnutrition and increased aridity (Thornton and Lipper, 2014).

The adaptation strategies of pastoral communities to changing environmental conditions have been studied for decades (Opiyo *et al*., 2015). Further, the livelihoods of most pastoralists have evolved to some extent under variable climatic conditions in arid and semiarid environments. The African Union (2010) reports that pastoralism has ‘‘evolved over generations as a response to marked rainfall and temperature variability”. Mobile and flexible pastoralism has great potential for reducing poverty, managing the environment, generating economic growth and promoting sustainable development.

Other researchers have shown that pastoralists have an intimate relationship with their environment and a rich knowledge that enables them to both exploit the changing rangeland conditions and protections (McGahey *et al.* 2008; Notenbaert *et al.* 2012). To understand how pastoral communities cope and adapt to extreme climatic conditions, particularly drought, becomes even more important as pastoralism in north-western Kenya already faces environmental, political, and socioeconomic marginalization (Schilling *et al*. 2012).

In Kenya, the pastoralist communities are still food insecure groups experiencing consistently high malnutrition rates above international emergency thresholds (Corbett and Chastre, 2007) especially during drought episodes of 2001, 2003, 2006, 2009 and 2011 (Fitzgibbon, 2012). The regular and periodic droughts have major socio- economic impacts, including reduced economic growth. The Government of Kenya's Post-Disaster Needs Assessment (PDNA) for the extended 2008-2011 drought period estimated the losses to the Kenyan economy at Ksh 968.6 billion (US$12.1 billion). The livestock sector accounted for 72 percent of damage and losses (GOK, 2012). The estimated economic impact of the drought was a slowing down of the country's economic growth by 2.8% per year (GOK, 2012).

The regularity of drought events and the subsequent recovery period means Kenya is expected to incur substantial economic costs and reduced long-term growth every 3 to 4 years. The Stockholm Environment Institute’s study estimated that existing climate-related shocks cost Kenya as much as US$0.5 billion per year (SEI, 2009). The prospect of the persistent vulnerability of the poor and an increased risk of drought is likely to have severe impacts on people-centred development, particularly in the ASALs, where the pastoralist communities could be worst affected.

CHAPTER THREE
DATA AND METHODOLOGY

3.0 Introduction

This section describes the data and methodology used in the study.

3.1 Data

The data used in this study comprised of both observed gauge rainfall and climate model output

3.1.1 Rainfall Data

The dataset used in this study included monthly total precipitation over the 3 synoptic stations spread in North Eastern counties of Wajir, Garissa and Mandera. These datasets were obtained from the Kenya Meteorological Department, Headquarters in Nairobi spanning the period 1971 to 2015.

Table 3-1: Summary of Selected Stations used in the Study

Station Name	Station Code	Altitude (metres)	Latitude	Longitude
Wajir	8840000	253	1.8ºN	40.1ºE
Mandera	8641000	230	4.3ºN	40.1ºE
Garissa	9039000	138	0.5ºS	39.6ºE

3.1.2 Regional Climate Model Data

In this study daily rainfall ensemble data from 8 CORDEX RCMs were used. The Regional Climate Models are driven by surface and lateral boundary conditions from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Re-Analysis. The downscaled data are available for the period 1980-2010 and 8 GCMs over the Africa domain, for both RCP4.5 and RCP8.5 and running in the transient mode for the period 1951-2100. All simulations were performed at 50km (0.448) resolution over the EAC domain. Table 3-1 presents a full list of the RCMs used (with full expansions) and the details of their dynamics and their physical parameterizations. More information on model output can be obtained from Nikulin *et al*. (2012).

Table 3-2: List of CMIP5 GCMs used in the Study

Institute name	**GCM name**	**Calendar**
CCCma (Canada)	CanESM2	365 days
CNRM-CERFACS (France)	CNRM-CM5	Standard
MOHC (UK)	HadGEM2-ES	360 days
NCC (Norway)	NorESMI-M	365 days
ICHEC (Europe)	Ec-EARTH	Standard
MIROC (Japan)	MIROC5	365 days
NOAA-GFDL (USA)	GFDL-ESM2M	365 days
MPI-M (Germany)	MPI-ESM-LR	Standard

3.1.3 Data Quality Control

The climate data were subjected to a quality control procedure primarily with the purpose of identifying outliers in the time series. Data consistency was also checked by comparing the data records amongst themselves and with that of neighbouring stations. Short-Cut Bartlett Test was used. The method is useful in testing the constancy of variability in a time series; it is applied by dividing the series into k equal sub-periods, where k≥2. In each of these sub-periods, the sample variance, S_k^2 is given by Equation 3.1

$$S_k^2 = \frac{1}{n}\left[\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2\right] \qquad 3.1$$

where the summations range over the n values of the series in the sub-period k and x represents individual values to be tested.

The largest and smallest values of S_k^2 are selected and denoted as S_{max}^2 and S_{min}^2 respectively. The 95% significance points for the ratio S_{max}^2/S_{min}^2 is obtained by comparing this ratio with the values in the F-distribution table (tabulated). The null hypothesis is rejected if the calculated F-value is less than the tabulated value.

3.2 Methodology

3.2.1 Spatial-temporal Characteristics of Rainfall in North Eastern Counties of Kenya

The spatial and temporal characteristics of rainfall were assessed based on time series analysis through determination of the trend and seasonality components of the time series.

3.2.1.1 Trend Analysis

The trend component of the time series was determined using Mann-Kendall rank statistic to detect abrupt changes rainfall. The test has been found to be most appropriate for the analysis of series that show a significant trend, to locate the period with the trend (Sneyers, 1990). The Mann-Kendall rank statistic is considered the most appropriate for the analysis of climatic changes in climatological time series for the detection of a climatic discontinuity (Sneyers, 1990; Chrysoulakis *et al.*, 2002).

To perform a Mann-Kendall test, compute the difference between the later-measured value and all earlier-measured values, ($y_i > y_j$), where j > i, and assign the integer value of 1, 0, or –1 to positive differences, no differences, and negative differences, respectively. The test statistic, S, is then computed as the sum of the integers:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \qquad 3.1$$

Where $sign(y_j - y_i)$, is equal to +1, 0, or -1 as indicated above.

When S is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. The test statistic τ can be computed as:

$$\tau = \frac{S}{n(n-1)/2} \qquad 3.2$$

which has a range of –1 to +1 and is analogous to the correlation coefficient in regression analysis.

3.2.1.2 Seasonality Analysis

Coefficient of Variation (CV) was used to indicate temporal variability of rainfall and measures the dispersion of the data in a series around the mean computed as shown in Equation 3.3.

$$CV = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \acute{x})^2}}{\acute{x}} \qquad 3.3$$

where N is the sample size, x_i is the selected variable and $\acute{x}$ is the mean

3.2.2 Drought Characteristics

3.2.2.1 Drought Severity and Duration

Drought severity was analysed using SPI for both past (1971-2015) and future (2015-2045) periods. Standardized precipitation series are calculated using the arithmetic average and the standard deviation of precipitation series (McKee *et al*., 1995). SPI is calculated from Equation (3.4):

$$SPI = \frac{X_{ij} - X_{\mathfrak{J}}}{\sigma} \qquad 3.4$$

where, $X_{ij}$is the seasonal precipitation at the i^{th} rain-gauge station and j^{th} observation $X_{\mathfrak{J}}$ is its long-term seasonal meanwhile σ represents the standard deviation. Positive values stand for wet events (precipitation excesses) while negative values obtained from this equation will indicate drought events (precipitation deficits). It was assumed that the occurrence of drought of any intensity (moderately dry or mild drought) in a given year implies the occurrence of drought across the region for that specific year.

3.2.2.2 Frequency and Probability of Drought Occurrence

The conditional probability (if a drought occurs, it will continue for a duration) used in prediction of drought occurrence. Equation 3.5 a shows the probability P’ *(L, i*) of drought occurence

$$P'(L,I) = \frac{F_L I}{N} \qquad 3.5a$$

Where N represents number of observation while the frequency of the drought of category L for the month I is represented by $F_L I$. In each drought category, drought (duration) of run length m (m months) can be described as the series of m months of that drought category preceded and followed by a different category and expressed in Equation 3.5b

$$F_L = \sum_{m=1}^{mm} F_{Lm} \qquad 3.5\,b$$

The expression for frequency F_{Lm} of drought at F_{LM1} at m_1 runs of category L is expressed in Equation 3.6

$$F_{LM1} = F_L - \sum_{m=1}^{m_1-1} F_L \qquad 3.6$$

Where

$$F_{LM1} = \sum_{m=1}^{mm} F_L \qquad 3.7$$

The frequency F_{dm} will refer to the frequency of a run of m months of drought. Therefore,the frequency of at least one month of drought F_{dm} is given in Equation 3.8

$$F_d = \sum_{m=1}^{mm} F_{dm} \qquad 3.8$$

The frequency $F_{dm1}$of at least $m_1$months of drought

$$F_{dm1} = F_d - \sum_{m=1}^{m_1-1} F_{dm} \qquad 3.9$$

The frequency gives useful information about how frequent drought of various lengths occurs.

3.2.2.3 Persistence

Effects of drought are severe if it extends over many months or even seasons. Using month above average and month below average, a logarithmic expression is derived between the run length m of the dry and wet month and frequency F_m. The relationship is in Equation 3.10

$$log(F_m) = (logT + 2logq) + mlogP \qquad 3.10$$

Where

P probability of dry month

q probability of wet month

T period of observation in months

A similar expression for frequency of at least m consecutive months of drought F_m is given by

$$\log(F_m) = (logT + logq) + mlogP \qquad 3.11$$

The probability of occurrence of m consecutive dry months φm

$$\varphi m = q^2 P^m \qquad 3.12$$

Therefore, the probability of at least m number of consecutive dry months is expressed in Equation 3.13

$$\varphi m = qP^m \qquad 3.13$$

Where, $P = \frac{No.of\ dry\ months}{Total\ No.of\ months\ of\ observation}$, and $q = 1 - p$

Values of φm describe the degree of persistence and hence indicate the probability of obtaining at least m consecutive drought months.

Persistence ratio $r_p$is of the form

$$r_p = \frac{1 - P(L)}{1 - P'(L)} \qquad 3.14$$

Where $P'(L)$ is the probability that a drought occurs immediately after another one of the category while $P(L)$probability of occurrence of given a category. Therefore, we have

$r_p > 0$ Persistence of drought

$r_p = 0$ Alternation of drought and no drought

$r_p < 0$ No drought persistence

The current study investigated the persistence of drought conditions,comparison of relative frequency of various runs for each drought category

3.2.2.4 Periodicity

Periodicity refers to the repetitive oscillations about a trend line/curve. Periodicity analysis was done for the drought to determine their recurrence. The formula is given by Eqn (3.15a & b):

$$f_{xy} = \frac{1}{2\pi} \sum_{r=-\infty}^{\infty} e^{-i\omega r} \rho_{xy}(r) \qquad 3.15\ a$$

$$f_{(\omega)} = \frac{1}{2\pi} \sum_{r=-\infty}^{\infty} e^{-i\omega r} \rho(r) \qquad 3.15\ b$$

Where $(-\pi \leq \omega \leq \pi)\rho_{xy}(r)$is the lagged correlation while r is the lag the frequency is represented byω, the spectral density function represented by $f_{(\omega)}$ and the autocorrelationfunction represented by $\rho(r)$

CHAPTER FOUR
RESULTS AND DISCUSSION

4.0 Introduction

This results obtained in this study using the methods outlined in the preceding chapter are discussed in this section.

4.1 Data Quality Control

Homogeneity of rainfall records was tested using the Short-Cut Bartlett test. This method was used to ascertain the significance of a break by testing the seasonal rainfall time series for the stability of variance. The F-statistics value and F critical value represented the computed and tabulated F distribution sample variances respectively.

Table 4-1: Short-cut Bartlett test

Station	F-value	F-critical
Garissa	1.22	2.23
Wajir	1.17	2.23
Mandera	0.82	2.23

The results are presented in Table 4-1 for the three stations used in the study at 95% significance points. The results showed that the computed variance (F-value) was less than the tabulated variance (F critical) for rainfall records over all stations used in the study. This indicated that the variance was the same for rainfall records at each station. Therefore, the null hypothesis which stated that all factor standard deviations (or equivalently variances) were equal was accepted i.e. the rainfall records used were homogeneous against the alternative hypothesis.

4.2 Spatial-temporal Characteristics of Rainfall in North Eastern Counties of Kenya

4.2.1 Rainfall Characteristics in North Eastern Kenya

The rainfall characteristics were analysed to examine the behaviour of long-term annual rainfall distribution in the stations under study and presented in Figures 4-1 to Figure 4-3. Analysis was also based on the RCM model Ensemble (ENS) and Observations (OBS).

Table 4-2: Summary of Mean Annual Rainfall in North Eastern Region

Month	**Garissa**	**Mandera**	**Wajir**
January	20.46	2.23	11.07
February	3.25	1.22	8.18
March	39.94	20.41	27.30
April	80.49	80.22	75.89
May	17.11	38.17	32.96
June	6.09	0.40	2.58
July	4.55	1.27	2.53
August	7.32	0.53	1.46
September	5.44	1.61	2.67
October	29.16	42.90	41.36
November	89.18	45.14	63.36
December	55.02	12.01	28.80

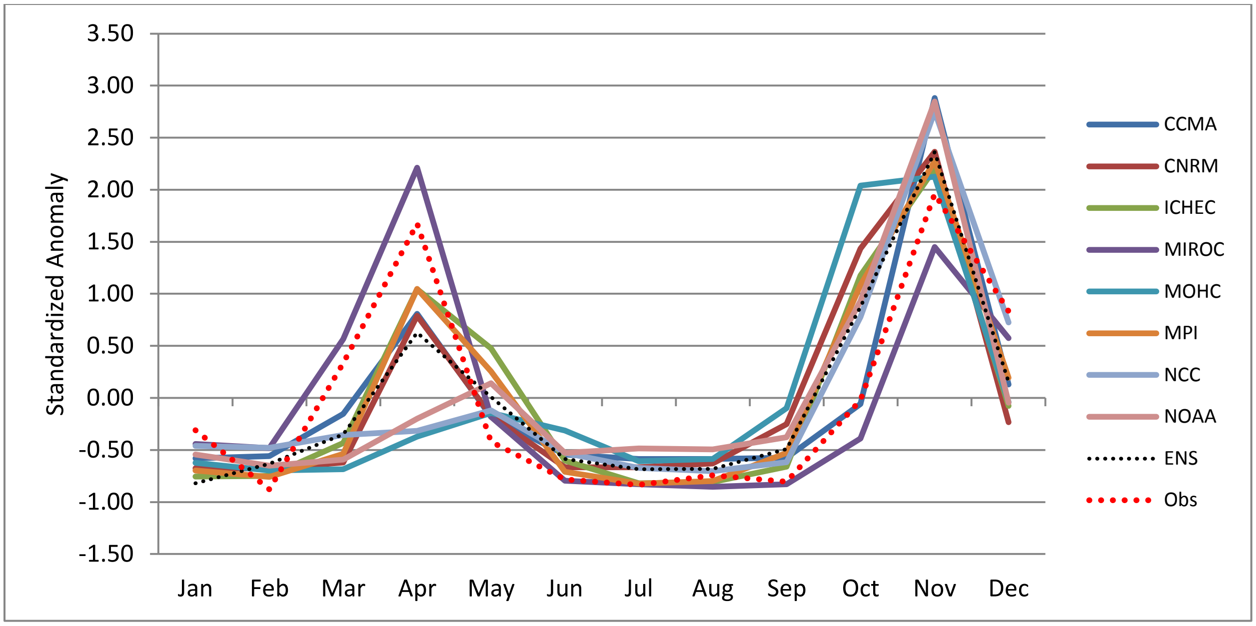

Figure 4-1: Annual rainfall distribution over Garissa.

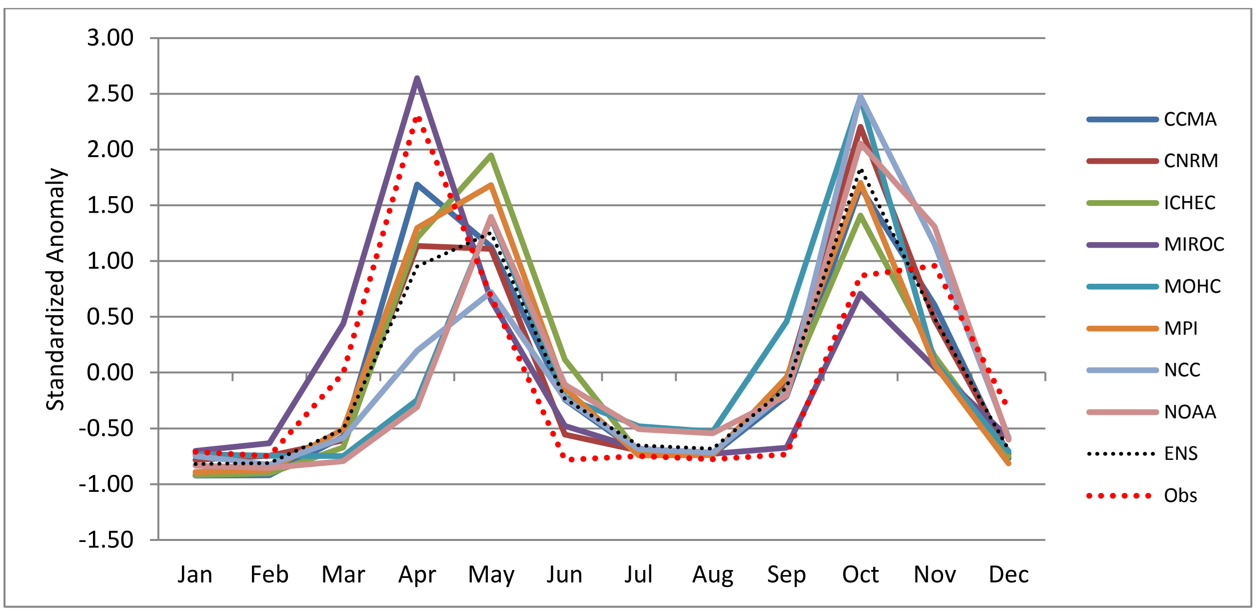

Figure 4-2: Annual rainfall distribution over Mandera

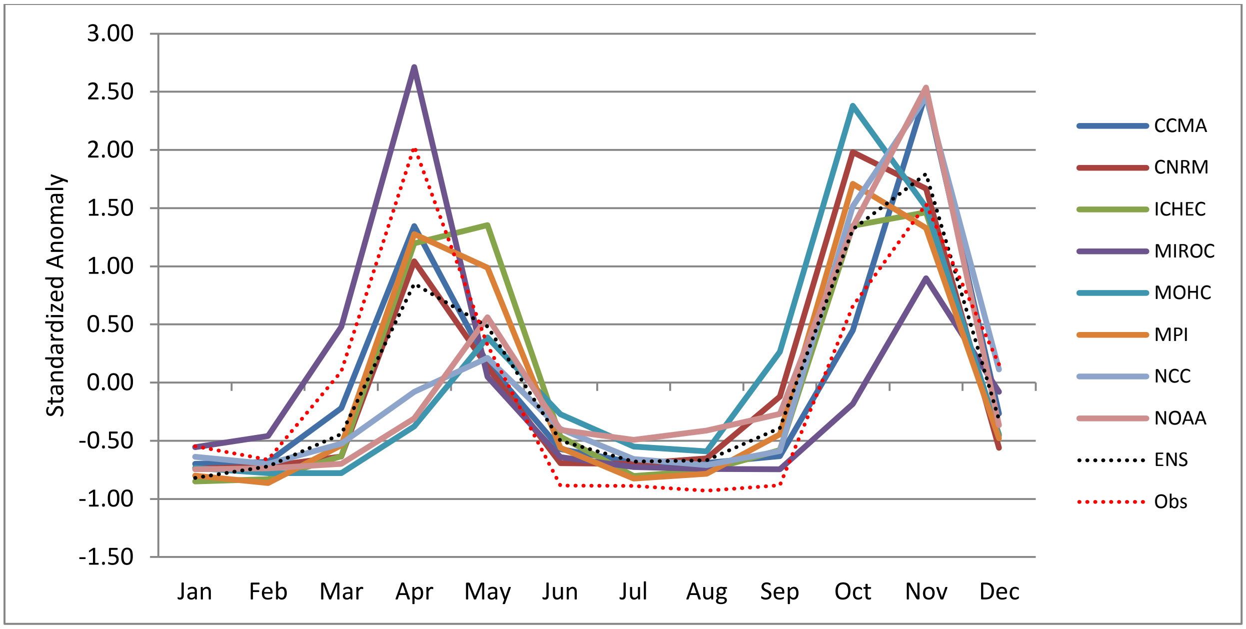

Figure 4-3: Annual rainfall distribution over Wajir.

The Figure 4-1 to Figure 4-3 shows that rainfall received in all stations was bi-modal the pattern commonly referred to as ‘short rain’ and ‘long rain.' In Figure 4-1 the long rains start from the month of March to May (MAM) while the short rains season starts from October to December (OND). In the Figure 4-2 and Figure 4-3 similar patterns of bimodal (OND and MAM) rainfall were observed in Mandera and Wajir respectively. The short rains season is related to the southern oscillation through zonal pressure gradients produced by sea surface temperature anomaly (Hastenrath *et al.*, 1993).

4.2.2 Trend Analysis

Trend of past and future rainfall based on observed and projected model (Ensemble CORDEX) output were computed and results presented in Table 4-3

Table 4-3: Trend Analysis Based on Mann-Kendall Statistic for Rainfall

Station	**1981-2010**	**RCP4.5 Wm^{-2}**	**RCP8.5 Wm^{-2}**
Garissa	0.0004	0.33	0.13
Wajir	0.0430	0.39	0.19
Mandera	0.0110	0.64	0.44

The Table 4-3 shows that computed p values for observed rainfall over Garissa, Wajir, and

Mandera stations are lower than the significance level alpha (0.05). The null hypothesis, H_0 of no change is rejected and the alternative hypothesis, Ha accepted and thus the conclusion that there has been a monotonic trend in rainfall over time. However, the computed p values based on RCP4.5 Wm^{-2} and RCP8.5 Wm^{-2} were greater than the significance level alpha (0.05) and thus the null hypothesis H_0 cannot be rejected. The risk of rejecting the null hypothesis H_0 while it is true ranged from 33% to 64%. Similarly, computed p values based on the RCP8.5 Wm^{-2} station were greater than the significance level alpha (0.05) and thus the null hypothesis H_0 cannot be rejected. Based on the observed and Ensemble CORDEX models, projected rainfall was noted to have the highest temporal variability in Northeastern region.

4.2.3 Coefficient of Variability

Based on the coefficient of variability, the spatial variability of rainfall was analyzed and the results presented in Table 4-4.

Table 4-4: Coefficient of Variability of Past and Projected Rainfall

	Past	**Projected Rainfall**	
Station	1981 to 2010	RCP4.5 (2015-2045)	RCP8.5 (2015-2045)
Wajir	3.02	1.38	3.41
Garissa	2.39	2.14	3.24
Mandera	1.96	1.92	2.63

The coefficient of variability values in Table 4-4 indicate that observed precipitation is highly variable in space and time. Notably, observed coefficient of variability values ranged from 1.96 to 3.02. Remarkably, projected rainfall indicates decreased Coefficient of variability during the RCP4.5. However, the variability increases significantly in RCP8.5 to values more than the past and RCP4.5. Projected precipitation variability was noted to be higher in RCP 8.5, compared to past and RCP4.5.

4.3 Past Drought Characteristics in North Eastern Region

4.3.1 Analysis of Standardised Precipitation Index

The results of applied SPI methodon season's precipitation totals are presented below.

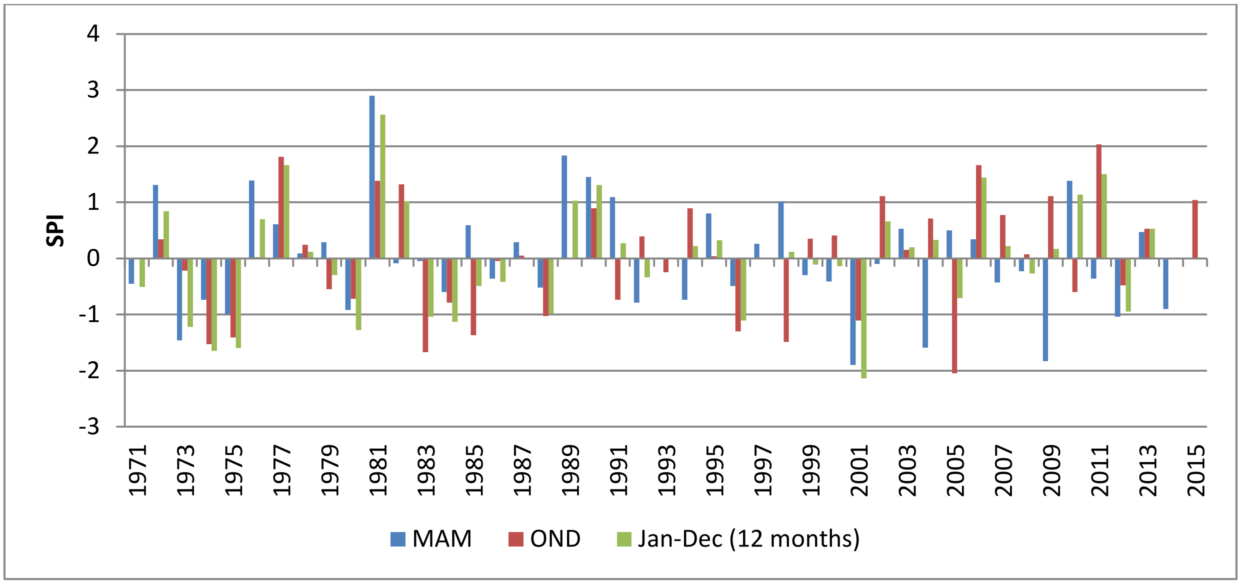

Figure 4-4:Variation of SPI between 1971 to 2015 for Mandera

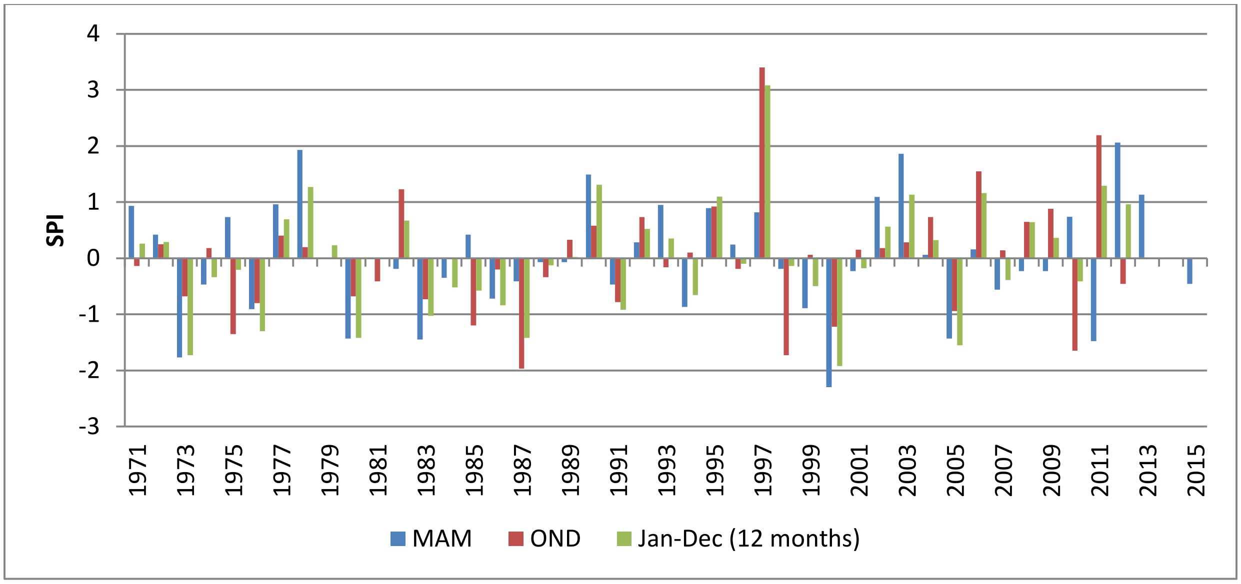

Figure 4-5:Variation of SPI between 1971 to 2015 for Wajir

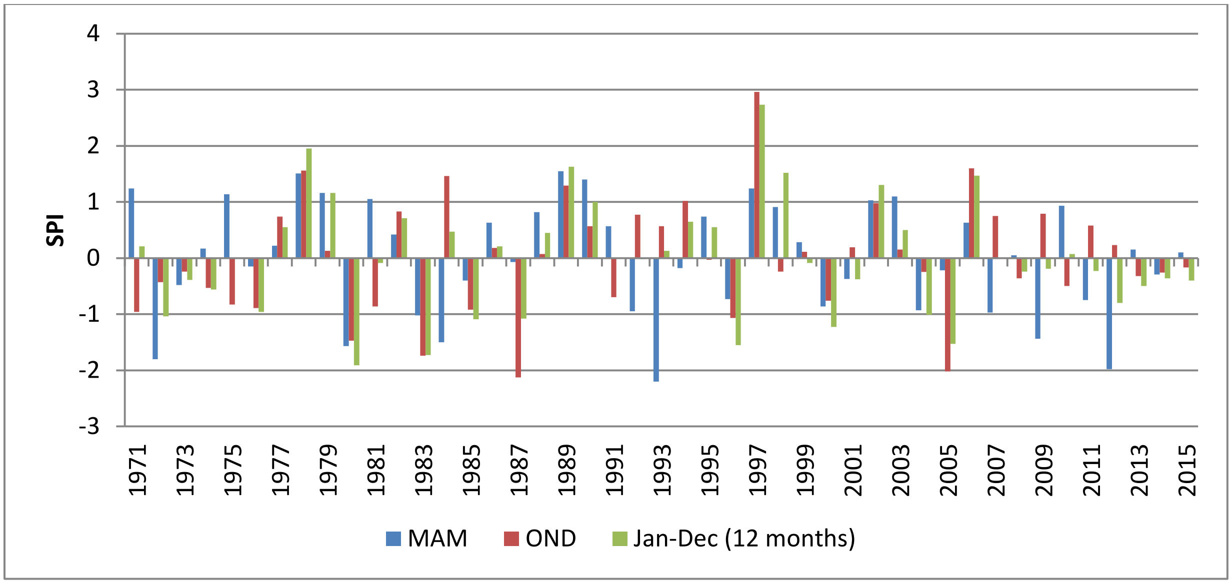

Figure 4-6:Variation of SPI between 1971 to 2015 for Garissa

The analysis was done turned into two drought characteristic which included the mild drought and moderately dry condition as shown in Figures 4-4 to Figure 4-6. The results of the applied SPI method on season's precipitation totals pointed out higher runs of the drought of varying intensity in the last decade with remarkably expressed drought intensity. Therefore, the drought is assumed to have occurred in 1973, 1974, 1976, 1980, 1983, 1984, 1986, 1987, 1992, 1994, 1999-2001, 2004-2005, 2008-2009 and 2011-2012. The longest drought period is considered to have occurred between 1999-2001 and 2004-2008 for the MAM season and 1971-1976, 1983-1988, 1998-2001, 2004-2007 for the OND Season. Studies (Ininda *et al.*, 2007; Okoola *et al.*, 2008; Ngaina, 2013) attributed the observed drought conditions over the region to El Niño Southern Oscillation (ENSO) event especially the La Niña. Therefore, the highest damage to rainfed agriculture and pastures was borne in these years.

4.3.2 Frequency of Drought Occurrence

The frequency of drought occurrence was analysed based on its probability of recurrence. The Table 4-5 presents results of probability values of drought occurrence in North Eastern Region. The examination of drought persistence i.e. the probability of occurrence of a given drought category lasting for given years is presented in Table 4-6. The Table 4-7 presents the results of conditional probability of drought occurrence of two, three, four and five successive seasons.

Table 4-5: Probability (values) of Drought Occurrence in Northeastern Counties

Drought category	**Mandera**		**Wajir**		**Garissa**	
	MAM	OND	MAM	OND	MAM	OND
Mild drought	0.55	0.67	0.53	0.69	0.49	0.55
Moderate drought	0.06	0.00	0.10	0.00	0.10	0.08

Table 4-6: Result of Drought Persistence

Station	**Season**	**Category**	**Runs**							
			1	2	3	4	5	6	7	8
Wajir	MAM	Mild drought	10	3	2	0	0	0	0	0
		moderate drought	5	0	0	0	0	0	0	0
	OND	Mild drought	3	2	2	0	0	2	0	1
		moderate drought	0	0	0	0	0	0	0	0
Garissa	MAM	Mild drought	3	4	4	1	0	0	0	0
		moderate drought	3	0	0	0	0	0	0	0
	OND	Mild drought	8	2	1	1	0	2	1	1
		moderate drought	0	0	0	0	0	0	0	0
Mandera	MAM	Mild drought	4	3	3	0	1	0	1	0
		moderate drought	3	0	0	0	0	0	0	0
	OND	Mild drought	8	4	0	1	0	0	0	0
		moderate drought	4	1	0	0	0	0	0	0

Table 4-7: Conditional Probability of Drought Occurrence

Runs	Wajir		Garissa		Mandera	
	MAM	OND	MAM	OND	MAM	OND
2	0.692	0.636	0.692	0.636	0.818	0.429
3	0.385	0.455	0.385	0.545	0.636	0.286
4	0.231	0.273	0.154	0.273	0.182	0.214
5	0.077	0.273	0	0.091	0.091	0.143

The Table 4-5 shows that there was a high probability of mild drought both in MAM and OND seasons in the three selected stations in the North-eastern region with Wajir recording the highest probability. While the probability of occurrence of the moderate dry season is 0 (zero) in Wajir and Mandera during the OND season, the probability for moderate drought is low in all stations; an indication that moderate drought condition rarely occurs during this season.

In Table 4-6, the study notes that individual drought category had the low probability for higher runs. Notably, moderate drought persistence in Wajir and Garissa for OND season was all zero. This could be attributed to the fact that the region normally receives enhanced precipitation during the OND season and thus higher probability of mild drought condition. Moreover, variation in the intensity would be expected from one season to another. In both seasons the probability of occurrence of drought decreased with increasing number of runs. In Mandera, the probability of occurrence of mild drought of a single run recorded the highest frequency in the OND season. The probability of occurrence of mild drought of only a single run recorded the highest frequency in MAM season in Wajir while the drought persistence of frequency beyond 3 runs were not recorded. Moderate drought condition only recorded a single run for MAM season with no runs observed for OND season other than in Mandera. In Garissa the probability of occurrence of mild drought of a single run recorded the highest frequency in OND season. Notably, the conditional probability of drought occurrence (Table 4.7) is higher for lower runs and lower for higher runs. Further, the study noted that the conditional probability of drought occurrence was higher in MAM compared to OND in the three counties.

4.3.3 Periodicity

The graphical results of analysis of drought recurrence (periodicity) pattern over the North eastern region are presented in Figure 4-7.

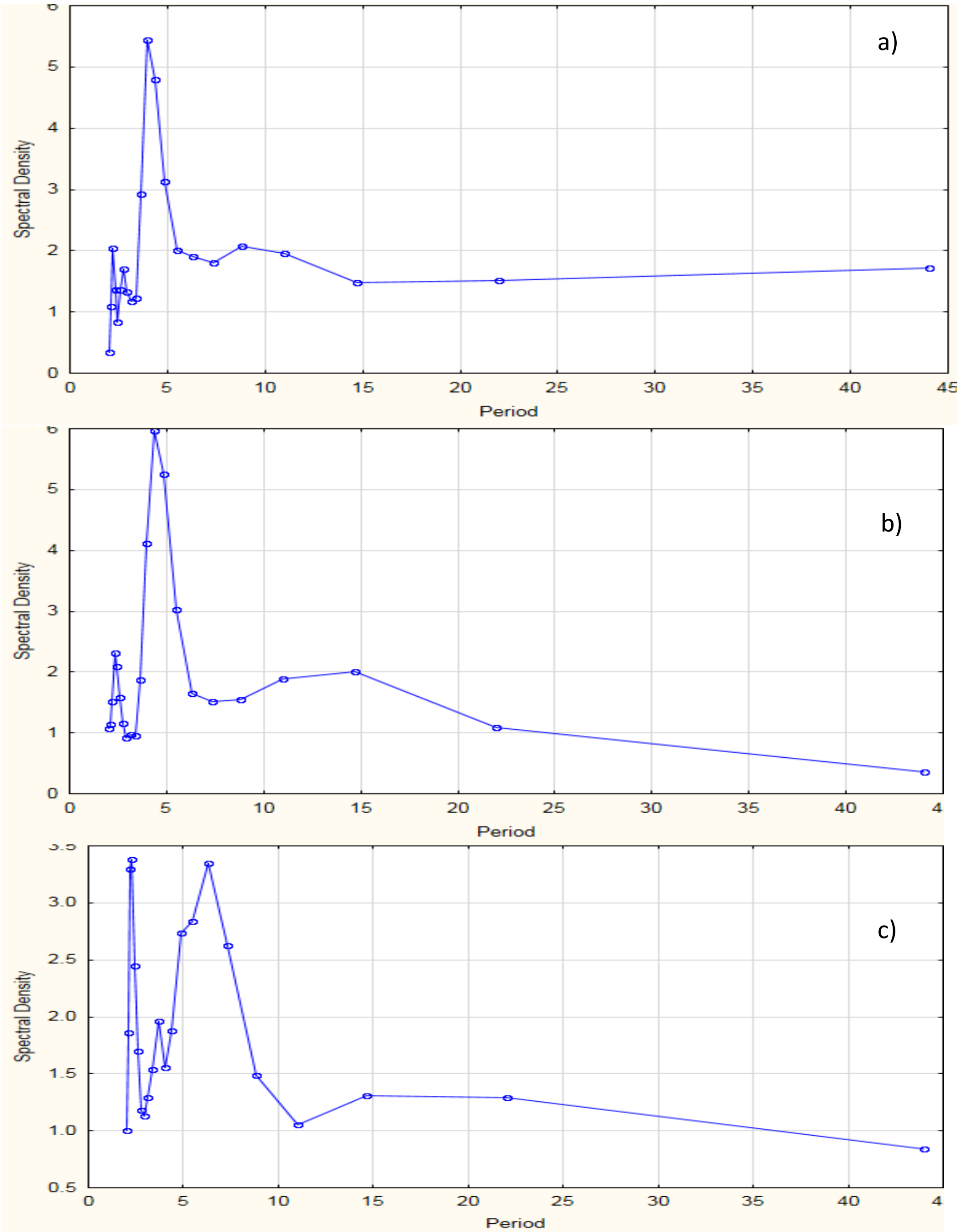

Figure 4-7: Periodicity of past drought conditions in a) Garissa, b) Mandera c) Wajir north eastern Kenya

The cycle observed from the spectral analysis (Figure 4-7) could be grouped into 2-3 years, 2.5-3.5years, 4.5-7years, and 8-12years. The 2-3years rainfall oscillation may be associated with QBO in the stratosphere (McQueen and Jury, 1993). According to Mason and Tyson (Mason and Tyson, 1992), QBO enhances rainfall when in westerly phase and enhances drought during its easterly phase. The relationship between stratospheric easterly wind and below normal rainfall during short and long rain are 71% and 75% respectively while the association between above normal rainfall and westerly stratospheric winds over East Africa is 80% (Ogallo and Anyamba, 1983). The oscillation of 2.5-3.5years and 4.5-7years obtained are in agreement with Ogallo and Anyamba (1983) and Nicholson and Nyenzi (1990). This periodicity is associated with ENSO and sea surface temperature fluxes in the Atlantic oceans and equatorial Indian Ocean.

4.4 Projected Drought Characteristics in North Eastern Counties

Projected drought characteristics was analysed based on Ensemble CORDEX RCP 4.5 and 8.5 for the period 2015 to 2045.

4.4.1 Analysis of Standardised Precipitation Index

Analysis of SPI based on RCP4.5 and RCP8.5 for the period 2015-2045 was done and the results presented in Figure 4-8 to Figure 4-13.

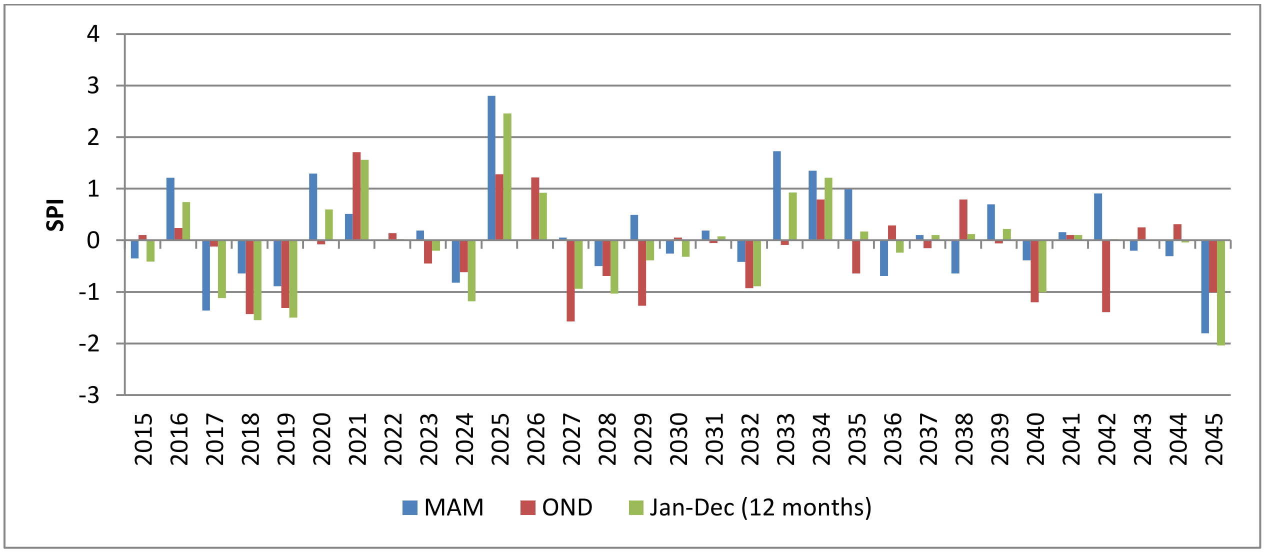

Figure 4-8:Variation of SPI based on RCP 4.5 for Mandera (2015-2045)

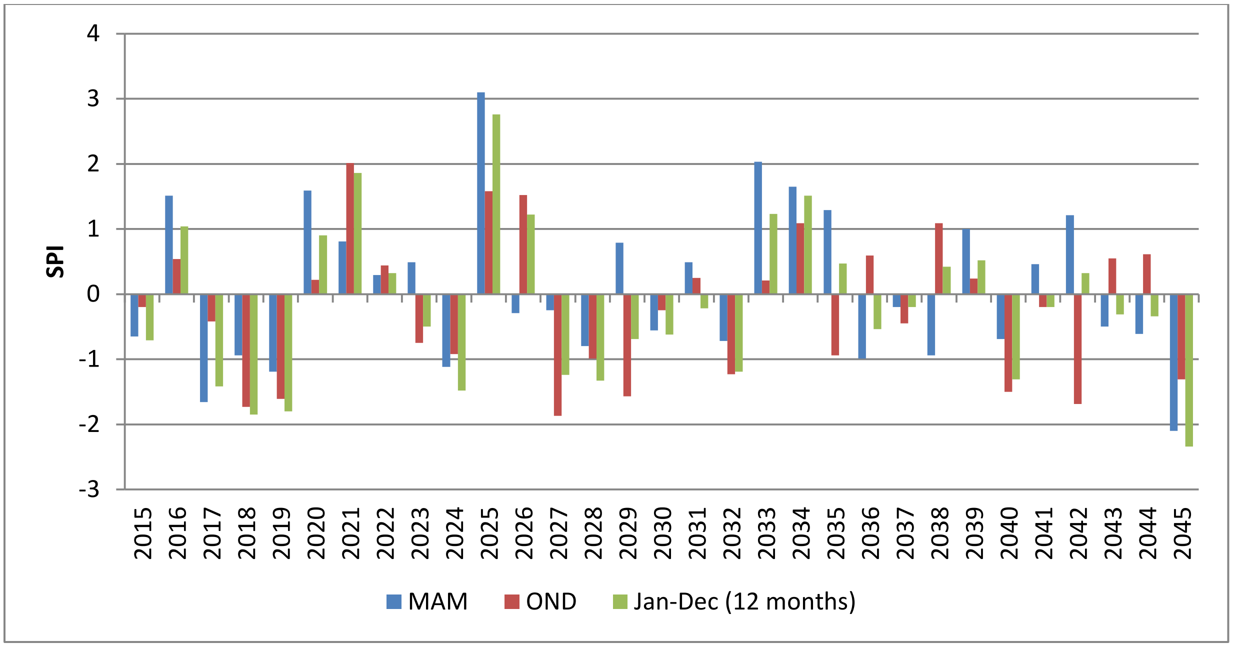

Figure 4-9:Variation of SPI based on RCP8.5 for Mandera (2015-2045)

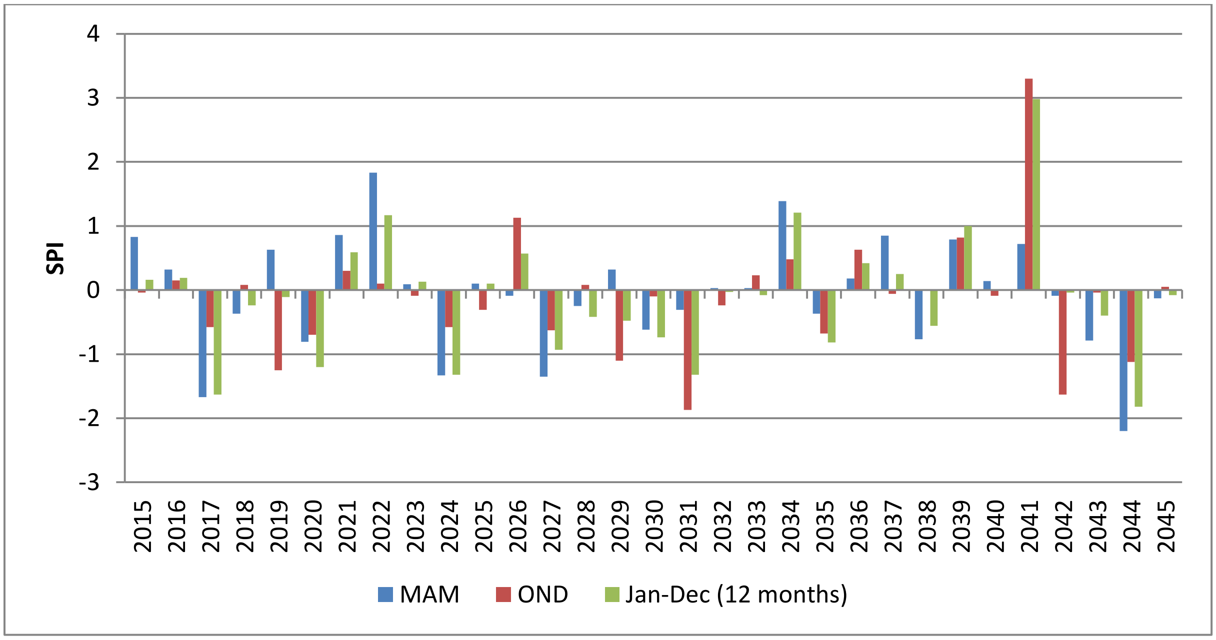

Figure 4-10:Variation of SPI based on RCP4.5 for Wajir (2015-2045)

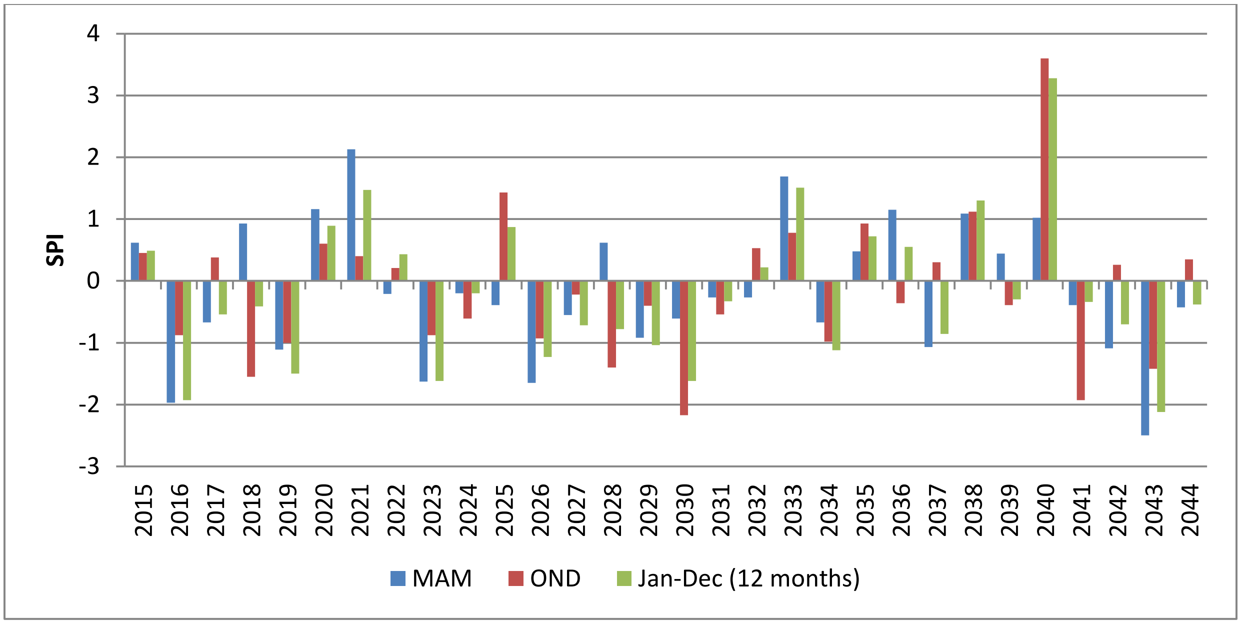

Figure 4-11:Variation of SPI based on RCP8.5 for Wajir (2015-2045)

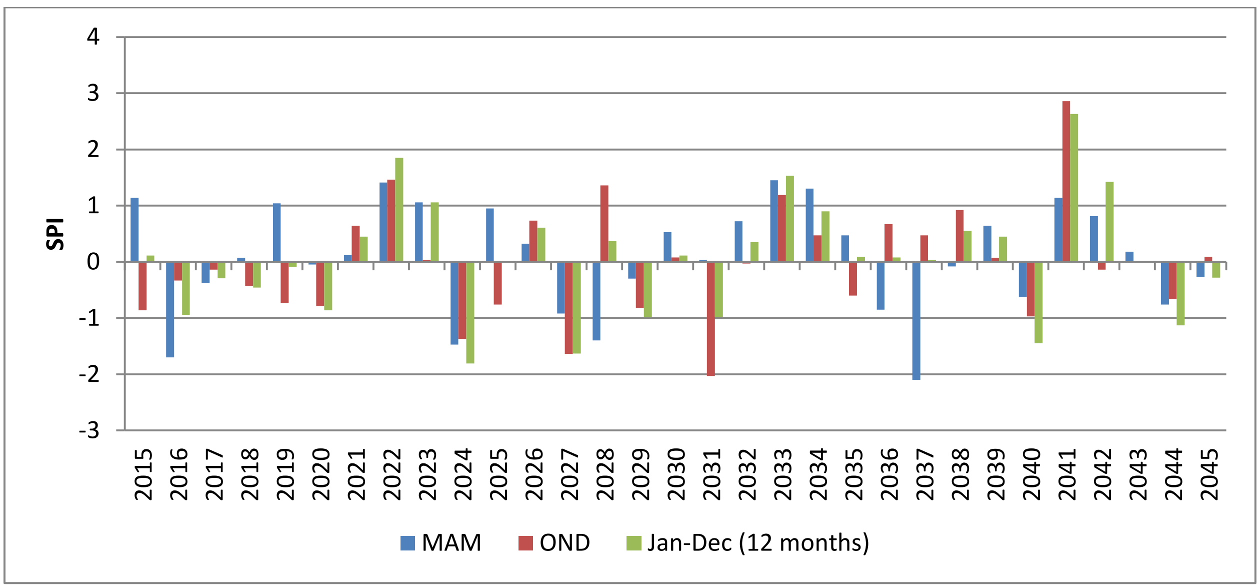

Figure 4-12:Variation of SPI based on RCP4.5 for Garissa (2015-2045)

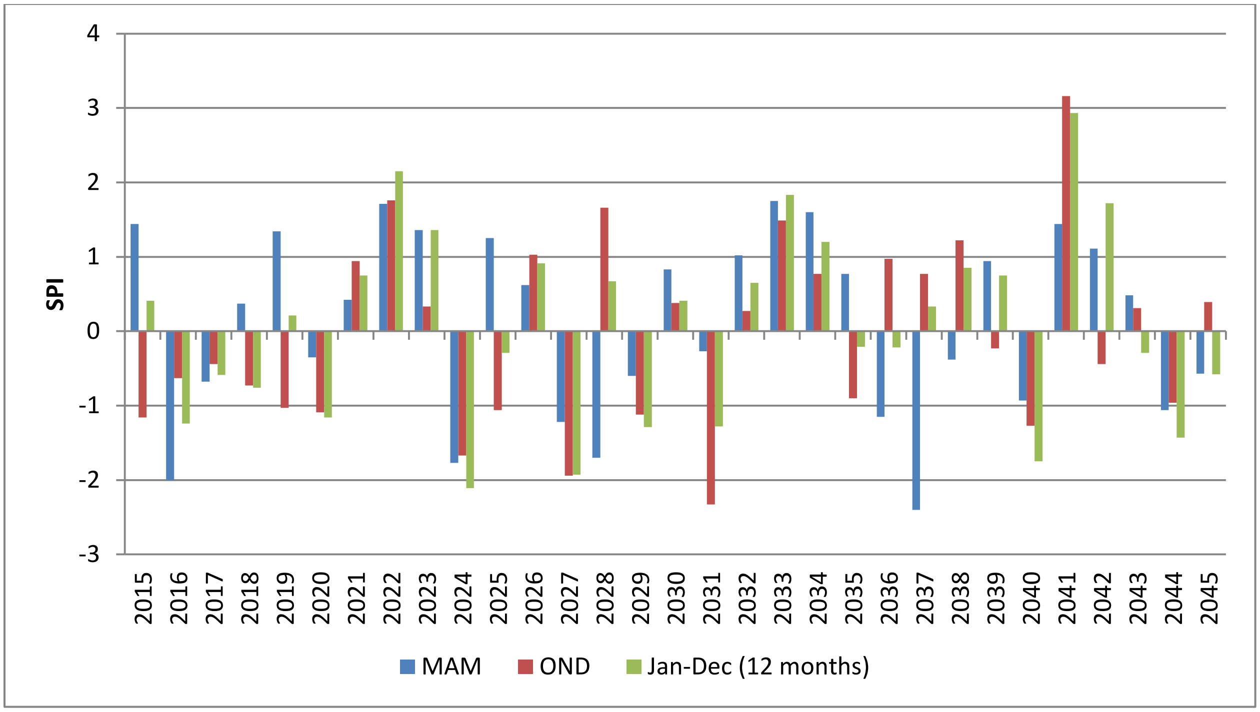

Figure 4-13:Variation of SPI based on RCP8.5 for Garissa (2015-2045)

In Mandera RCP4.5, mild drought frequency for MAM season was higher than OND season while moderate drought, OND season was higher than MAM season during the period 2015-2015. The same was the case for RCP8.5.

In Wajir RCP4.5, mild drought frequency for MAM season was higher than OND season while for moderate drought, OND season was higher than MAM season during the period 2015-2045. RCP8.5, mild drought frequency for MAM season was higher than OND season while for moderate drought was the same for both MAM and OND seasons.

In Garissa, mild and moderate droughts frequency for RCP4.5 during the period 2015-2045 was higher in OND season than MAM season. RCP8.5 had the same number of years of mild drought during the same period but the moderate drought had higher frequency in OND season than MAM season.

4.4.2 Frequency of Projected Drought Occurrence

The frequency of drought occurrence was analyzed based on its probability of recurrence for the projected rainfall. The Table 4-8 presents results of probability values of drought occurrence in North Eastern Region. The examination of drought persistence i.e., the probability occurrence of a given drought category lasting for given years is presented in Table 4-9. The Table 4-10 presents the results of conditional probability of drought occurrence of at least more than two, three, four and five successive seasons.

The Table 4-8 shows that there was a high probability of moderate drought both in MAM and OND seasons based on RCP4.5 and RCP8.5 scenarios. However, Wajir recorded the highest probability of moderate drought compared to the other two stations. Computed projected (2015-2045) drought persistence (Table 4.9) indicated that individual drought category had low probability for higher runs. On the other hand drought of varying intensity were observed to last for several seasons indicating that drought may persist but intensity varies from one season to another. Computed conditional probability of drought occurrence (Table 4-10) indicated higher probability values based on lower run values during MAM compared to OND for both RCP4.5 and RCP8.5 scenario with the higher runs indicating lower conditional probability values

Table 4-8: Projected (2015-2045) Probability Values of Drought Occurrence

Scenario	**Drought Category**	**Mandera**		**Wajir**		**Garissa**	
		MAM	OND	MAM	OND	MAM	OND
RCP4.5	Mild drought	0.10	0.05	0.15	0.01	0.11	0.15
	Moderate drought	0.40	0.51	0.45	0.59	0.40	0.50
RCP8.5	Mild drought	0.20	0.15	0.25	0.11	0.21	0.25
	Moderate drought	0.60	0.71	0.65	0.79	0.6	0.7

Table 4-9: Result of Projected (2015-2045) Drought Persistence

Station	**Season**	**Category**	**RCP4.5**								**RCP8.5**							
			1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Wajir	MAM	Mild drought	3	2	0	0	0	0	0	1	5	0	0	0	0	0	0	0
		moderate drought	8	1	0	0	0	0	0	0	10	3	2	0	0	0	0	0
	OND	Mild drought	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		moderate drought	1	1	1	0	1	0	0	1	3	2	2	0	0	2	0	1
Garissa	MAM	Mild drought	1	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0
		moderate drought	1	1	0	0	0	0	0	0	3	4	4	1	0	0	0	0
	OND	Mild drought	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		moderate drought	6	1	0	0	3	0	1	0	8	2	1	1	0	2	1	1
Mandera	MAM	Mild drought	1	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0
		moderate drought	2	1	0	1	0	1	1	0	4	3	3	0	1	0	1	0
	OND	Mild drought	2	3	0	0	0	0	0	0	4	1	0	0	0	0	0	0
		moderate drought	6	1	1	0	0	0	0	0	8	4	0	1	0	0	0	0

Table 4-10: Projected (2015-2045) Conditional Probability of Drought Occurrence

Scenario	**Runs**	**Wajir**		**Garissa**		**Mandera**	
		MAM	OND	MAM	OND	MAM	OND
RCP 4.5	2	0.74	0.69	0.74	0.69	0.87	0.48
	3	0.44	0.51	0.44	0.6	0.69	0.34
	4	0.28	0.32	0.2	0.32	0.23	0.26
	5	0.13	0.32	0.05	0.14	0.14	0.19
RCP 8.5	2	0.79	0.74	0.79	0.74	0.92	0.53
	3	0.49	0.56	0.49	0.65	0.74	0.39
	4	0.33	0.37	0.25	0.37	0.28	0.31
	5	0.18	0.37	0.1	0.19	0.19	0.24

4.4.3 Periodicity

The graphical results of analysis of drought recurrence (periodicity) pattern over the North eastern region are presented in Figure 4-14 and Figure 4-15

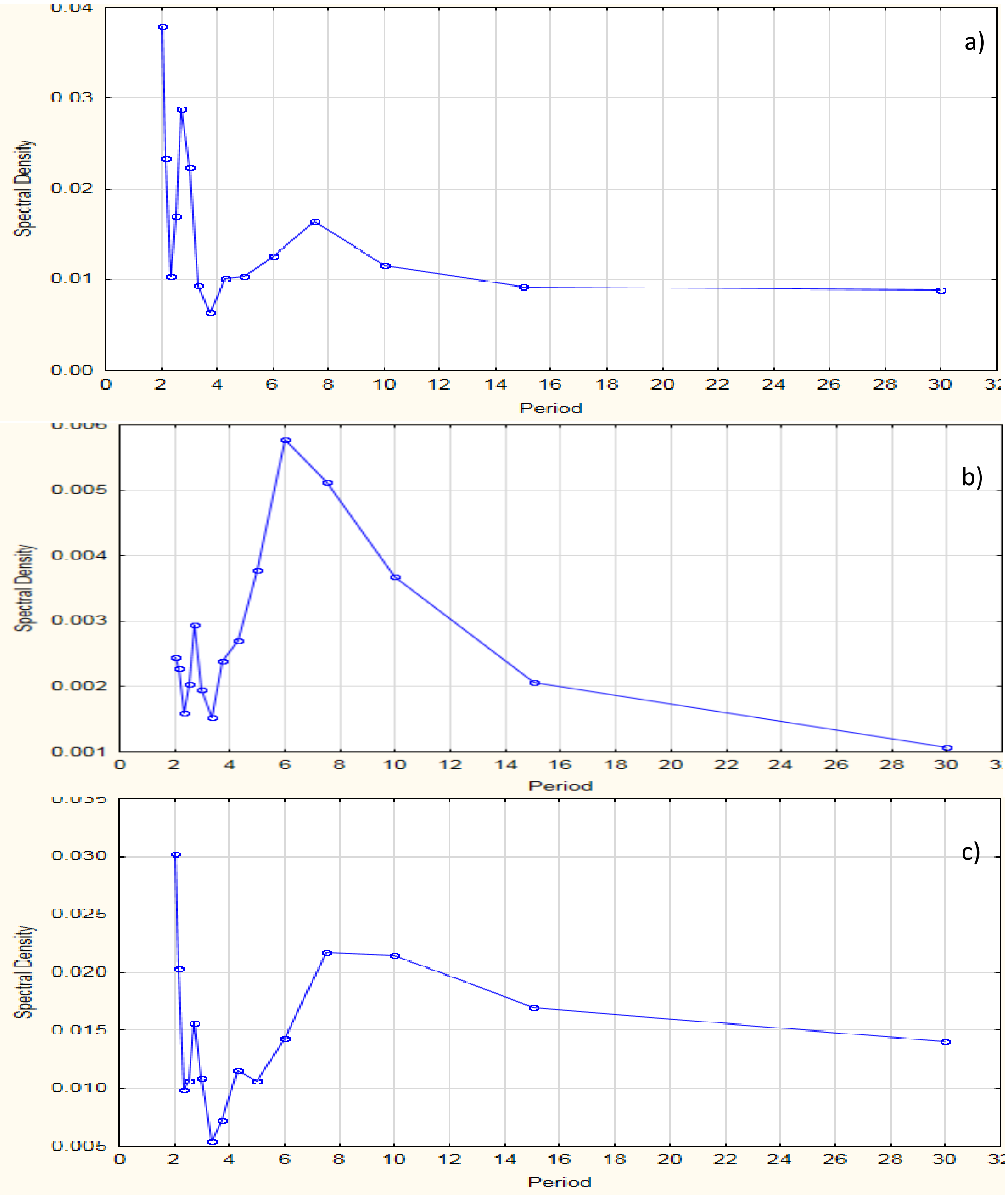

Figure 4-14: Periodicity of projected (2015-2045) drought conditions based on RCP4.5 for a) Garissa, b) Mandera c) Wajir in north-eastern Kenya.

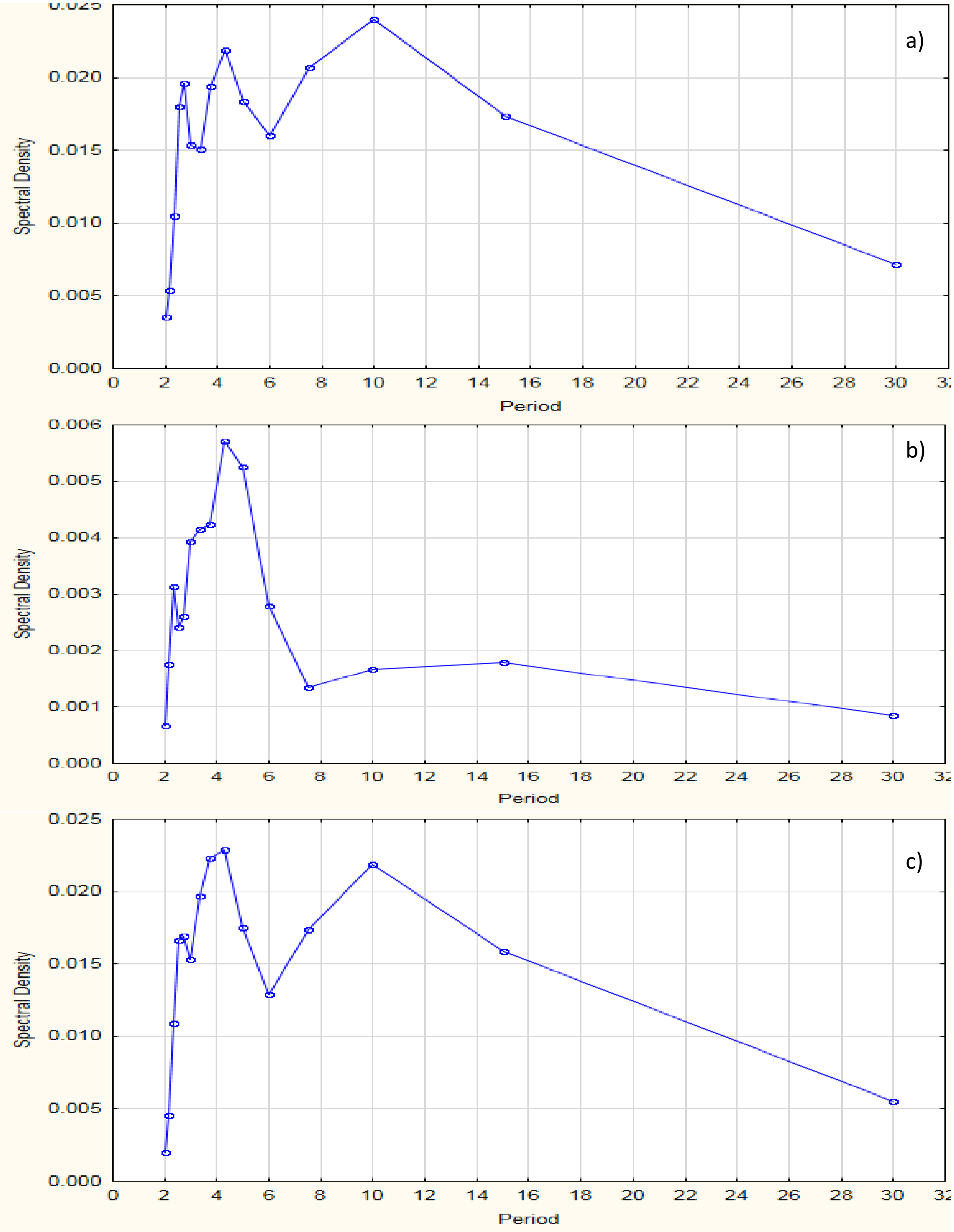

Figure 4-15: Periodicity of projected (2015-2045) drought conditions based on RCP8.5 for a) Garissa, b) Mandera c) Wajir in North Eastern Kenya.

The periodicity of projected drought conditions based on RCP4.5 (Figure 4-14) could be grouped into 2 to 3 years, 4.5 to 7 years and eight to12 years in Garissa. Similar periodicity of drought conditions was noted for Wajir and Mandera. For lower periodicity (< 3 years), Garissa and Wajir indicated a higher magnitude of the drought conditions compared to Mandera, which showed higher magnitudes for drought conditions for the periodicity of between 4 and seven years. The periodicity of projected drought conditions based on RCP8.5 could be grouped into 2.5 to 4 years, 6 to 10 years and ten to15 years (Figure 4-15). Higher magnitudes were recorded for periodicity values of between 3.5 and six years for Mandera and Wajir whereas, the periodicities for Garissa was noted to be upto 10 years. In general, spectral analysis based on RCP4.5 and 8.5 indicated distinct groups of 2-3 years, 4.5-7years, and 8-12years and thus could be attributed to a different scale of motions. The 2-3years rainfall oscillation may be associated with QBO in the stratosphere (McQueen and Jury, 1993). According to Mason and Tyson (1992), QBO enhances rainfall when in westerly phase and increases drought when in an easterly phase. The association between westerly stratospheric winds and above normal rainfall over east Africa is 80% while the relationship between stratospheric easterly wind and below normal rainfall during short and long rain are 71% and 75% respectively (Ogallo and Anyamba, 1983). The oscillation of 2.5-3.5years and 4.5-7years obtained are in agreement with Ogallo and Anyamba (1983) and Nicholson and Nyenzi (1990). This periodicity is associated with ENSO and sea surface temperature fluxes in the equatorial Indian and Atlantic oceans. The 8-12 years cycle may be associated with sun’s activities.

Comparison of periodicity of drought conditions for the past and projected drought indicates notable changes in the magnitude and frequency of drought conditions with higher values for RCP8.5 scenario compared to the RCP4.5 scenario

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter gives the summary, major conclusions that were drawn from the various results of the study together with recommendations for future research work.

5.1 Summary

Climate exerts a significant control on the day-to-day socio-economic development. Notably, numerous challenges exist in assessing changes in climate extremes not only due to intrinsically rare nature of these events, but because they invariably happen in conjunction with disruptive conditions especially in key sectors such as agriculture in many developing countries whose vulnerability to climate change has been exacerbated by its weak adaptive capacity. Climate can affect livestock both directly and indirectly climate shocks can have devastating effects among the poor. Droughts have major economic and humanitarian impacts because rain-fed agriculture is the backbone of most economies in East Africa. Therefore, the study sought to assess the trend of past, present and future rainfall and temperature and severity of drought conditions using Mann Kendall test, coefficient of variability and Standardized Precipitation Index (SPI) over North Eastern Region Counties. Agriculture is a key socio-economic sector in the North Eastern region of Kenya. In planning for drought mitigation, it is important to understand the drought characteristics through drought analysis.

The development of National programs can be informed by the experiences of regional drought management programs. The ability of societies to reduce drought effects and build resilience is a grave significant concern on a global level. An effective drought monitoring and early warning systems is a way to prevent or reduce drought impacts. An effective drought monitoring system has the ability to deliver an early warning in a case of the drought’s onset, successfully measure drought severity and spatial extent, and communicate facts to decision-making groups in a timely manner.

The data used in this study comprised of both observed gauge rainfall and Climate model output. Observed data included monthly total precipitations over the three synoptic stations spread in

North Eastern counties of Wajir, Garissa and Mandera. These datasets were obtained from Kenya Meteorological Department, Headquarters in Nairobi spanning the period 1971 to 2015. Daily downscaled rainfall ensemble data from 8 CORDEX RCMs were also used for the period 1980-2010 for both RCP4.5 and 8.5 and running in transient mode for the period 1951-2100. The climate data were subjected to a quality control procedure primarily with the purpose of identifying outliers in the time series. The consistency of the data were also be checked by comparing the data records amongst themselves and with that of neighbouring stations. Short-Cut Bartlett Test was used. The spatial and temporal characteristics of rainfall were assessed based on time series analysis through determination of the trend and seasonality components of the time series. The trend component of the time series was determined using Mann-Kendall rank statistic to detect abrupt changes rainfall. Coefficient of Variation (CV) was used to indicate temporal variability of rainfall. Drought severity was analysed using SPI for both past (1971-2015) and future (2015-2045) period. The frequency, probability of drought occurrence and persistence of drought occurrence was also analysed. The periodicity analysis was done for the drought to determine their recurrence was done using the Single Series Fourier (Spectral) Analysis based on Statistica software.

Homogeneity of rainfall records were tested using Short-Cut Bartlett test and showed that computed variance (F-value) was less than the tabulated variance (F critical) for rainfall records over all stations used in the study. This indicated that the variance were the same for rainfall records over each rainfall received in all stations and were bi-modal in pattern commonly referred to as ‘short rain’ and ‘long rain’ the long rains start from the month of March to May (MAM) while the short rains season starts from October to December (OND) reported similar patterns of bimodal (OND and MAM) rainfall were observed in Mandera and Wajir respectively. Computed p values for observed rainfall over Garissa, Wajir and Mandera stations are lower than the significance level alpha (0.05). Based on the observed and Ensemble CORDEX models, projected rainfall was noted to have the highest temporal variability in North eastern region coefficient of variability values indicated that observed precipitation is highly variable in space and time observed coefficient of variability values ranged from 1.96 to 3.02. Projected rainfall indicates decreased Coefficient of variability during the RCP 4.5. However, the variability increases significantly in RCP 8.5 to values more than the past and RCP 4.5. Generally, projected precipitation variability was noted to be higher in RCP 8.5WM^{-2}, compared to past and

RCP 4.5

SPI analysis in north eastern region indicated two dominant drought conditions namely the mild drought with values ranging between -0.01 to – 0.99 and moderately dry condition with SPI values ranging from -1.0 to -1.49. The results of the applied SPI method on season's precipitation totals are pointing out a higher runs of drought of varying intensity in the last decade with remarkably expressed drought intensity. Therefore, the drought is assumed to have occurred in 1973, 1974, 1976, 1980, 1983, 1984, 1986, 1987, 1992, and 1994, 1999-2001, 2004-2005, 2008-2009 and 2011-2012. The longest drought period is considered to have occurred between 1999-2001 and 2004-2008 for the MAM season and 1971-1976, 1983-1988, 1998-2001, 2004-2007 for the OND Season the highest damage to rain fed agriculture and pastures was borne in these years. Most of the drought experienced during the MAM season is seen to have started building up during the OND season of the previous year. There was a high probability of mild drought both in MAM and OND seasons in the three selected stations in North-eastern region with Wajir recording the highest probability. While the Probability for moderate drought is low in all stations; the probability of occurrence of moderate dry season was zero in Wajir and Mandera during the OND season.

Individual drought category had low probability for higher runs. Notably moderate drought persistence in Wajir and Garissa for the OND season was all zero. This could be attributed to the fact that the region normally receives more rainfall during OND season and thus has higher probability of mild drought condition. On the other hand drought of varying intensity were observed to last for several seasons indicating that drought may persist but intensity varies from one season to another. In both seasons the probability of occurrence of a given drought characteristic decreased as the number of runs increased. The probability of occurrence of mild drought of only a single run recorded the highest frequency in MAM season in Wajir while the drought run of frequency beyond 3 runs were not recorded. In Mandera, the probability of occurrence of mild drought of a single run recorded the highest frequency in OND season. Moderate drought condition only recorded a single run for MAM season and no runs recorded for OND season except in Mandera. In Garissa the probability of occurrence of mild drought of a single run recorded the highest frequency in OND season. The cycle observed from the spectral analysis could be grouped into 2.5-3.5years, 4.5-7years and 8-12years

The results of projected SPI analysis on seasonal rainfall pointed out to a higher run of drought of varying intensity for the projected period based on RCPs scenarios with significantly increasing intensity. There was a high probability of moderate drought both in MAM and OND seasons based on RCP 4.5 and RCP 8.5 scenarios. However, Wajir recorded the highest probability of moderate drought compared to the other two stations. Projected drought persistence indicated that individual drought category had low probability for higher runs. On the other hand drought of varying intensity were observed to last for several seasons indicating that drought may persist but its intensity varies from one season to another. Computed conditional probability of drought occurrence indicated higher probability values based on lower run values during the OND compared for MAM for both RCP 4.5 and RCP 8.5 scenario with the higher runs indicating lower conditional probability values. The periodicity of projected drought conditions based on RCP 4.5 could be grouped into 2 to 3 years, 4.5 to 7 years and 8 to12 years in Garissa. Similar periodicity of drought conditions was noted for Wajir and Mandera. For lower periodicity (< 3 years), Garissa and Wajir indicated higher magnitude of the drought conditions compared to Mandera which showed higher magnitudes for drought conditions for periodicity of between 4 and 7 years. The periodicity of projected drought conditions based on RCP 8.5 could be grouped into 2.5 to 4 years, 6 to 10 years and 10 to15 years. Higher magnitudes were recorded for periodicity values of between 3.5 and 6 years. In general, spectral analysis based on RCP 4.5 and 8.5 indicated distinct groups of 2-3 years, 4.5-7years and 8-12years and thus could be attributed to different scale of motion.

5.2 Conclusion

The droughts analysis over the area of study varied between mild drought and moderately dry condition. Given that these are rainfall seasons and as such the conditions might worsen during other dry seasons, reducing the risks and therefore the impacts of drought is of utmost importance and requires that greater emphasis be placed on preparedness and mitigation. In the past period, the study has established that recorded an increase in drought events and thus could be attributed to climate change.

5.3 Recommendations

5.3.1 Research Community

More research is needed to fill gaps in understanding different types of drought in the region. Future research can look into different spatial scale and compare performance of different drought indices in the region. It will be also useful to do case studies with patterns of drought emergence such as fast or slow onset droughts.

5.3.2 Society and Policy Makers

A more elaborate way of studying drought would be use of areal averaged rainfall records. Before areal rainfall calculation is done regions are grouped into areas experiencing same climatic condition e.g. use of principal component analysis. Considering the recurrence pattern of drought as seen from the study, drought Monitoring and early warning is therefore, essential and can provide the foundation for making timely decision by decision makers and concerned subjects (i.e., farmers and national policy makers).

One of the limitations of the study is the availability and adequacy data set archives used. Therefore, improvement of meteorological monitoring over region will greatly improve drought monitoring in support of key decisions.

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