UNIVERSITY OF NAIROBI

ASSESSING THE POTENTIAL EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON LIVESTOCK IN THE ARID LANDS OF KENYA

BY

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Declaration

I hereby declare that this project is my work and has not been presented in any University or learning institution for any academic award. Where other people's work, or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements

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Dedication

I dedicate this dissertation to my family, Mr. Kepher Ouma and Mrs. Mary Ouma who encouraged me to work hard in order to achieve the best in life.

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Abstract

Extreme temperatures and rainfall patterns are being experienced in many parts of the world including Eastern Africa. These have been associated with droughts, floods, cold/hot spells, cyclones, among others that have had devastating socio-economic impacts. Thus extreme climate variability and change will in future have serious impacts on future sustainability of our socio economic systems. The objective of this study was to assess the potential impacts of extreme climate variability and change on livestock in the Arid and Semi-Arid Lands (ASALs) of Kenya, with specific reference to Turkana, Marsabit, Samburu, and Isiolo Counties, using past, present, and future patterns of rainfall and temperature extremes.

Rainfall and temperature data used were obtained from IGAD Climate Prediction and Application Centre (ICPAC) while gridded observations used were from Climate Research Unit (CRU), University of Anglia. ICPAC and CRU data were for the period 1961-2013 and 1901-2013 respectively. The climate projection data sets were obtained from ICPAC for the period 2006-2100. The data were subjected to various trend methods in order to delineate the temporal patterns of rainfall characteristics at specific locations. The trend methods adopted included graphical, regression, and non-parametric approaches based on Mann-Kendal statistics. Gaussian Kernel density distribution was used to assess the changes in the mean, variance, skewness and kurtosis coefficients, and extremes in rainfall and surface air temperature. Spectral analysis was further used to determine the cycle of extremes over the study area. The standardized precipitation index was used to determine the past, present, and future abnormal wet and dry conditions and their effect on cattle population. The skill of the models was examined by the use of root mean square error, correlation analysis, model bias, and standard deviation. Graphical methods were then used to examine the probable effect of future climate on cattle farming.

It was evident from the study that both maximum and minimum temperatures are increasing at all locations as have been observed at many locations worldwide. The highest increase in seasonal mean of surface air temperature ranging from 0.33-1.45^{0}C was observed for June-August season. Results from rainfall analyses did not delineate any homogenous changing patterns at all locations and seasons, however, increase in drought risk was evident at most locations within the study area when recent mean rainfall (1991-2013) was compared with the means of 1901-30, 1931-60, and 1961-90. Some changes in the pattern of temperature and rainfall extremes were also evident from the patterns of higher order time series moments which included skewness and kurtosis. It was observed that the recurrences of extremes were centered on 2.3, 3.5, 5.5, and 9-10 years which were attributed to Quasi-biannual oscillation, El Nino, and sun spot cycle. The study observed that during the period of abnormal wetness, cattle populations were higher than those of the abnormal dryness thus climate affects cattle population. An ensemble of the models was found to have a better skill in replicating the observation and hence was used for analysis of future climate. The wet and dry conditions and temperature are projected to increase in the future in all the scenarios used in this study. Cattle farming are likely to be affected negatively in terms of high temperatures resulting to severe thermal heat comfort as well as severe dry conditions. Hence development of an adaptation mechanism is necessary to cattle farming in the ASALs of Kenya.

The result from this study can be used in the planning and management of the livestock sector in the ASALs of Kenya and support national sustainable development planning. The SPI tool is recommended for monitoring and forecasting abnormal wetness and dryness over the ASALs of Kenya to improve the timely identification of the emerging extreme conditions to be action by the government. Livestock farming should be addressed appropriately using the expected future climatic conditions over the ASALs of Kenya. The study information can be used by the policy makers to develop policies that can address the problem of high livestock mortality due to extreme weather and climate conditions in the country. Further studies on the effect of climate change on other aspects of livestock such as forage as well as a methodology way to distinguish human factors from climate factors that affect livestock farming are recommended.

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List of Abbreviations

ADW	Angular-Distance Weighted
ASALs	Arid and Semi-Arid Lands
BHR	Buishand Range test
CERF	Central Emergency Response Fund
CORDEX	Coordinated Regional Downscaling Experiments
CPC	Climate Prediction Center
CRU	Climate Research Unit
DJF	December, January, February
ECF	East Coast Fever
ECMWF	European Centre for Medium Range Weather Forecasting
ENSO	El Niño/Southern Oscillation
ERA-Interim	ECMWF Re-Analysis Interim
FAO	Food and Agricultural Organization
FEWSNET	Famine Early Warning Systems Network
FMD	Foot and Mouth disease
GCMs	Global Climate Models
GDP	Gross Domestic Product
GHA	Greater Horn of Africa
GIS	Geographical Information System
GoK	Government of Kenya
ICPAC	IGAD Climate Prediction and Application Centre
ICTP	International Centre for Theoretical Physics
IGAD	Inter-Governmental Authority on Development
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel for Climate Change
ITCZ	Inter-Tropical Convergence Zone
JJA	June, July, August
MAM	March-April-May
MESA	Monitoring for Environment and Security in Africa
MJO	Madden-Julian Oscillation

MPI	Max Planck Institute
NCDC	National Climate Data Center
NDVI	Normalized Difference Vegetation Index
NS	Not Significant
OND	October-November-December
PDNA	Post Disaster National Assessment
PDSI	Palmer Drought Severity Index
PET	Pettitt Test
PPR	Pest des Petits Ruminants
PRB	Population Reference Bureau
QBO	Quasi-Biennial Oscillation
RCMs	Regional Climate Models
RCPs	Representative Concentration Pathways
RMSD	Root Mean Square Difference
RVF	Rift Valley Fever
SD	Standard Deviations
SNHT	Standard Normal Homogeneity Test
SON	September, October, November
SPI	Standardized Precipitation Index
SST	Sea Surface Temperature
TC	Tropical cyclone
THI	Temperature Humidity Index
UEA	University of East Anglia
UNISDR	United Nations Secretariat of the International Strategy for Disaster Reduction
UNOCHA	United Nation Office for the Coordination of Humanitarian Affairs
VON	Von Neumann ratio
WMO	World Meteorological Organization

CHAPTER ONE

1.0 Introduction

This chapter provides the background of the study, statement of the problem, research questions, objectives, justification, area of study and the climatology of the study area.

1.1 Background

Increase in variability and change in temperature and rainfall patterns are being experienced in many parts of the world including Eastern Africa. Recent Intergovernmental Panel for Climate Change (IPCC, 2013) assessments have indicated that climate change is one of the key challenges threatening the current and future sustainability of the socio-economic systems. Floods/droughts associated with too much or too little rainfall are known to displace and kill people, livestock, destroy property and investments, degrade environment and basic fabrics that support the communities (Indeje *et al.,* 2000; IPCC 2007, 2013). Developing countries like Kenya are more vulnerable to the effect of climate change due to their high degree of low adaptive capacity (IPCC, 2013).

Over 80% of Kenyan land mass may be classified as arid and semi-arid lands (ASALs) with livestock being key activity in these areas. Subsistence and commercial farming are the key activities in the high potential agricultural areas. Agriculture in Kenya accounts for up to 26% of the country's gross domestic product (GDP) and 60% of the export earnings (Indeje *et al.*, 2000; ICPAC, 2006; Orindi *et al.*, 2007).

Agriculture is extremely vulnerable to extreme climate variability and change as has been witnessed during the years of the major floods and drought. The impacts of climate extremes on livestock and agriculture often affect the rural poor communities who depend on agriculture and livestock for survival (Muhati *et al.*, 2007; Mureithi and Opiyo, 2010; Rourke, 2011; PDNA, 2012; Dutra *et al.*, 2013; Djikeng *et al.*, 2014; Omondi *et al.*, 2014). In Kenya, agriculture is the backbone of the economy as 75% of the Kenyan population are dependent on agriculture for food and income. Statistics have also shown that, about one-third of the total land area of Kenya is agriculturally productive, including the Kenyan highlands, coastal plains and the lake region (FAO, 2006). About 75% of livestock are found in the ASALs of Kenya, and this sector contributes approximately 13% of Kenya's GDP, 40% to agricultural GDP and it also employs 50% of the labor force (Rege, 2001; FAO, 2005; Orindi *et al.*, 2007; PDNA, 2012).

The arid and semi-arid areas of Kenya are characterized by unreliable, low, variable and poorly distributed rainfall. Orindi *et al.* (2007) and FAO (2006) indicated that the mean annual rainfall in the semi-arid and arid areas of Kenya is between 300 – 500 mm and that the soils in these areas are shallow and infertile with Lake Turkana region receiving less than 250 mm of rainfall per year. But areas such as Marsabit with an altitude above 1,200 m have fertile soil and receive rainfall up to 600 mm per year (FAO, 2006). Eastern side of Turkana County receives an annual rainfall of 200mm and over 500mm in the western highlands (Omolo, 2010; Mureithi and Opiyo, 2010). Mean annual temperature in the ASALs of Kenya is between 22 ^{0}C and 40 ^{0}C. The temperature for Turkana County ranges between 26 ^{0}C and 38 ^{0}C (Jaetzold and Schmidt, 1983; Omolo, 2010; Mureithi and Opiyo, 2010).

Northern Kenya's ASALs depend mostly on livestock, which is the major domestic wealth and account for more than two-thirds of mean income (Chantarat *et al.*, 2013). Zebu cattle is the most common breed for the majority of Kenyans living in the ASALs and constitutes 77% of total cattle population in Kenya (Rege, 2001), concentrated mainly in arid and semi-arid lands. A study by Omondi *et al.* (2014) showed that cattle are the most important livestock type kept mainly for income, milk, meat and dowry, while goats and sheep are kept for income, meat and skins by the Masaai in the rangelands of Kenya.

Floods and drought are key challenges to sustainable livestock development in Kenya. Floods lead to inundation of grazing land and animal mortality. They are often associated with diseases such as Rift Valley Fever (RVF),.while drought leads to heat stress, lack of water and pasture, death of livestock, and devastation of the livelihoods, among many other miseries (Oludhe, 2002; FAO, 2006; Indeje *et al.*, 2006; Muhati *et al.*, 2007; Hoffmann, 2010; Mureithi and Opiyo, 2010; Omondi *et al.*, 2014). Studies by IPCC

(2007; 2013), Omondi *et al.* (2014), and King'uyu *et al.* (2000) showed that climate change, leading to changes in the magnitudes and frequency of extremes, is real.

Since livestock sector has a significant contribution to the formal and informal economy of the country, adaptation in this sector should thus be a significant focus in order for Kenya to respond to the impacts of extreme climate variability and change. This will help in safeguarding the provision of adequate food for a growing population and also for export to generate foreign exchange (Garderen, 2011; GoK, 2013; Tibbo and Steeg, 2013). This study therefore examines the potential impacts of extreme climate variability and change on livestock in the ASALs of Kenya, with specific reference to Turkana, Marsabit, Samburu, and Isiolo Counties.

1.2 Problem statement

Changes in temperature and rainfall extremes are already being experienced in many parts of the world and Kenya is not an exception. IPCC (2013) indicate that climate change is real with the livelihoods likely to be exposed to more climate extremes in the future (Orindi *et al.*, 2007; Christensen *et al.*, 2007; Hoffmann, 2010; Ngaina and Mutai, 2013; Darkoh *et al.*, 2014). Rainfall variability has also increased, with a decline in long rains season and appositive trend for short rain season (Darkoh *et al.*, 2014).

Northern Kenya's ASALs depend mostly on livestock (Chantarat *et al.*, 2013). Floods and droughts are natural events which cannot be controlled (Indeje *et al.*, 2000). They are the main extremes of the climate spectrum that have been associated with poor vegetation, diseases, loss of livestock, and devastation of the livelihoods among many other miseries. Drought in particular is a troublesome hazard that has been documented to have adverse impact on livestock and agricultural development. Rangeland degradations have also been caused by over-grazing due to limited resources thus soil erosion (Ogallo, 1989; Diaz and Markgraf, 2000; Indeje *et al.*, 2000; Orindi *et al.*, 2007; Rourke, 2011; Vanya, 2012; Ngaina and Mutai, 2013).

Livestock production is adversely affected by drought in terms of quality and quantity of feed which has led to low level of productivity, high mortality, reduced market value and conflicts among the pastoral communities for water and pasture (Orindi *et al.*, 2007; Dutra *et al.*, 2013; Djikeng *et al.*, 2014). Extreme climate conditions therefore lead to livestock mortality which is the most severe economic risk faced by pastoralists in Kenya (PDNA, 2012; Chantarat *et al.*, 2013). Little has been done on the impact of extreme climate variability and change to livestock farming in Kenya. This study, therefore, was aimed at assessing the potential impacts of extreme climate variability and change on livestock in the ASALs of Kenya, with specific reference to Turkana, Marsabit, Samburu, and Isiolo Counties.

1.3 Research questions

1. Are there evidence of variability and change in rainfall and temperature extremes in ASALs of Kenya?
2. Are there any evidence in the change of the past and present livestock population trends that may be associated with past and present climate extremes?
3. What is the possible impact of future climate change scenarios in Kenya's ASALs and how would they impact on pastoral systems?

1.4 Objectives

The overall objective of this study was to assess the potential effects of extreme climate variability and change on livestock in the ASALs of Kenya, with specific reference to Turkana, Marsabit, Samburu, and Isiolo Counties. This was achieved through the following specific objectives:

a) Determine the evidence of variability and change in rainfall and temperature extremes in Kenya ASALs.
b) Assess the change in livestock population that may be associated with past and present climate extremes.
c) Assess the future climate change scenarios and their potential impacts on pastoral systems in ASALs of Kenyan.

1.5 Justification of the study

Society is impacted more by changes in extremes than by changes in the means. Risks posed by climate variability are high in Kenya due to lack of coping capacity among large and small sectors of the society. Poor farmers are more exposed to the effect of extreme climate events and are unable to absorb the shocks of climate related hazards due to lack of resources and general coping capacity. Increase in temperature and decline in rainfall as projected by different Global Climate Models (GCMs) are likely to cause several challenges to livestock farming which may lead to increased loss of domestic livestock during extreme events in highly prone areas (Garderen, 2011; Kilel, 2014)

Livestock contributes to food security and diet, poverty reduction, employment and economic growth, financial saving, social security, living insurance and fertilizer. Persistent climate variability and change will continue impacting this important sector of the economy in Kenya unless action is taken (Muhati *et al.*, 2007; Shisanya *et al.*, 2011; Rourke, 2011). Hence, this study was aimed at assessing the effect past and present climate extremes on livestock and likelihood of future impact of extreme climate variability and change on livestock in the ASALs of Kenya. The four counties were chosen due to the availability of livestock data and the Zebu cattle are the livestock considered in this study.

1.6 Study area

Kenya is located between latitudes 5^0S and 5^0N and longitudes 34^0E and 42^0E. It is bordered by Uganda to the west, Tanzania to the south, Ethiopia to the north, South Sudan to the north-west, Indian Ocean and Somalia to the east. It covers an area of 58,037 (1000 Ha), agriculture 27,450 (1000 Ha), land area 56,914 (1000 Ha), forest areas 3,456 (1000 Ha) (FAO estimates, 2011). Kenyans population is approximately 44.2 m with a birth rate of 2.7% and is projected to be 96.8 m by mid-2050 (PRB, 2013). The case study area which is a subset of the ASALs of Kenya is located in the northern part of Kenya as shown in Figure 1. The main lake over the study area is Lake Turkana. In terms of altitude, Isiolo County has the lowest altitude while the highest altitude covers much of Samburu County and the western part of Turkana County.

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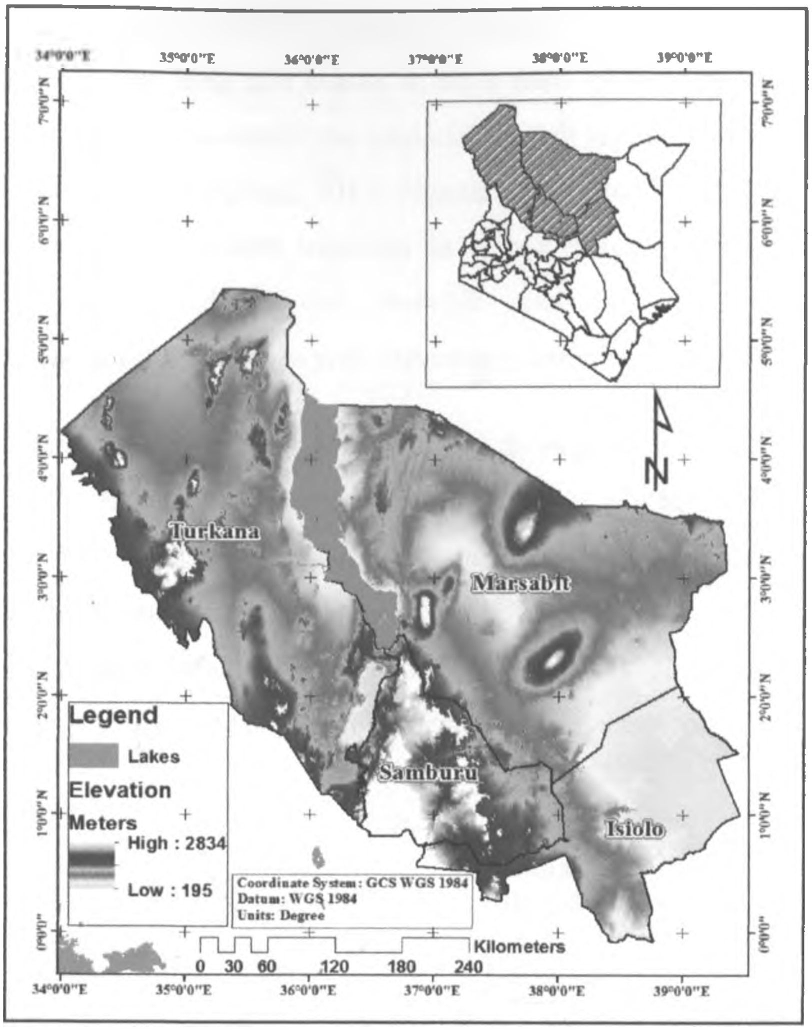

Figure 1: A map showing the elevation of the four counties i.e. Turkana, Marsabit, Samburu and Isiolo.

(*Source: Author, 2015*: Elevation data obtained from MESA)

1.6.1 Climatology of the study area

East Africa climate results from the interaction between Inter-tropical Convergence Zone (ITCZ), Indian Ocean Dipole (IOD), Quasi-biennial Oscillation (QBO), Monsoonal Winds, El Niño/Southern Oscillation (ENSO), extra-tropical systems (Mascarene, St. Helena, Azores and Arabian) and meso-scale circulations (Asnani and Kinuthia 1979; Ogallo, 1988; Mukabana and Pielke 1996; Mutai *et al.*, 1998; Nicholson and Yin, 2002; Ngaina and Mutai, 2013). East Africa experience bimodal rainfall regimes owing to its location along the Equator (Omeny *et al.*, 2006; Ngaina and Mutai, 2013). Thus most parts of Kenya experiences two rainy seasons i.e. March-April-May (MAM) known as the long rain and

October-November-December (OND) referred to as the short rains, with higher amounts mainly received during the long rain season in most parts of the country. Parts of the Rift Valley and Lake Victoria basin exhibit the trimodal rainfall regime with the third peak being observed in July and August (Gitau, 2011; Ngaina and Mutai, 2013). In his study Gitau (2011) also indicated that different locations in Kenya may have unimodal, bimodal or trimodal nature of rainfall distribution. Rainfall variability is more remarkable than temperature since temperature changes with elevation (Orindi *et al.*, 2007).

The climate of Kenya ranges from humid tropical through to arid and semi-arid climate (Orindi *et al.*, 2007). A greater percentage of Kenyan land is semi-arid and arid (Table 1, Zones V, VI, and VII), characterized by high temperatures, low rainfall, regular drought, water scarceness and climate variability (FAO, 2006; Darkoh *et al.*, 2014). The spatial and temporal variability of weather over Kenya is as a result of complex interaction of systems/processes in local, regional and global scale at various temporal scales.

Table 1: Agro-climatic zones of Kenya

Agro-climatic zone	Classification	Moisture index (%)	Annual rainfall (mm)
I	Humid	>80	1,100 – 2,700
II	Sub-humid	65 – 80	1,000 – 1,600
III	Semi-humid	50 – 65	800 – 1,400
IV	Semi-humid to semi-arid	40 – 50	600 – 1,100
V	Semi-humid	25 – 40	450 – 900
VI	Arid	15 – 25	300 – 550
VII	Very arid	<15	150 – 350

(*Source:* FAO, 2006.)

1.6.1.1 Inter-Tropical Convergence Zone

Kenyan annual cycle of rainfall is strongly linked to the north-south movement of the ITCZ (Asnani, 1993, 2005; Ngaina and Mutai, 2013). Okoola (1999) and Nicholson (2008) defined the ITCZ as a narrow zone where low-level tropical equator ward moving air mass converge from both hemispheres, it is also marked with maximum cloudiness and its migration is governed by the overhead sun. It crosses the country twice a year and therefore it's largely responsible for the bimodal rainfall pattern over most parts of Kenya due to its quasi-continental belt (Ngaina and Mutai, 2013). The meridional arm of the ITCZ fluctuates from east to west and vice versa. The July-August rainfall received over most parts of western Kenya and parts of the Rift valley has been associated with the eastward extent of the ITCZ bringing in moisture from the Atlantic Ocean and the Congo basin (Omeny *et al.*, 2006).

1.6.1.2 The Monsoonal wisnds

Monsoon is a season phenomenon responsible for most of the rainfall season within the tropics (Philippon *et al.*, 2002; IPCC, 2013). Northeast and southeast monsoons normally trails the ITCZ, they also cause drastic changes in rainfall and temperature patterns (Mukabana and Piekle 1996), thus the two main rainfall seasons are experienced during the transition periods between the peaks of the monsoons (Anyah, 2005; Gitau 2011). The monsoonal flow takes the form of a low level jet crossing the equator in east Africa (Camberlin *et al.*, 2010); these winds are modification by the inland topography (Ogallo, 1988). The differential heating of land and ocean by solar radiation is the driving force for monsoonal circulation due to ocean–land pressure contrast (Philippon *et al.*, 2002). The southeast monsoon are cool and moist, occurs during the months of June to August and it comes from the Mascarene high over the south Indian Ocean. The northeast monsoon emanates from the Arabian high and changes direction on crossing the equator to become north-westerly. They are warm and dry winds which occur during the months of December to February

1.6.1.3 El Niño/Southern Oscillation

ENSO is an irregular phenomenon that reoccur every 2 - 7 years and is caused by coupled ocean-atmosphere interactions that occur in the tropical-subtropical Indian Ocean and Pacific basins (Diaz and Markgraf, 2000; Chang and Zebiak, 2003; Rourke, 2011; IPCC, 2013). Some extreme rainfall has been associated with the ENSO events (Ogallo, 1988; Indeje *et al.*, 2000; Williams and Funk, 2011). The ENSO event has two phases known as the cold phase and warm phase i.e. La Niña and El Niño and its impacts extend to weather patterns around the globe (Chang and Zebiak, 2003; Ngaina and Mutai, 2013). Above normal rainfall amounts and flooding in the short-rain season is normally associated with the El Niño years (warm phase) (Ogallo, 1988; Nicholson, 1996; Indeje *et al.*, 2000; Muhati *et al.*, 2007). Meso-scale circulations contributes towards high spatial rainfall variability in Kenya due to diverse topography, lake surface temperature and other factors (Mukabana and Piekle 1996; Nicholson and Yin 2002; Anyah *et al.*, 2006) while dry condition during the short rain is associated with La Niña. There is a linkage between ENSO and the Indian Ocean Dipole (IOD). When the two are in phase (Positive IOD and warm ENSO event), they lead to lots of rain resulting to floods in east Africa e.g. 1961 flooding (Rourke, 2011). Rourke (2011) noted that IOD is the most dominant forcing in east African rainfall than ENSO.

1.6.1.4 Indian Ocean Dipole

The IOD is the fluctuations in the sea surface temperature (SST) anomalies across the Indian Ocean (Saji *et al.*, 1999; Webster *et al.*, 1999; Rourke, 2011). The SST anomaly leads to changes in the atmospheric circulations and rainfall across the Indian Ocean basin. Positive IOD has been observed to enhance rainfall over East Africa during the short rain season (Zablone and Ogallo, 2008; Williams and Funk, 2011; Rourke, 2011; Ngaina and Mutai, 2013). The negative IOD leads to enhanced subsidence over East Africa thus moisture is driven away from the continent leading to reduced rainfall over East Africa (Hastenrath *et al.*, 1993; Hastenrath 2000; Mapande and Reason 2005; Ngaina and Mutai, 2013). Long rains have a weak correlation with the IOD (Ogallo, 1988; Williams and Funk, 2011). This suggests that the inter-annual variability in this season is associated with the internal atmospheric variability such as Madden-Julian Oscillation (MJO) (Williams and Funk, 2011). Williams and Funk, (2011) reported that wet conditions during the early part of the long rain season are associated with the MJO.

1.6.1.5 Madden-Julian Oscillation

The MJO is an atmospheric phenomenon in the tropics developing from the Indian Ocean and propagates eastwards with a period of 30-60 days (Omeny *et al.*, 2006; Rourke, 2011). It has a strong association with the east African rainfall during the wet and dry spells of the long and short rain seasons (Williams and Funk, 2011; Rourke, 2011; Ngaina and Mutai, 2013; Berhane and Zaitchik, 2014). Williams and Funk (2011) noted that, when the amplitude of MJO is high during the long rain season, the westerly wind anomalies occurs throughout the atmospheric column above tropical Africa and overturning circulation anomalies over the tropical Indian Ocean. The effect of MJO have also been observed by Berhane and Zaitchik (2014) to occur in early March and towards the end of May (long rains) and during the last days of the short rain season. In the beginning of the short rains, MJO is associated with dry or wet spells along the East-African coast (Berhane and Zaitchik, 2014).

1.6.1.6 Quasi-biennial Oscillation

The QBO occurs in the tropical stratosphere with a period of 28–29 months and it is a quasi-periodic oscillation of the equatorial zonal wind between westerlies and easterlies and propagates downward (Indeje *et al.*, 2000; Ng'ongolo and Smyshlyaev, 2010; Rourke, 2011; IPCC, 2013; Ngaina and Mutai, 2013). Indeje and Semazzi (2000) reported that QBO has high correlation with the long rains of east African. In this regard, QBO can be used as index for long rainfall forecasting in east Africa (Ng'ongolo and Smyshlyaev, 2010), but Rourke (2011) performed the same correlation test and concluded that the correlation result are not stable for any place in Kenya and therefore QBO should not be used as an index for forecasting the long rains (MAM).

1.6.1.7 Tropical cyclone

Tropical cyclone (TC) is another system that affects the east African rainfall. It occurs mainly in the South West Indian Ocean basin up to about 100^0 E from November to May and are more common in the months of January to March. They derive their energy from the warm SST at least 26.5^0 C (Gitau, 2011; Rourke, 2011). Its effect on East African rainfall may be direct or indirect. The occurrence of TC between the months of May and April, often lead to delay and below normal rain during the long rain season over East Africa (Okoola, 1999; Ngaina and Mutai, 2013).

CHAPTER TWO

2.0 Literature review

This section presents literature review on livestock, and climate extremes in Kenya. The future climate change and threats to future livestock systems are also addressed.

2.1 Importance of livestock in Kenya

Cattle's farming remains a central feature of rural populations. Statistics by the African Union indicates that pastoralism contributes between 10% and 44% of the GDP of the African continent (Abdel Aziz, 2011; Garderen, 2011)/. The livelihood of the African continent over time has mainly been livestock domesticated farming (Garderen, 2011). Northern Kenya's ASALs depend mostly on livestock, which account for more than two-thirds of mean income (Makishima, 2005; Chantarat *et al.*, 2013). They are sold for grains or to meet other domestic requirements (Mureithi and Opiyo, 2010). When the pastoralist lose their livestock, they organize social insurance activities that offer informal inter-household transfers of a breeding cow, but the scheme does not cover everyone (Huysentruyt *et al.*, 2009; Santos and Barrett, 2011; Chantarat *et al.*, 2013).

Cattle breeds in Kenya comprise of Sahiwal, Boran, Maasai zebu, Kamba zebu, Charolais, and Simmental and their crosses, Friesian and Ayrshire dairy cattle breeds have also been introduced in some areas of Kenya (Mwacharo and Drucker, 2005). The Zebu cattle are tethered on farm, taken to graze on the roadsides or in communal areas. They are mainly kept for beef and milk (FAO, 2006), and the cows are milked for approximately five months of lactation. Most of the dairy farmers in Kenya practice zero grazing, free–grazing or a combination of both (FAO, 2006).

Livestock production in northern Kenya is characterized by low productivity as a result of poor and degraded rangelands due to drought, insecurity, diseases outbreaks, absence of veterinary care and inadequate livestock marketing systems among other factors (Mureithi and Opiyo, 2010). There is need to increase livestock productivity in the ASALs of Africa including Kenya, this is because the demand for livestock products has increased globally.

This will lead to changes in livestock production in Africa to meet the increasing demand (Tolera and Abebe, 2007; Thornton *et al.*, 2009).

2.2 Climate extremes affecting cattle farming

Spatiotemporal variability of precipitation in East African affects the livelihood of tens of millions of people in terms of flash floods, droughts, and rainfall variability on intra-seasonal time scales (Berhane and Zaitchik, 2014; Omondi *et al.*, 2014). Agricultural production losses due to extreme weather have been documented to have some degree of positive spatial correlation, since weather patterns are generally similar over a large area. Drought in particular, affects both agriculture and pastoralisms and its highest impacts are felt by the pastoralists since it results to drying up of water resources and reduction in forage resources for livestock (Muhati *et al.*, 2007; Orindi *et al.*, 2007; Omondi *et al.*, 2014). Garderen (2011) reported that scientists in southern Africa and elsewhere focusing on climate change and agriculture are increasingly demonstrating how sensitive livestock is to climate change.

Climate change and variability leads to the spatial distribution of disease outbreaks (Hoffmann, 2010). Seasonal rainfall changes leads to outbreaks of Rift Valley Fever (RVF), Pest des Petits Ruminants (PPR), bluetongue virus, East Coast Fever (ECF), Foot and Mouth disease (FMD), facial eczema and anthrax among others, and they are mainly set off by definite weather conditions (Hoffmann, 2010; Mureithi and Opiyo, 2010). Livestock resistance and immunity to diseases are diminished by drought and are likely to be exposed to new diseases due to rapid increase of pathogens and seasonal variation in disease distribution (Hoffmann, 2010; Mureithi and Opiyo, 2010). Policy and response in terms of climate change and agriculture over different regions tend to focus more on crops (Garderen, 2011); therefore, these need to examine the impact of climate variability on livestock farming.

2.2.1 Drought

Drought is climate phenomenon that occurs naturally affecting large population globally and is considered to be a widespread and costliest natural disaster (Below *et al.*, 2007; Sheffield and Wood 2011; NCDC, 2012; Sheffield *et al.*, 2014, Di Lena *et al., 2014*). A study by

UNISDR (2009) indicated that drought accounts for more than 80% of the population affected but accounts for less than 20% of natural disasters. The most recent drought has led to famine as well as food shortages over southern Somalia and northern Kenya with an estimate of 250,000 deaths in southern Somalia (UNOCHR, 2011; FAO/FEWSNET, 2013). Drought leads to low quality and quantity of forage and thus decreases livestock productivity while reduced availability of water increases the chances of water-borne diseases for livestock and humans (FAO, 2006; Hoffmann, 2010; Mureithi and Opiyo, 2010; Rourke, 2011). FAO (2006) also reported that during this period, water is limited since most springs are seasonal. The extensive effect of drought has led to debate on how the drought will change in the future under the effect of the changing climate (Kotir, 2011). It has been reported that droughts in the ASALs of Kenya are a common phenomenon with 28 major droughts recorded in northern Kenya for the past 100 years (GoK, 2007, Christensen *et al.*, 2007). Mureithi and Opiyo (2010) observed that mature cattle and calves are more vulnerable to the negative effect of drought. Table 2 shows the analysis done by the Kenya Post Disaster National Assessment (PDNA, 2012) for the drought period spanning 2008 to 2009 and estimated the disaster risk reduction needs at Ksh 184.8 billion. Failure of the 2008 short rains was declared a national disaster since it had impact on water, pasture, food among other resources (Hastenrath *et al.*, 2010). The analyses (PDNA, 2012) also showed that livestock sector was significantly affected by the drought leading to death of different types of domestic animals to an estimated amount of Ksh. 56.1 billion. Rift Valley province had the highest damage in 2009 but in 2011, Eastern province suffered the highest damage (PDNA, 2012).

Table 2: Overall summary of damages, losses, and needs by sector in million Ksh for 2008-2011 Drought

Sectors	Impact			Needs			Indicative DRR Needs
	Damage	Losses	Total	Recovery	Reconstruction	Total	
Agriculture		121,104.1	121,104.1	5,048.8		5,048.8	13,736.8
Livestock	56,141.7	643,194.5	699,336.2	50,237	56,142	106,379	85,103.0
Fisheries	502.6	3,661	4,163.6	406.4	753.9	1,160.3	2,991.2
Agro-industry		7,159.6	7,159.6			-	
Health		4,745.7	4,745.7	5,099		5,099	
Nutrition		6,699.4	6,699.4	225.1		225.1	130.9
Education	41.9	3,937.8	3,979.7	590.1	55.7	645.8	3,592.1
Energy		32,392.3	32,392.3	13,000		13,000	
Water & sanitation	7,736.1	80,466.9	88,203	4,964.2	12,304.1	17,268.3	78,627.3
Environment, Tourism Forestry, Wildlife	22.2	762.4	784.6	7,387.9		7,387.9	647.5
Total	64,444.5	904,123.7	968,568.2	86,958.5	69,255.7	156,214.2	184,828.8

(*Source:* PDNA, 2012).

Demand for water and pasture in northern Kenya has led to community conflicts which are mainly seasonal and escalates during the dry season when the competition over water and grazing land intensifies and may involve cross-border conflicts (Mkutu, 2001; Oguge *et al.*, 2006; Orindi *et al.*, 2007; Mureithi and Opiyo, 2010). Orindi *et al.* (2007) indicated that, when drought occurs, pastoralists are faced with several challenges including; low productivity level, high mortality rate, poor calving rates and reduced animal weight that leads to low market value. Due to climate change and variability, these conflicts on natural resources are likely to increase in the future, therefore, there is need for research on the future climate change impact on natural resources.

2.2.2 Floods

Floods in Kenya are mainly associated with the positive phase of ENSO (El-Niño). The 1997/98 El-Niño lead to an outbreak of Rift Valley Fever (RVF) which is a vector borne disease transmitted by mosquitoes (genus Aedes) which breed in flooded areas. The RVF was first discovered in Kenya in 1931 (Indeje *et al.*, 2006) in the Rift Valley where the flock suffered serious losses. Kenya was a net exporter of dairy products till 1990s, but since 1997, exports have declined and imports have grown (FAO, 2006). The 1997/98 flood caused the Greater Horn of Africa (GHA) millions of dollars and negative impact to pastoralist livelihoods due to the RFV outbreak and trade bans (Indeje *et al.*, 2006). It was also reported that many cases were confined in the northern and northeastern Kenya during this period and was related to 1961/62 incidence. Indeje *et al.* (2006) also reported that the RVF occurs in Kenya at intervals of 3-12 years.

It has also been reported that temporal and spatial patterns of NDVI in the semi-arid areas of East Africa has a significant relationship with rainfall (Davenport and Nicholson 1993; Anyamba *et al.*, 2002; Indeje *et al.*, 2006). Davenport and Nicholson (1993) reported that this significant relationship (about 0.89) between annually integrated NDVI and the log of annual rainfall occurred when the annual rainfall was below 1000 mm and monthly rainfall below 200 mm. Indeje *et al.* (2006) found out that NDVI can be used to forecast RVF with a 1-3 months lead time and that it has better forecasting skill over the lowlands of Kenya and Tanzania.

2.2.3 Heat stress

Heat stress has been defined by Hansen (2009) as the environment that drives body temperature above a particular temperature threshold, above which key physical functions are, disrupted (e.g. feeding and reproductive health). Heat stress also increases mortality (Hoffmann, 2010). Genetic adaptation to higher temperatures is a function of the regulation of body temperature and cellular resistance (Garderen, 2011). Dangerous body temperatures in most species are beyond 45–47^{0}C and therefore heat stress is an important factor in determining suitable environment for livestock farming (Zwald *et al.*, 2003; Hoffmann, 2010). An observation by Hansen (2009) also concluded that mammals tend to be more tolerant of low temperatures than high temperatures.

Increase in temperature has impacted cattle farming in many ways and research has focused mainly on the issue of heat stress. It is also a fact that different cattle breeds have different thermoregulatory capacity (Garderen, 2011). The high productive modern dairy cow starts to lose the ability to regulate body temperature at air temperatures ranging from 25^{0}C to 29^{0}C. Pszczola *et al.* (2009) noted that heat stress causes a decline in fertility in the summer in all regions of the United States.

From a range of literature Garderen (2011) summarized key temperature thresholds critical to cattle heat stress as shown in Table 3 below. He also indicated that 32^{0}C appears to be the generally accepted comfort threshold for most cattle breeds. Temperature–Humidity Index (THI) or dry-bulb temperature is also given in Table 3. Hoffmann (2010) reported that "Dry-bulb temperature or THI are used to as indicators of heat stress."

Table 3: Temperature thresholds critical to cattle heat stress

Threshold	*Relevant to*
72 THI (22^{0}C at 100% humidity)	Comfort threshold for U.S. Holsteins heat stress (Sanchez *et al.*, 2009; Ravagnolo *et al.*, 2000; Freitas *et al.*, 2006)
72 THI (22^{0}C at 100% humidity)	Comfort threshold for high-producing dairy cows (Hernandez *et al.*, 2002); higher for *Bos indicus* breeds (which are highly adapted to heat stress)
27^{0}C	Upper limit of comfort zone for maximum milk production in India, which is 2^{0}C higher than for temperate countries (Sirohi and Michaelowa 2007)
28^{0}C and high humidity	Heat stress begins in most breeds (Agricultural Information Centre, Government of Alberta)
30^{0}C ambient temperature	Point at which *Bos Taurus* and *Bos indicus* show differing response to heat stress (Hernandez *et al.*, 2002)
32^{0}C	Accepted comfort threshold for most cattle breeds
78 THI	Critical limit for every kind of livestock

(*Source:* Garderen, 2011.)

2.3 Climate conditions for cattle farming

The rangelands have limited support for crop farming but they support livestock farming i.e. cattle, goats, sheep, donkeys and camels (FAO, 2006). Water is important in livestock production system. Animals mainly drink water daily to be productive and every few days for their survival (King, 1983). King (1983) reported that East African Zebu can be estimated to take 140 liters of water per day. Hansen (2009) and Hoffmann (2010) identified heat stress as an important component that drives body temperature for livestock above a particular temperature threshold. High temperature has a negative effect on their normal functionalities i.e. feeding, reproductive health and increase in mortality. On average, the high productive dairy cow starts to lose the ability to regulate body temperature at air temperatures of 32^0C as summarized by Garderen (2011) in Table 3.

2.4 Livestock adaptation to climate change

Adaptation is the ability to produce and reproduce by cattle breeds in a given environment or acquiring alternative breeds for a specific environment as defined by Barker (2009). IPCC defined adaptation as "the initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (Pachauri and Reisinger, 2008; Hoffmann, 2010; IPPC, 2013). Adaptation behaviors are characterized by low heritability, and one way to adapt to climate change is through the utilization of animal genetic variety (Hoffmann, 2010). Hoffmann (2010) reported that ruminants have higher degree of thermal tolerance than mono-gastric species and therefore, there are substantial differences in thermal tolerance between species. Breeds in temperate regions supply bulk product in the market but they don't adapt well to heat stress (Hoffmann, 2010). Several research have been done on heat stress but still there is need for simulating livestock adaptation to climate change and future impacts of climate change on livestock farming under the changing climate.

Zebu cattle have been reported to sustain low rectal temperatures, low respiratory rates as well as low water intake (King, 1983; Hoffmann, 2010). A study by Moonga and Chitambo (2010) deduced that traditional livestock breeds are likely to play a significant role in adaptation to climate change. It has also been reported that commercial dairy and beef are more vulnerable to the effect of climate change than small farms (Hoffmann, 2010). Therefore there is need for more research on the adaptive nature of traditional livestock to different climatic conditions.

Pastoralism in harsh climatic conditions has been the livelihood of many communities in northern Kenya for centuries (Birch and Grahn, 2007; Schilling *et al.*, 2011). In case of losses (animal death), the pastoralist borrow money from families and friends in order to restock their animals. They also migrate in response to spatiotemporal variability in water availability and forage (Chantarat *et al.*, 2013). In order for farmers to protect their livestock from the physiological stress of climate change, they need access to capital and technologies (Hoffmann, 2010) otherwise, breed displacement and losses may increase. The Government of Kenya (GoK, 2010) has prioritize livestock as an area for policy support and recommended the creation of special livestock insurance schemes to transfer or spread climate related risk that impacts negatively on the livestock sector mainly on the on northern Kenya. Donor agencies and governments have developed and implemented ways of reducing the vulnerability of pastoralists to the impacts of drought (Orindi *et al.*, 2007).

Hoffmann (2010) gave two ways in which climate change adaptation can be considered. These ways are, "How can animals genetic resources cope with and adapt to climate change while continuing to contribute to food security and rural livelihoods?" and "How can the option value of genetic resources be maintained and potential loss of diversity minimized in the event of climate change?"

As the temperature rises, livestock models that consider agro-ecological conditions, production systems and climate change effects have indicated that farmers will change from cattle and chickens farming to goats and sheep as shown in Table 4 (Orindi *et al.*, 2007; Herrero *et al.*, 2008; Seo and Mendelsohn, 2008; Hoffmann, 2010). An example is the Sahel region where cattle have been replaced by dromedaries and sheep replaced by goats. They also indicate that livestock in ASALs of Africa will expand at the cost of humid and temperate highlands systems provided that there will be enough rainfall to support vegetation growth (Seo and Mendelsohn, 2008; Hoffmann, 2010). It is also important to note that environmental degradation is likely to worsen the impact of climate change which further leads to increased cost of climate change adaptation (Hoffmann, 2010).

Table 4: Projected human and livestock population over Africa

Population ('000)	Year		
	2000	**2030**	**2050**
Human Population	30,529	41,169	44,313
Cattle	13,840	12,988	12,452
Goat	9,600	11,058	10,803
Sheep	8,439	9,415	9,157

(*Source:* Orindi *et al.* 2007)

Coping strategy by the pastoral communities are aimed at facilitating recovery and minimizing losses due to drought (Orindi *et al.*, 2007). They also keep mixed herds as a means of risk management since different group of animals are affected differently during drought. The knowledge of coping and adapting to the effect of climate change by farmers should be the foundation for designing agricultural innovation systems to deal with climate change impacts (Lema and Majule, 2009). Lema and Majule (2009) recommended that communities in the semi-arid areas should focus more on water harvesting in order to store water for livestock and crops. There is need not only to harvest and store water but also to identify areas that are adversely affected by the climate extremes in the ASAL regions of Kenya.

New climate change model outputs are available from Coordinated Regional Downscaling Experiments (CORDEX). In order to achieve the objective of this study, CORDEX datasets were used to assess the future impact of extreme climate change and variability on livestock in ASALs of Kenya.

CHAPTER THREE

3.0 Data and methodology

This chapter presents the data type and source together with the methodology that were employed to address the specific objectives of this study.

3.1 Data

The data used include rainfall, maximum and minimum air temperature all at monthly time series, yearly livestock population data set, and the CORDEX Representative Concentration Pathways (RCP 4.5 and 8.5) data. Detailed descriptions of the data set that were used and their sources are described in the next sub-sections.

3.1.1 Observed climate and livestock population data

Monthly rainfall and temperature data set for the period 1961 to 2013 were used. These data sets were obtained from the IGAD Climate Prediction and Prediction Centre (ICPAC). Livestock population data from 1970 to 2012 was obtained from Food and Agricultural Organization of the United Nation (FAO) department of livestock production. This data mainly consisted of beef cattle and dairy cattle of the Zebu breed for different counties in northern Kenya.

3.1.2 Climate Research Unit Data

The CRU gridded observations dataset for station and satellite data from the University of East Anglia (UEA) and provides a gridded monthly time series from 1900 to present covering the global land surface and have been interpolated over a 0.5^0 x 0.5^0 grid spacing (Mitchel *et al.*,2005; Omondi, 2010). This data set is based on an angular-distance weighted (ADW) interpolation method similar to that of Willmott *et al.* (1985) using the station data. CRU version CRUTS 3.2.2 was extracted from the University of Anglia database for the period 1961 to 2013. In this study, precipitation, maximum and minimum surface air temperature were used to examine the effect of past climate on cattle farming and for model validation. Studies that have used CRU data set over East Africa have shown that CRU is a good representation of rainfall in relation to station observation over the region (Sabii, 2008; Omondi, 2010; Otieno, 2014).

3.1.3 Climate projection data sets

The CORDEX representative concentration pathways (RCPs) are a set of four new pathways (near-term and long-term modelling experiment) developed for the climate modelling community (Van Vuuren, *et al.*, 2011). They span a range of years up to 2100 with values of radiative forcing being 2.6, 4.5, 6.0 and 8.5 W/m^2 (RCP2.6, RCP4.5, RCP6.0 and RCP8.5 respectively). RCPs are developed scenario set containing emission, concentration and land use trajectories (Moss *et al.*, 2010; Van Vuuren *et al.*, 2011; IPCC, 2013). An overview of the RCPs is given in Table 5 below. From literature, RCP8.5 is seen as a high emission scenario, RCP6.0 is medium baseline or a high mitigation case, RCP4.5 may be considered as an intermediate mitigation scenario and RCP2.6 is lowest mitigation scenario (Van Vuuren *et al.*, 2011). These characteristics are summarised in Table 6.

The CORDEX RCPs climate scenario runs were initiated by the world climate research program using the domain of Africa (Endris *et al.*, 2013). The runs were forced by lateral and surface boundary condition from the European Centre for Medium Range Weather Forecasting (ECMWF) Interim Re-Analysis (ERA-Interim). The simulations for CORDEX African domain were performed at 50 km resolution and the experimental data are available for the period 1989-2008 (Endris *et al.*, 2013).

The climate projection dataset were obtained from ICPAC data repository for the period 2006 to 2100. Simulated monthly rainfall and maximum temperature from the CORDEX models (RCP4.5 and RCP8.5) we used in this study.

Table 5: Overview of the representative concentration pathways

	Description	Publication-IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100.	(Riahi *et al.*, 2007)-MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100.	(Fujino *et al.*, 2006; Hijioka *et al.*,2008)-AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100.	(Clarke *et al.*, 2007; Smith and Wigley 2006; Wise *et al.*, 2009) – GCAM.
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).	(Van Vuuren *et al.*, 2007a; Van Vuuren *et al.*, 2006)-IMAGE

(*Source:* Van Vuuren, 2011)

Table 6: Main Characteristic of each representative concentration pathways (RCPs)

Scenario Component	**RCP2.6**	**RCP4.5**	**RCP6**	**RCP8.5**
Greenhouse gas emissions	Very low	Medium-low mitigation. Very low baseline	Medium baseline; high mitigation	High baseline
Agricultural area	Medium for cropland and pasture	Very low for both cropland and pasture	Medium for cropland but very low for pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium-low	Medium	Medium	Medium-high

(*Source:* Van Vuuren, 2011)

3.1.4 Estimation of missing data

The World Meteorological Organization (WMO) standards for estimating missing data is that, the missing data of a station should be less than 10% of the total records. There are several techniques for estimating missing data including; Thiessen polygon method, Isohyetal method, the arithmetic means, the isopleths method, finite differencing method, Correlation and regression method.

Station correlation analysis was used to estimate the missing data for a station. When the correlation value is +1, it denotes perfect positive linear relationship and if it is -1, it denotes a perfect negative linear relationship (Indeje *et al.*, 2000).The period with complete data was correlated with the neighboring station using Equation 1.

$$r_{xy} = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2 \cdot \frac{1}{N}\sum_{i=1}^{N}(y_i - \bar{y})^2\right]^{1/2}} \quad (1)$$

Where (Equation 1), r_{xy} is the correlation coefficient between the values of the two stations, N is the total number of years with complete records, x_i is the available datasets for station with missing data, $\bar{x}$ is the mean of the available data for the same station, y_i is the dataset for the neighboring station with complete records and $\bar{y}$ is the long-term mean of the station with complete records.

The student T-test was used to test for the significance of the correlation coefficient by comparing the t-statistic given as Equation 3. Correlation coefficient is significant if the computed value of t is greater than the tabulated value for a given value of confidence.

$$t_{n-2} = r\sqrt{\frac{(n-2)}{1-r^2}} \quad (2)$$

Where, n represents the length of the data that were used, $n-2$ is the degrees of freedom, t_{n-2} is the value of the confidence level computed from the correlation coefficient and r is the correlation coefficient.

In order to fill in the missing records, a regression equation using the least-squares approach was developed. Regression equation of the form given in Equation 2 was developed for the period with complete data and then used to estimate the record in the station with missing data.

$$y_i = a + b_1 x_1 \tag{3}$$

Where, x_i are the predictor, a and b_i are constants, and y_i is the predicted missing value for the affected station with missing data.

3.1.5 Homogeneity tests

Quantitative climate analyses require a good foundation of reliable climate data. However, several factors affect the quality of data and should be considered for any analyses (Sahin and Cigizoglu, 2010). The common techniques of evaluating data quality are single and double-mass curves. It should be noted that this method have been adopted in many past. Conversely, Coaster and Soares (2009) hold that these methods are subjective and should only be used for trial purposes without any scientific interest. Much robust methods were therefore applied in this study, i.e. Standard Normal Homogeneity Test (SNHT), Pettitt test, Buishand range test, and Von Neumann ratio. These techniques have been found useful for testing the homogeneity of climate dataset (Pettitt, 1979; Wijngaard *et al.*, 2003; Costa *et al.*, 2008; Costa and Soares, 2009; Kang and Yusof, 2012; Orlowsky, 2015).

These methods involve transforming the data to a value statistic that can be assigned a critical value depending on the size of the dataset. The SNHT is more sensitive to detect inhomogeneity near the beginning and the end of the dataset. However, the Buishand test is powerful in detecting breaks at the middle of the data (Wijngaard *et al.*, 2003; Sahin and Cigizoglu, 2010). According to Pettitt (1979), the Pettitt test can be used to detect a single breakpoint in a time series. The SNHT is given by Equation 4 while the Buishand test is given by Equation 5 (González-Rouco *et al.*, 2001; Tank, 2007; Sahin and Cigizoglu, 2010; Orlowsky, 2015).

$$T(k) = k\bar{z}_1^2 + (n-k)\bar{z}_2^2 \qquad k = 1, \dots, n \tag{4}$$

Where

$$\bar{z}_1 = \frac{1}{k}\frac{\sum_{i=1}^{k}(Y_i - \bar{Y})}{s} \quad \text{And} \quad \bar{z}_2 = \frac{1}{n-k}\frac{\sum_{i=k+1}^{k}(Y_i - \bar{Y})}{s}$$

In Equation 4, Y_i is the annual series to be tested, $\bar{Y}$ is the mean, k years of record with that of the last n-1 years and s is the standard deviation.

$$S_0^* = 0 \;\; and \;\; S_k^* = \sum_{i=1}^{k}(Y_i - \bar{Y}) \qquad k = 1, \dots, n \tag{5}$$

The terms (Eqn. 5), S^*_k is the partial sum of the given series, Y_i is the annual series, and $\bar{Y}$ is the mean. A series is said to be homogeneous when the value S^*_k fluctuates around zero, since there is no deviations of Y_i values with respect to the mean (González-Rouco *et al.*, 2001; Tank, 2007; Sahin and Cigizoglu, 2010).

Pettitt test is based on the rank, r_i of the Y_i and does not consider the normality of the series and it's given by the equation below.

$$X_y = 2\sum_{r=1}^{y} r_i - y(n+1), \;\; y = 1,2, \dots, n \tag{6}$$

Where the break occurs at year k is given by

$$X_k = \max_{1 \le y \le n} |X_y| \tag{7}$$

The simulated values of Pettitt are given in Table 7 which can be compared with the analyzed result.

Table 7: 1% and 5% critical values for X_k of the Pettitt test as a function of n.

n	20	30	40	50	70	100
1%	71	133	208	293	488	841
5%	57	107	167	235	393	677

The final test is the Von Neumann ratio test, it uses the ratio of mean square successive (year to year) difference to the variance (Costa and Soares, 2009; Kang and Yusof, 2012). If the sample is homogeneous, the expected value is two (N=2). If there is a break in the sample, then the value of N is lower than 2. The Von Neumann ratio test is given by Equation 8 (Kang and Yusof, 2012).

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \quad (8)$$

The result of these test were categorized into three classes, i.e. "useful", "doubtful" and "suspect" depending on the number of rejected null hypothesis which state that, the annual values Y_i of the testing variable Y are identically distributed, independent and it's homogeneous at 1% significant level (Wijngaard *et al.*, 2003; Kang and Yusof, 2012; Orlowsky, 2015). The data was classified as useful if it rejected one or none null hypothesis under the four tests, it was then considered as homogeneous and can be used for further analysis. If the series reject the two null hypotheses of the four tests, it was then considered doubtful and was inspected before further analysis. A data series was considered suspect if it rejects three or the four null hypotheses and therefore was not considered for further analysis (Wijngaard *et al.*, 2003; Kang and Yusof, 2012). This classification was adopted in this study to analyze observed data homogeneity.

3.2 Methodology

Methodologies presented in this section are those that were used to address the specific objectives of the study. These include methodologies for determining the evidence of variability and changes in rainfall and temperature extremes in Kenya ASALs, assessing the changes in livestock population that may be associated with past and present climate extremes, and assessing the future climate change scenarios and their potential impacts on pastoral systems in ASALs of Kenyan.

3.2.1 Determining the evidence of variability and changes in rainfall and temperature extremes in Kenya ASALs

This specific objective was investigated through analyses of the past trends in both rainfall and surface air temperature. Three methods were adopted in this study namely arithmetic average method comparing averages of two sub-periods, Graphical analysis and time series analysis. Under arithmetic mean method, the observed data for the individual seasons (DJF, MAM, JJA, and SON) were grouped into four categories namely 1901 - 1930, 1931 – 1960, 1961 – 1990, and 1991 - 2013. The WMO climatological baseline of 1961 to 1990 was used to assess the change in the mean with the period 1991-2013 and their statistical differences tested using the student t-test (see Equation 3). Graphical method involved the spatial analysis of the distribution of rainfall and surface air temperature over the study area, while time series analysis were trend test, cyclic and the seasonal analysis

Gaussian Kernel density distribution was also used to assess change in the patterns of the extremes over the study area (Equation. 9).

$$g_y(fs) = \sum_{t=1}^{T} \frac{1}{h^N} K\left(\frac{y_t - fs}{h}\right) \quad (9)$$

Where fs is the variable, *K:* is the Kernel, *h* is a scaling factor (Bandwidth), *N* is the number of sample, and h^N indicates *h* to the power of *N* (Terrell and Scott, 1992; Bessa *et al.*, 2012; Mohseni *et al.*, 2014).

Several studies have also used this method to analyze the evidence of climate change (IPCC, 2012; Bessa *et al.*, 2012; Ogungbenro and Morakinyo, 2014; Mohseni *et al.*, 2014; McCabe *et al.*, 2014; Chu *et al.*, 2015; Chen *et al.*, 2015, Van Ackooij and Minoux, 2015). Gaussian Kernel density distribution method examines changes in the first four moments represented with mean, variance, skewness and kurtosis coefficients (IPCC, 2012).

Mann-Kendall trend test was then used to examine the trends in rainfall and surface air temperature using Equation. 10.

$$tau = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (10)$$

Where x_j are the sequential values, n in the length of the data set, and

$$\mathrm{sgn}(\theta) = \begin{cases} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{cases} \quad (11)$$

This test was suggested by Mann in 1945 and it has been widely used (Yue *et al.*, 2002; Hipel and McLeod, 2005; Hamed, 2008; Ngaina and Mutai, 2013; Orlowsky, 2015).

In this test, *tau* is the test statistic and it gives a positive trend when the value of *tau* is positive and negative trend when *tau* gives a negative value. The level of significance used in this study was 0.05 (P-value=0.05). The trend tests were considered significant if their P-value was equal to or less than 0.05 (P-value =< 0.05).

3.2.2 Assessing the changes in livestock population that may be associated with past and present climate extremes

This specific objective investigates the effect of climate extremes on cattle farming in the ASALs. Cattle start to lose its ability to regulate body temperature at an air temperature of 29^0C. From a wide range of literature Garderen (2011) summarized key temperature thresholds critical to cattle heat stress as shown in Table 3. Accepted comfort threshold for most cattle breeds is 32^0C (Garderen, 2011). In this study, temperature 32^0C was used as the comfort threshold for cattle farming.

Indices have been developed in recent years to detect and monitor drought. The more commonly used ones are the Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI). The SPI which is the World Meteorological Organization (WMO) approved index for meteorological drought (McKee *et al.*, 1993; Bonaccorso *et al.*, 2003; WMO, 2012; Sheffield *et al.*, 2014) was adopted in this study to identify the abnormal wetness and dryness of an area. This index is marked with its simplicity and its ability to identify the onset, the ending, and the severity levels of a drought event (Christos, 2011).

The SPI computation starts with building a frequency distribution for rainfall data at a place for a given time period (Wu *et al.*, 2001; 2005). Wu *et al.* (2001) further highlighted that a probability distribution function gamma is then fitted in order to determine the cumulative distribution of precipitation. With zero being the mean and one being the variance, the standard normal distribution is obtained by an equi-probability transformation (Figure 2) made from the cumulative distribution (Wu *et al.*, 2001; Wu *et al.*, 2005; Cancelliere *et al.*, 2007). The transformation probability is then referred to us the SPI value which ranges from - 2.0 to + 2.0 (Edwards, 1997; Wu *et al.*, 2001). The SPI calculation requires at least 30 years period of data with no missing data and users can choose the time scale (1, 2, 3, ..., to 72 months) of the SPI for different application (Edwards, 1997; Wu *et al.*, 2001; Wu *et al.*, 2005; Cancelliere *et al.*, 2007). Table 8 gives the threshold that categorizes different types of drought (Cancelliere *et al.*, 2007; WMO, 2012).

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{For } x > 0 \qquad (12)$$

Where α is a shape parameter (α > 0), β is a scale parameter (β > 0), x is the precipitation amount ($x > 0$), and

$$\Gamma(\alpha) = \int_0^{\infty} y^{\infty-1} e^{-y}\, dy \qquad (13)$$

Where Γ (α) is the gamma function (Wu *et al.*, 2005).

The SPI values are computed through the following simple standardization procedure (Equation 13).

$$Z_{v,\tau}^{(k)} = \frac{Y_{v,\tau}^{(k)} - \mu_{\tau}^{(k)}}{\sigma_{\tau}^{(k)}} \qquad (14)$$

With

$Y_{v,\tau}^{(k)} = \sum_{i=0}^{k-1} X_{v,\tau-i}$ being the aggregated precipitation at k months, μ_τ being the mean at τ months and σ_τ is the standard deviation at τ months (Cancelliere *et al.*, 2007).

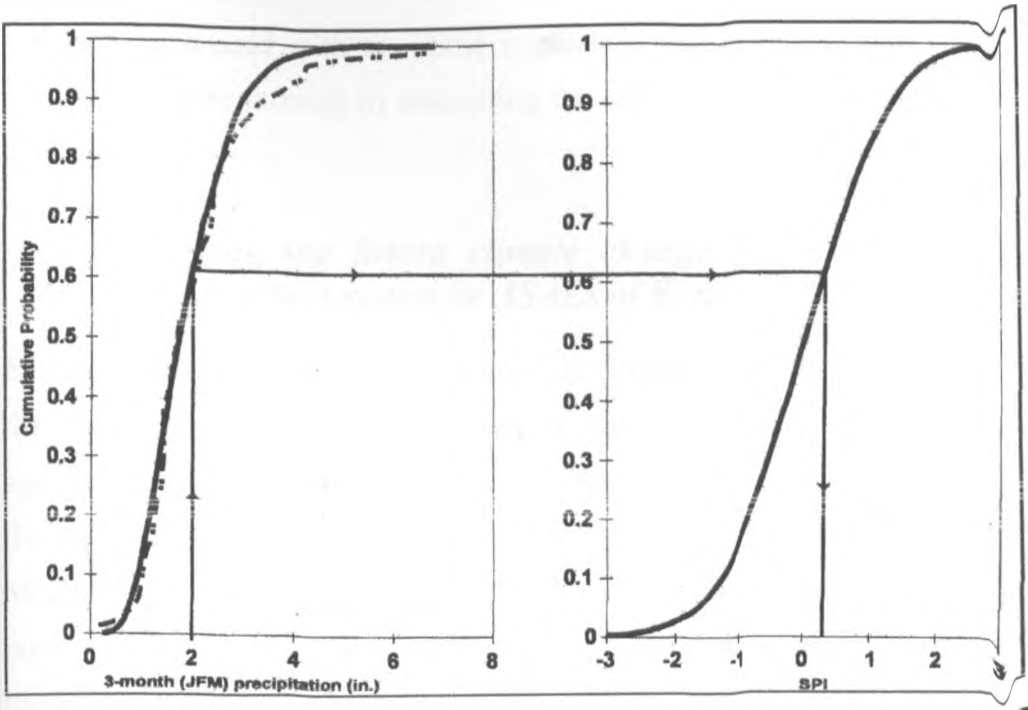

Figure 2: SPI equi-probability transformation corresponding to a 3-month SPI

(*Source:* Wu et al. 2001)

Table 8: Standardized Precipitation Index (SPI) values

2.0 +	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

(*Source:* WMO, 2012)

The SPI is better than PDSI since it gives a better representation of abnormal wetness and dryness of an area, it is also less complex than PDSI among other indices since the only input is precipitation and that it can be computed for different time scale (Wu *et al.*, 2005; Cancelliere *et al.*, 2007; WMO, 2012; Di Lena *et al.*, 2014). Its main shortcoming is that it doesn't account for the effect of temperature (Di Lena *et al.*, 2014). The SPI analysis was done at different run time i.e. 3, 6, 12, 24, 36, and 48 months. The results generated by the

SPI were then used with the cattle population dataset to examine the effect of climate extreme on cattle farming by comparing the cattle population for the extreme wet and dry conditions.

3.2.3 Assessing the future climate change scenarios and their potential impacts on pastoral system in ASALs of Kenya

Each model has its weaknesses and strengths (Endris *et al.*, 2013), therefore, an ensemble of the models was computed and its performance evaluated with the other individual models against observation. In order to assess the performance of the models against observations, the study used the following methods: time series analysis, model bias, correlation, Root Mean Square Difference (RMSD), and Standard Deviations (SD). Time series analysis was noted to be a subjective way of identifying the best model that replicates the observation, therefore, model bias, correlation analysis, RMSD and SD methods were used to identify the best model. Taylor diagram was used in the study since it provide a statistical summary of how well patterns match each other in terms of their correlation, RMSD, and SD when tracking changes in performance of a model (Taylor, 2012). From Figure 3, the position of each letter appearing on the plot quantifies how closely the model's simulates the observations. The closer the models are to the observation, the more reliable the models are in simulating the observation.

Below is the Taylor diagram equation,

$$E^2 = \sigma_p^2 + \sigma_o^2 - 2\sigma_p \sigma_o \rho_{po} \qquad (15)$$

Where E is the mean square error, σ_p is the standard deviation for model simulated and σ_o is the standard deviation for observed value and ρ_{po} is the correlation between model predicted values and observed values.

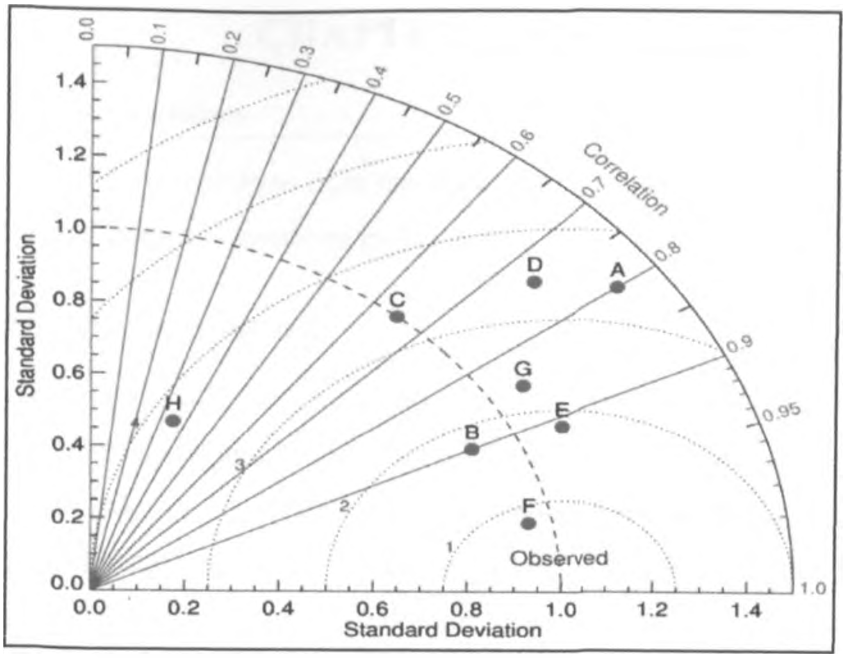

Figure 3: Schematic representation of Taylor diagram.

(*Source:* Taylor, 2012)

To achieve this specific objective, the chosen model was then subjected to further analysis which involved Gaussian kernel method, graphical methods, and the SPI analysis. Graphical methods were used to assess the possible impact of the future climate change scenarios (2030, 2050, and 2070) on cattle farming in the study area based on the temperature thresholds discussed in section 3.2.2 above, future suitable cattle farming areas were developed for different seasons in a year (DJF, MAM, JJA and SON). In this study, the comfort threshold for cattle were classified as non-existing for temperature less than 30^0C, moderate for 30–32^0C, moderately high for 32–34^0C, and severe for temperatures greater than 34^0C. The Gaussian kernel method discussed in subsection 3.2.1 was also used with the future non-overlapping climatic period which were 2017-2046, 2047-2076, and 2077-2100, to analyse future climate change for rainfall and maximum temperature. The SPI method as discussed in subsection 3.2.1 above was also used to analyse the future occurrences of abnormal wetness and dryness (Table 8) and their periodicity and magnitude over the study area under the current climate scenarios (RCP 4.5 and RCP 8.5).

CHAPTER FOUR

4.0 Results and Discussion

The results and discussion that arise from the various methods that were used to achieve the main objective of the study are presented in this chapter.

4.1 Data Quality Control

The observed datasets (rainfall, maximum and minimum temperature) that were used in this study were subjected to homogeneity test. Two significant levels were used in these tests i.e. 1% significant level (p1), 5% significant level (p5) while NS means Not Significant in Table 9. Observed rainfall data was found to be homogeneous for both Lodwar and Marsabit stations (Table 9) with a Von Neumann ration of 1.96 and 1.99 respectively. Temperature data set was noted to be "suspect" (inhomogeneous) except maximum temperature for Marsabit which was "useful" (homogeneous) and was used for further analysis. Maximum temperature for Lodwar station (Turkana County) was found to be inhomogeneous, on the contrary; a study by King'uyu *et al.* (2011) indicated that this temperature is homogeneous and the possible cause of the inconsistency if the use of single and double mass curve methods.

Table 9: Homogeneity test result for SNHT, BHR, PET and VON for Turkana and Marsabit observed datasets

Station			MaxTemp	MeanTemp	MinTemp	Rainfall
LODWAR	Tests	SNH	p1	p1	p1	NS
		BHR	p1	p1	p1	NS
		PET	p1	p1	p5	NS
		VON	p1	p1	p1	NS
	Breaks	SNH	20	12	10	51
		BHR	21	28	31	24
		PET	23	30	30	20
		VON	0.75	0.69	0.76	1.96
	classes		**suspect**	**suspect**	**suspect**	**useful**
MARSABIT	Tests	SNH	p5	p1	p1	NS
		BHR	NS	p1	p1	NS
		PET	NS	p1	p1	NS
		VON	NS	p1	p1	NS
	Breaks	SNH	35	17	22	25
		BHR	21	18	23	26
		PET	17	17	22	25
		VON	1.64	1.00	0.69	1.99
	classes		**useful**	**suspect**	**suspect**	**useful**

4.2 Validation of CRU data

Figure 4 show a time series performance of CRU against observation from Lodwar station in Turkana County and the correlation between CRU and observation rainfall (mm). Figure 4 represents Lodwar annual rainfall total in millimeters for the period 1951 to 2013. The CRU data was obtained by extracting a grid box over the Lodwar station. The correlation of CRU and observation was above 70% (0.72) as evident in Figure 4; therefore, CRU indicates a high agreement with observation, other studies that have used CRU data set as satellite observation over east Africa (Sabiiti, 2008; Omondi, 2010; Endris *et al.*, 2013; Otieno, 2014). This study has also shown that CRU is a good representation of rainfall and temperature in relation to station observation over the region. CRU was therefore used as proxy for observed data in this study for rainfall and temperature.

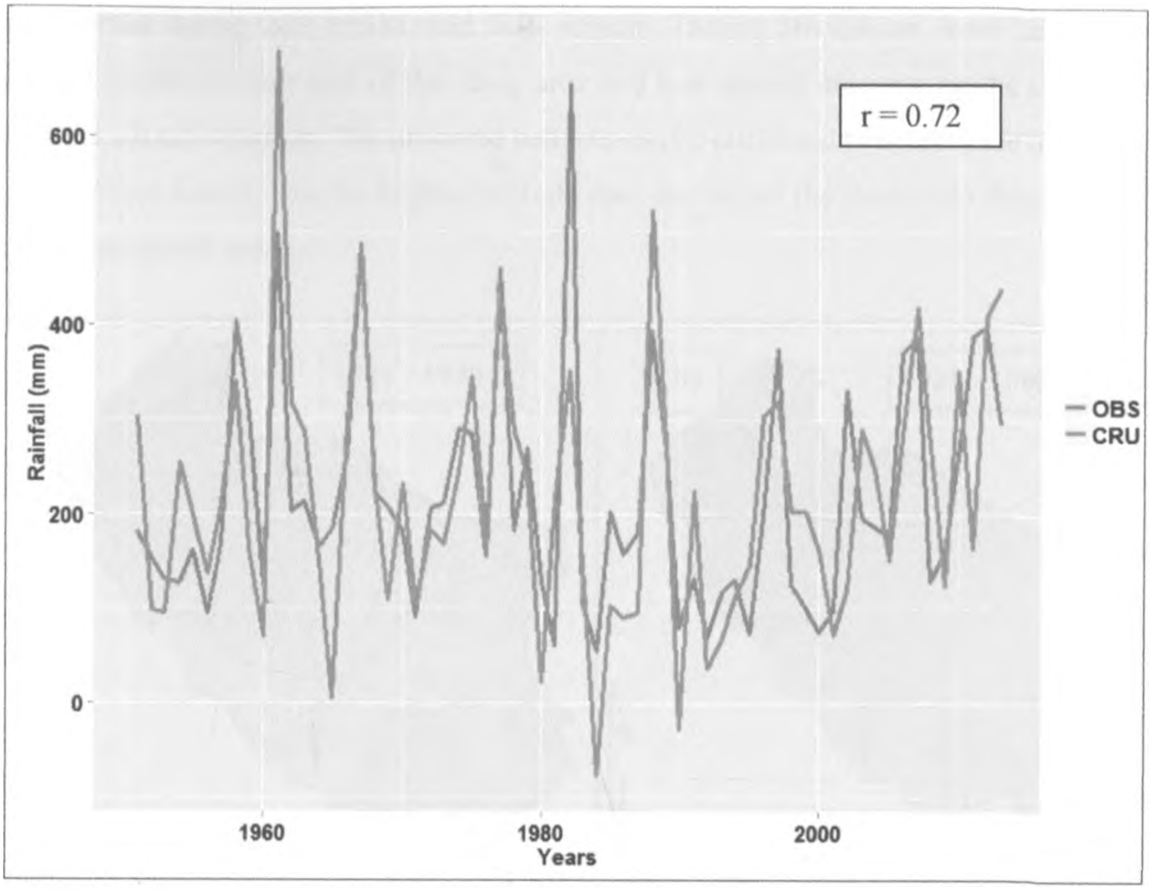

Figure 4: Comparison between CRU and observed rainfall (mm) dataset and the correlation for the period 1951 to 2013 over Turkana County.

4.3 Determining the evidence of variability and change in rainfall and temperature extremes in Kenya ASALs

This subsection presents the discussion on rainfall patterns and variability, surface air temperature patterns, evidence of past climate change, and trends in rainfall, maximum and minimum surface air temperature for the study area.

4.3.1 Rainfall patterns

Observed rainfall range for the seasons were; 30–180 mm for DJF, 110–500 mm for MAM, 0–300 mm for JJA and 110–380 mm for SON over the study area. Figure 5 and Figure 6 show rainfall distribution for DJF and MAM respectively for different climatic periods i.e. 1901–1930 (a), 1931-1960 (b), 1961–1990 (c) and 1991–2013 (d). From these figures, it's clear that rainfall is high in the southern part of the study area (Samburu and Isiolo County) and low in the north-western part of the study area (much of Turkana County). The pattern was observed during DJF, MAM, and SON seasons. During JJA season, more rainfall were observed on the western part of the study area and low rainfall amounts on the eastern part for all the climatic periods. The observed patterns can be attributed to the altitude of the study area. Samburu County has the highest altitude than the rest of the study area thus it receives the highest rainfall amount.

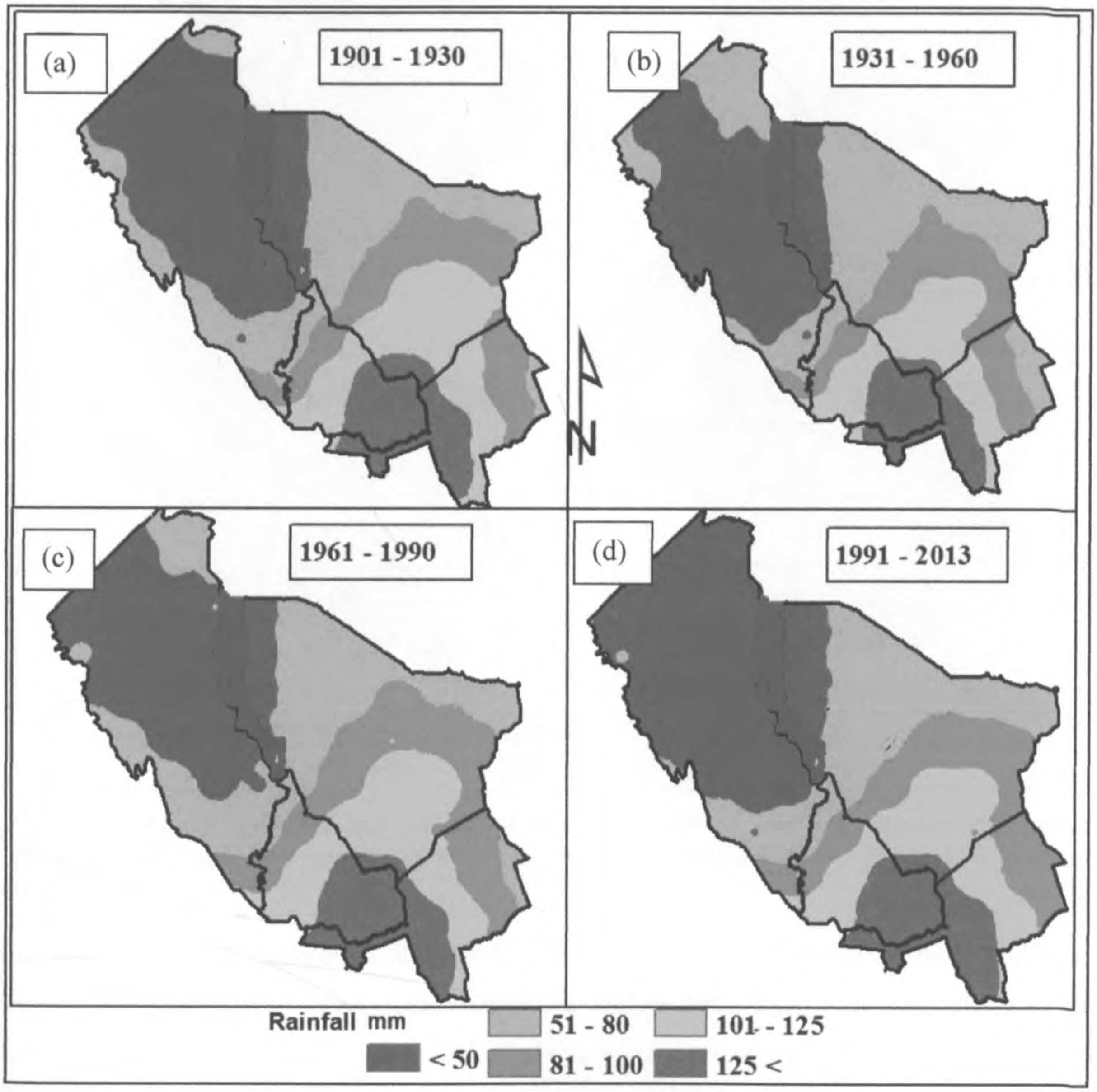

Figure 5: The mean seasonal rainfall over the ASALs of northern Kenya during the December, January, and February season of (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013.

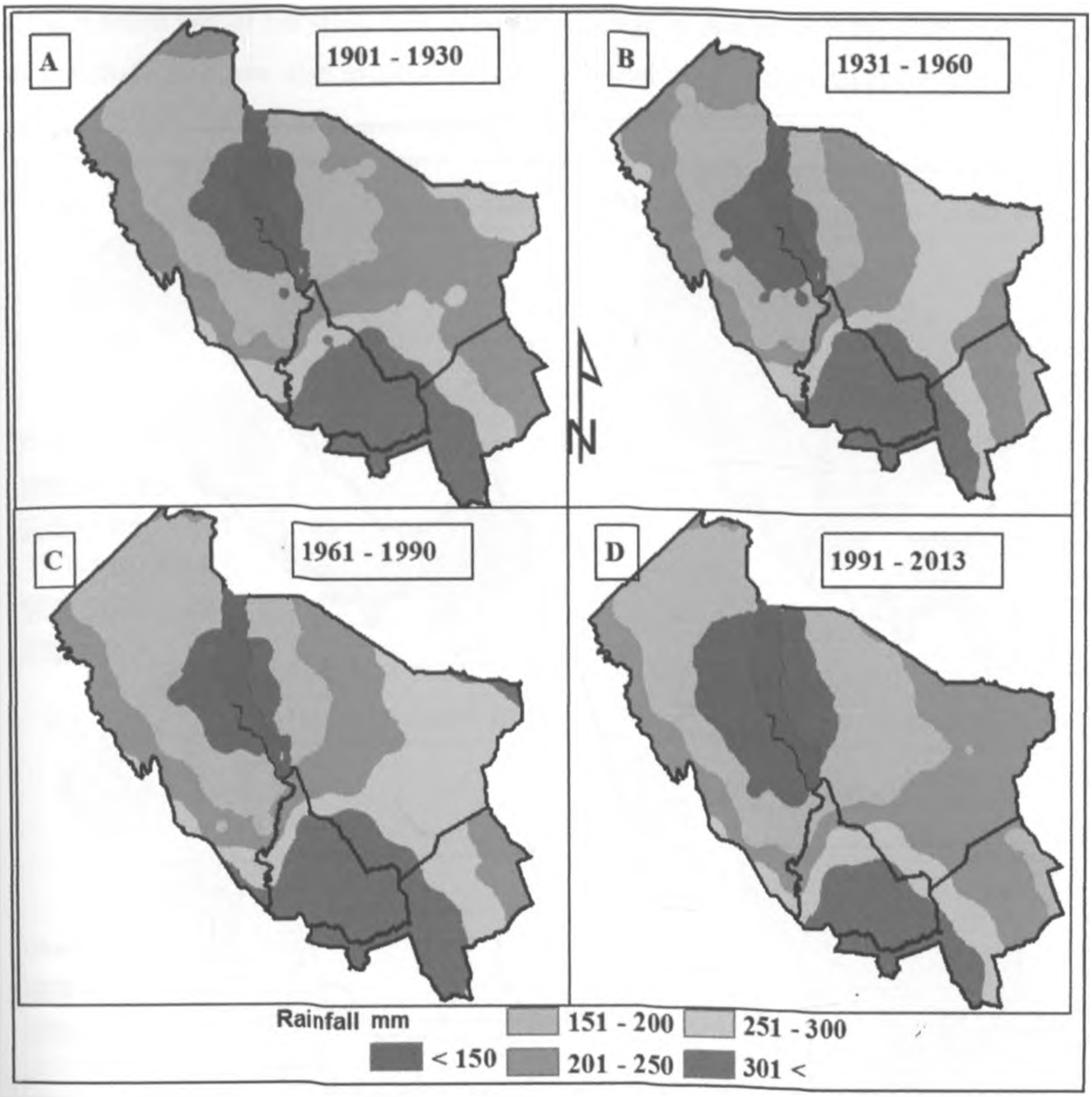

Figure 6: The mean seasonal rainfall over the ASALs of northern Kenya during the March, April, and May season of (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013.

However, changes in spatial distribution of rainfall for different climatic periods are not clear in Figure 5 and Figure 6. Therefore, changes in rainfall distribution were computed and are clearly shown in Figure 7. In Figure 7, DJF changes are represented in the first row (a and b) while changes in JJA are shown in the second row (c and d). Part (a) clearly indicates that rainfall has increased over south eastern part of the study area while the north western part shows a decrease in rainfall during DJF season. But difference in the recent past (Figure 7 (b)) showed that DJF rainfall has decreased in much of the study area covering central to north western part of the study area. A positive change in rainfall over the south eastern part of the study area was also evident. For JJA seasonal rainfall the changes in rainfall were positive at all locations study area Figure 7 (c) and (d).

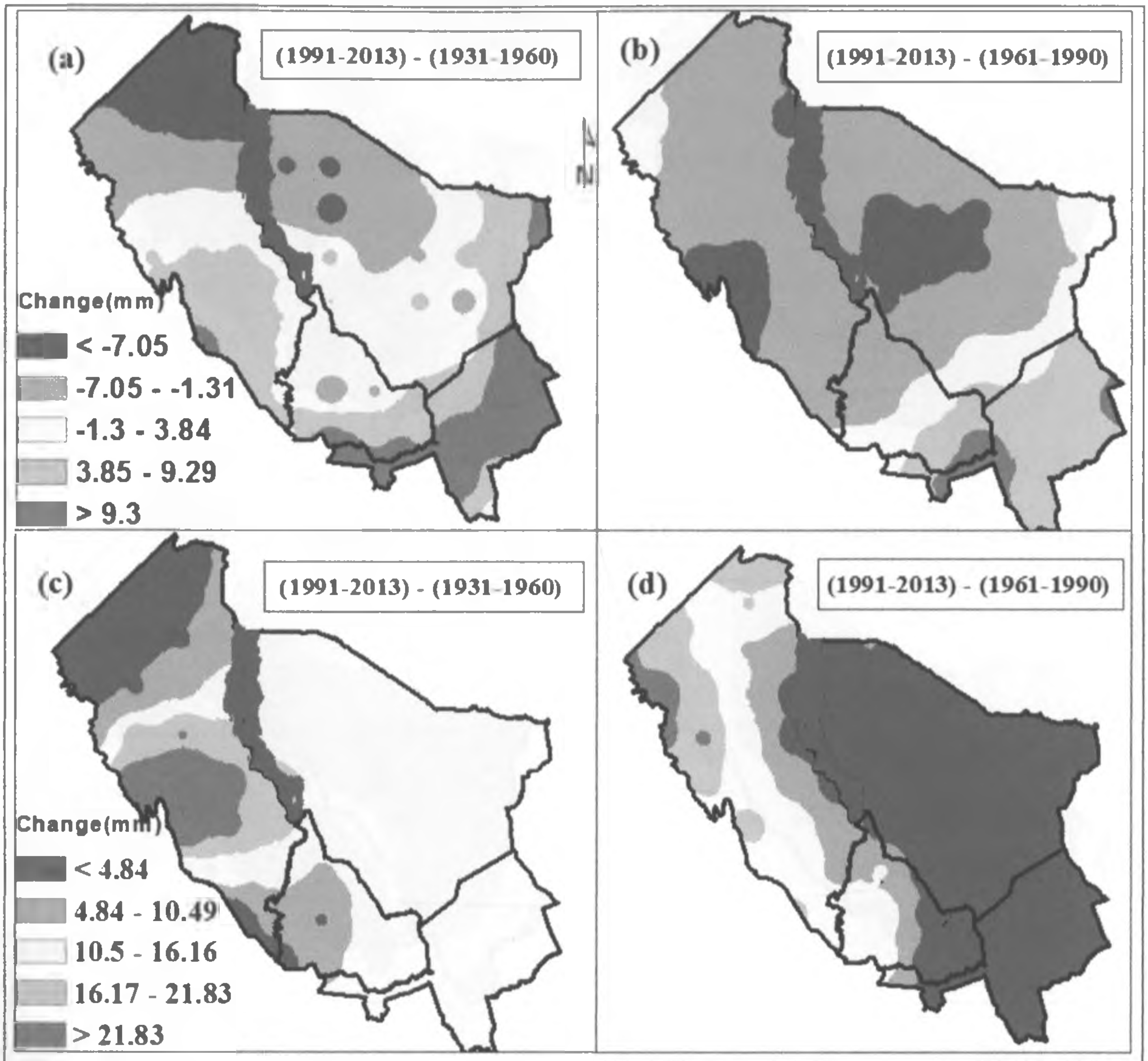

Figure 7: Changes in mean seasonal rainfall over the ASALs of northern Kenya during the December, January, and February (a) (1991-2013) – (1931-1960), (b) (1991-2013) – (1961-1990) and during the June, July, and August (c) (1991-2013) – (1931-1960), (d) (1991-2013) – (1961-1990).

Unlike the DJF which had mixed signals, the MAM season have a clear decreasing signal over the entire study area. However, the magnitude for DJF was moderate compared to the MAM season. It is clear that the decrease in rainfall has occurred in much of the study area except southeastern part of the study area, this is in line with the study of Orindi *et al.* (2007)

who indicated that rainfall means have decreased inland of Kenya. Change in the recent past for the SON season indicates a decrease in rainfall for the entire study area.

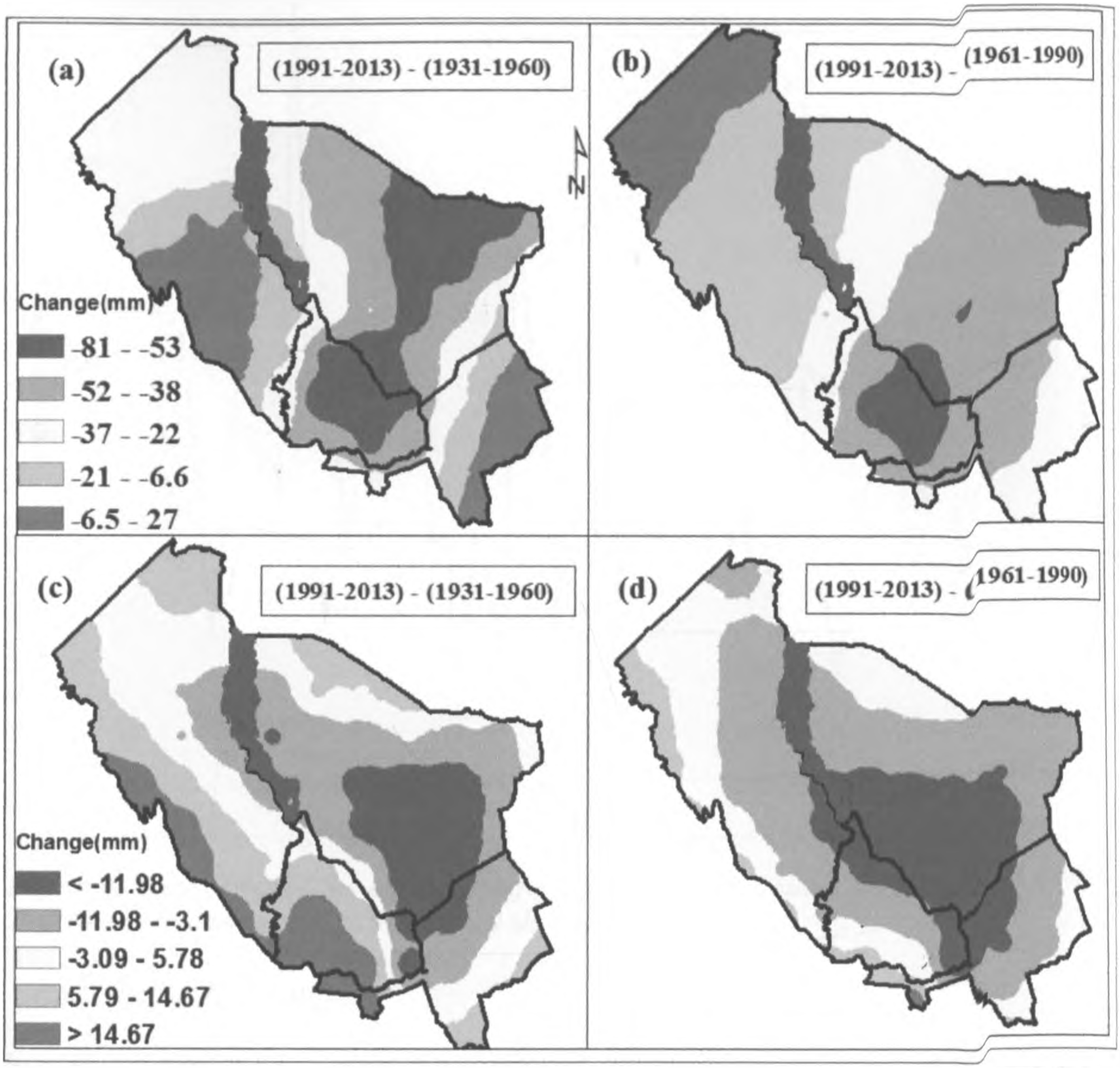

Figure 8: Changes in mean seasonal rainfall over the ASALs of northern Kenya during the March, April, and May (a) (1991-2013) – (1931-1960), (b) (1991-2013) – (1961-1990) and during the September, October, and November (c) (1991-2013) – (1931-1960), (d) (1991-2013) – (1961-1990).

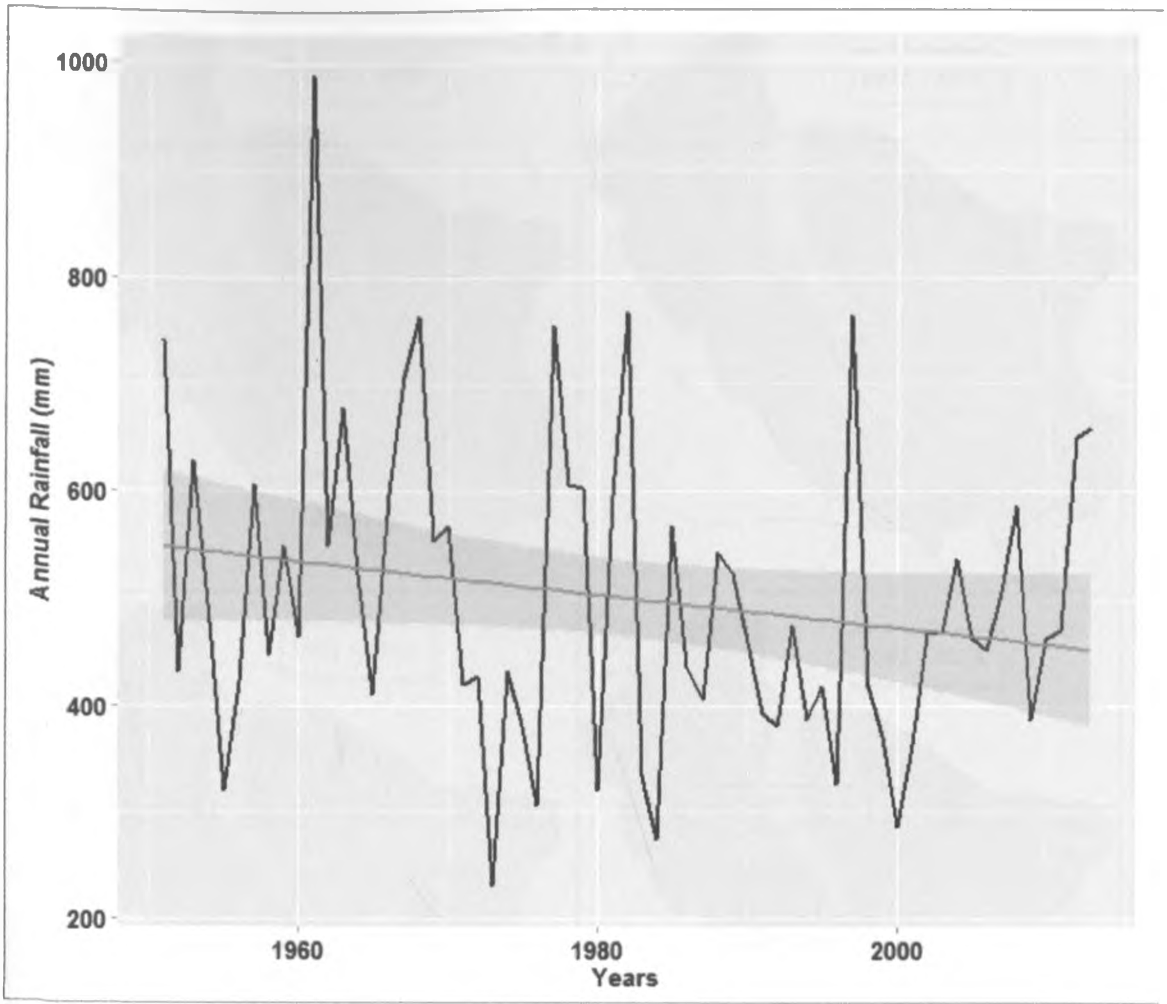

Figure 9: Time series of the annual rainfall over Marsabit County for the period 1951 to 2013. The decreasing tendency is clearly shown by the blue line.

4.3.2 Rainfall variability

In order to detect the area affected by extremes, rainfall variability (standard deviation) was plotted for DJF, MAM, JJA, and SON seasons. Figure 10 indicates that rainfall variability is high in the southern part of the study area covering Samburu and Isiolo Counties and low in western and north western part of the study area during DJF season. The same pattern is also observed for MAM and SON seasons. Areas of high variability are attributed the high rainfall received in the area.

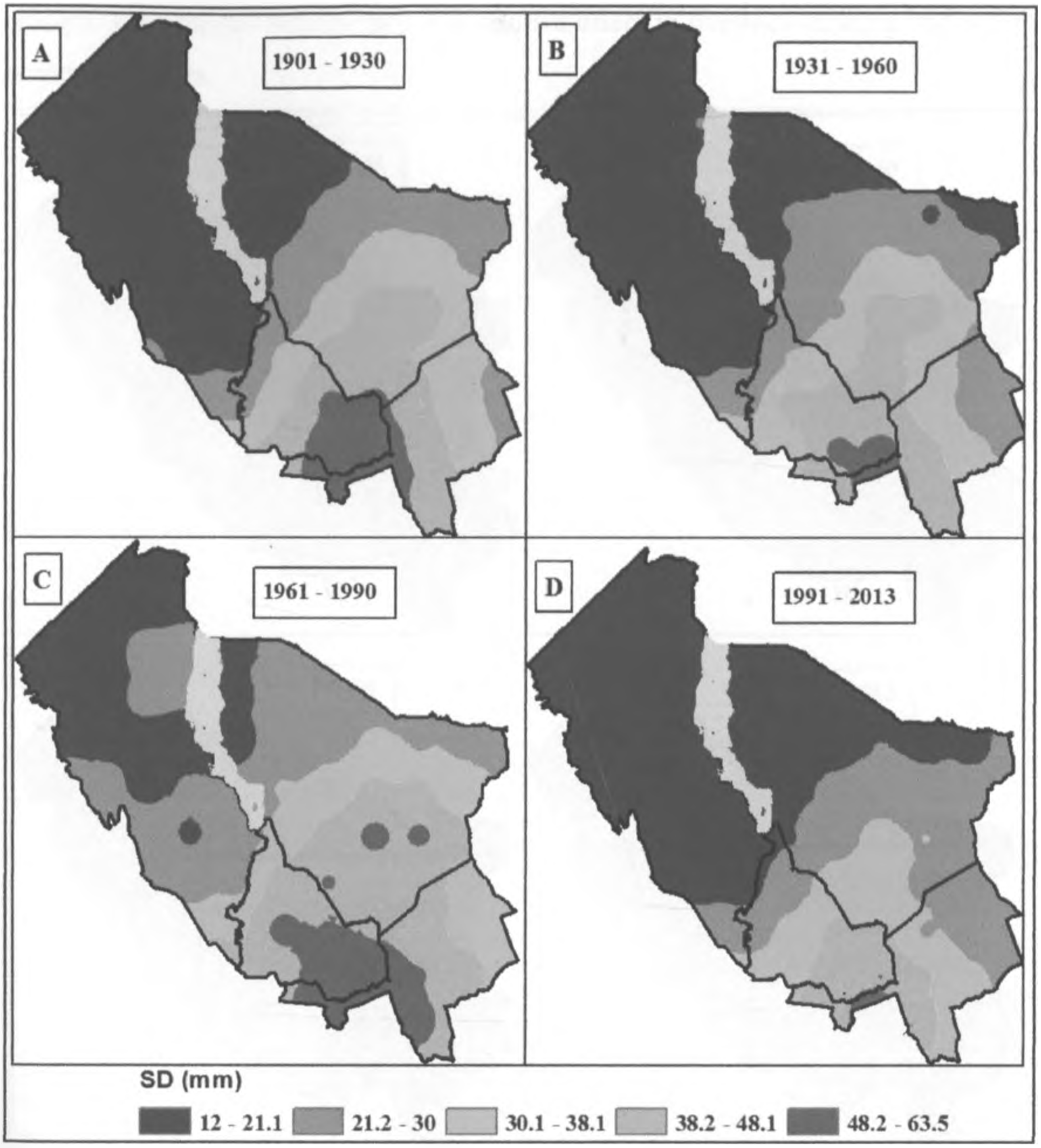

Figure 10: Standard deviation of the December, January, and February seasonal rainfall over the ASALs of northern Kenya over (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013.

A different pattern was observed in JJA season as shown in Figure 11. JJA season indicated that rainfall variability was high in western part of the study area covering much of Turkana County and low variability observed on the eastern part. This may be attributed to the rainfall distribution which was high on the western part than the eastern part of the study area. High rainfall variability exposes regions to rainfall extremes which are likely to cause flooding and drought. Low rainfall variability has a positive effect to livestock farming and other socio-economic sectors.

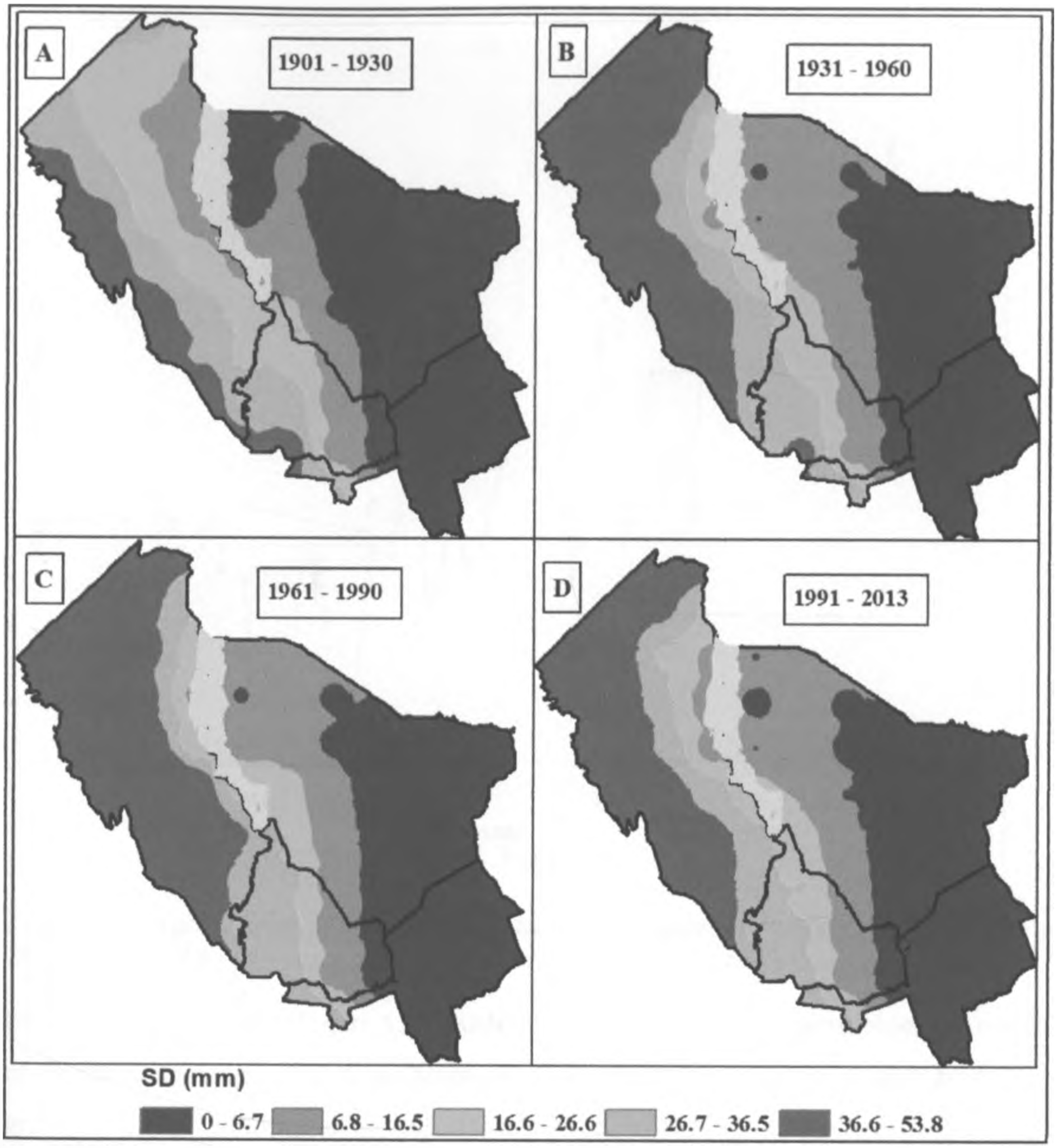

Figure 11: Standard deviation of the June, July and August seasonal rainfall over the ASALs of northern Kenya over (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013.

4.3.3 Temperature patterns

Maximum surface air temperature over the study area has an increasing trend indicating that temperatures over the ASALs are increasing (Figure 12). In order to determine the evidence of change in temperature, spatial analysis was performed for the four different seasons (DJF, MAM, JJA, and SON) in each climatological period.

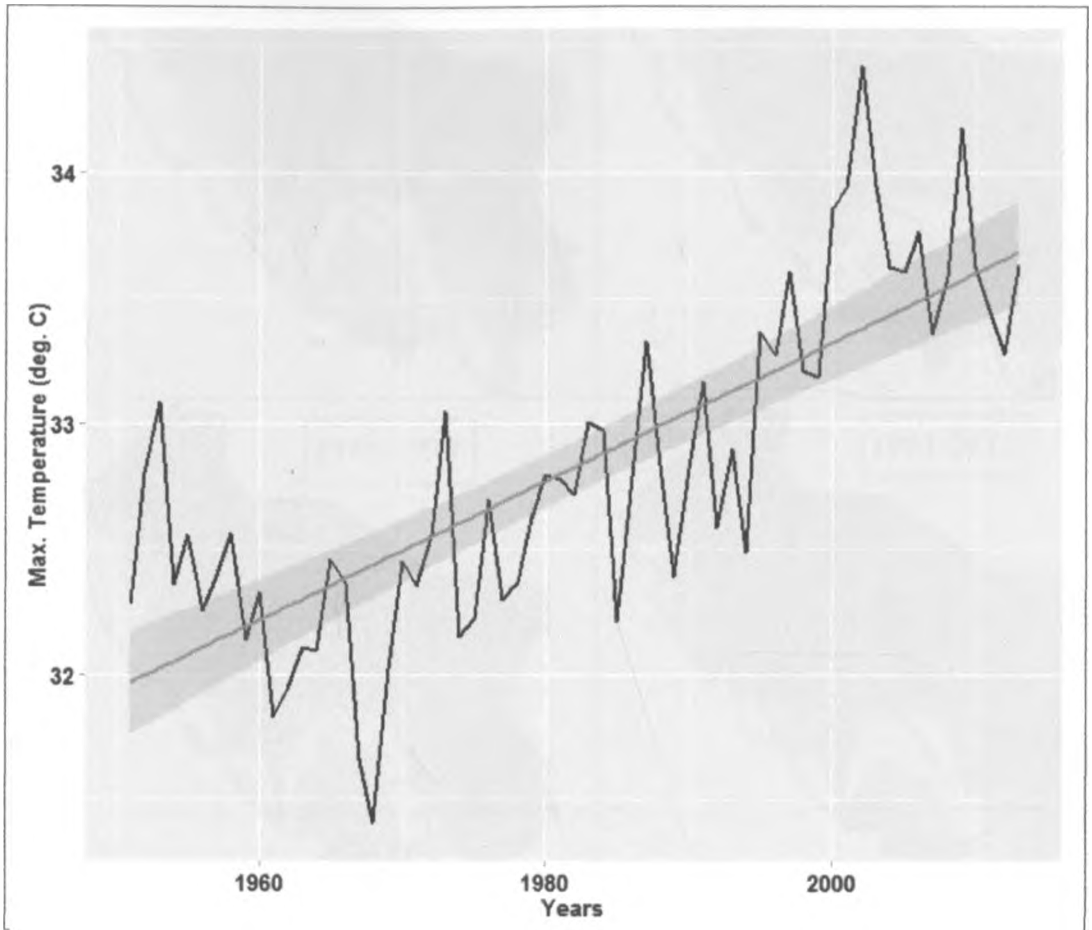

Figure 12: Time series of the annual temperature over Turkana County for the period 1951 to 2013. The decreasing tendency is clearly shown by the blue line.

During the DJF season (Figure 13), much of the study area has a mean observed temperature of 25.4^{0}C. From Figure 13, areas around Lake Turkana have a mean surface air temperature greater than 27^{0}C and the same was also observed in the south eastern part of the study area (Isiolo County). In the most recent past (Figure 13 (d)), the temperature greater than 27^{0}C covers a wider area compared to the other climatic periods in Figure 13 (a), (b), and (c). The same pattern was observed in the other seasons (MAM, JJA, and SON) with difference in the magnitude of temperature. In order to clearly identify the change in temperature in the different climatic periods, the temperature for 1931–1960 was subtracted from that of 1991–2013 and temperature for the period 1961–1990 was also subtracted from that of the 1991–2013.

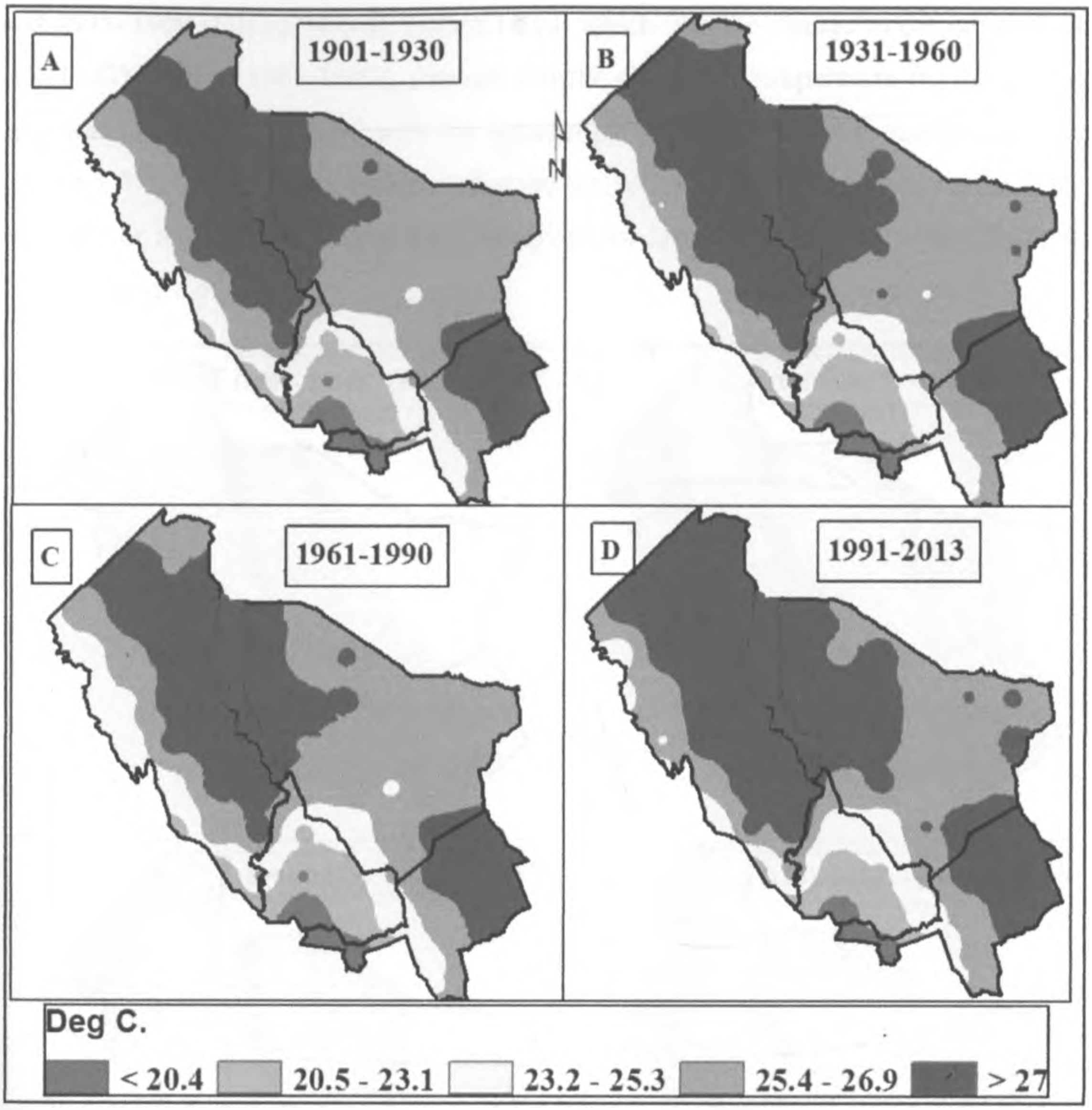

Figure 13: The mean seasonal surface are temperature over the ASALs of northern Kenya during the December, January, and February season of (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013.

Figure 14 (a) (DJF) shows that the change in the mean temperature ranges between 0.05 and 0.9^0C. The eastern part of the study area recorded a change of 0.05 to 0.52^0C for the difference in the period (1931-1960) and (1991-2013). In the most recent past, the change range from 0.05 to 1.45^0C for the period 1991-2013 minus 1961-1990, this was also observed by Christensen *et al.* (2007) at a regional scale. Figure 14 (b) shows that the eastern part of the study area recorded the lowest change and the highest change was observed on the western part of the study area. The season MAM, indicated that the north western part of the study area recorded a change of 0.72 to $0.1.45^0$C for the difference in the period 1991–2013 and 1931–1960 (Figure 14 (c)). Figure 14 (d) which was the change in the most recent past (1991–2013 minus 1961-1990), showed that the change in temperature for the entire study area was greater than 0.53^{0}C with the western part of the study area recording a change of 0.91 to 1.45^{0}C. This clearly indicates that the surface air temperature is on the rise. The same patterns for temperature change were observed for JJA and SON season with difference in the magnitudes of change.

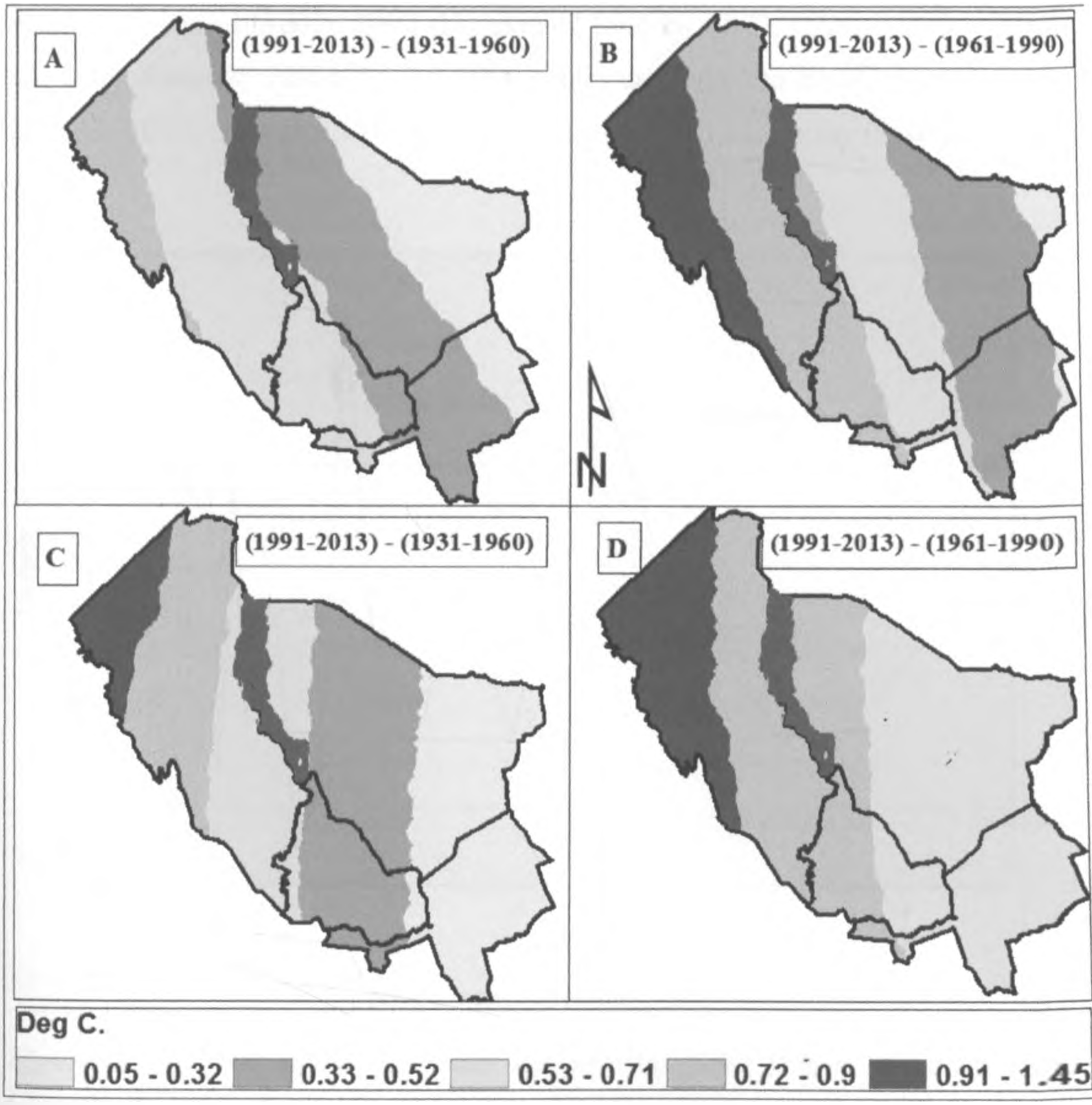

Figure 14: Seasonal changes for mean surface air temperature of the December, January, and February seasonal rainfall over the ASALs of northern Kenya over (a) 1901–1930, (b) 1931-1960, (c) 1961-1990, and (d) 1991-2013

4.3.4 Spectral analysis

The results obtained from spectral analysis for annual rainfall in ASALs indicates that dominant and significant spectral peaks observed were for the periods 2.3, 3.5, 5.5, and 9-10 years. The same observations have also been made by several studies (Ogallo, 1979, 1982; Nicholson, 1996; King'uyu *et al.*, 2000; Indeje *et al.*, 2000; Omondi, 2010). The observed periods have been link to different climatic events by several studies. The periods 2.0 – 3.3 years cycle were linked to QBO (Holton and Lindzen, 1972; Ogallo, 1979, 1982; Indeje *et al.*, 2000; Omondi, 2010), 5.0-7.5 years cycles are linked to ENSO events (Ogallo, 1988; Mutemi, 2003; Omondi, 2010) and 9-10 linked to solar variability (Rodhe, 1974; Omondi, 2010).

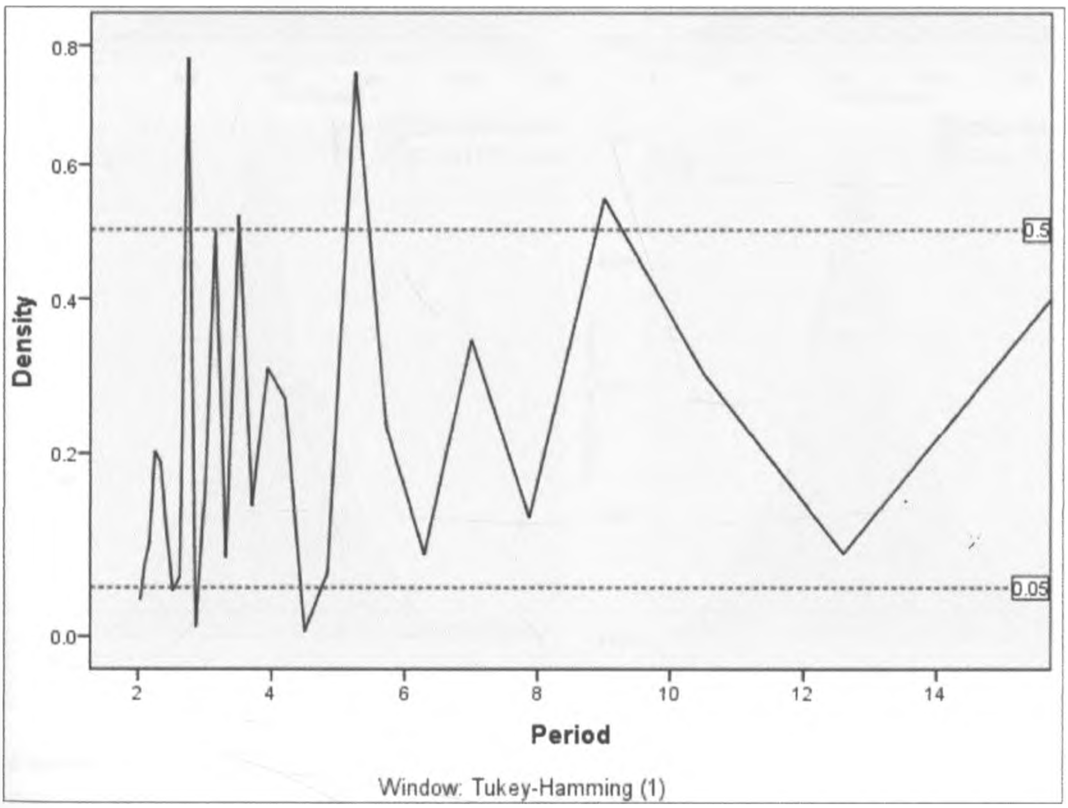

Figure 15: Spectral analysis for total annual rainfall for Lodwar County for the period 1961-2013.

4.3.5 Changes in extreme annual rainfall over the study area

In order to analyze the distribution of rainfall, the data was divided into two non-overlapping climatic periods i.e. 1961-1990 (WMO baseline) and 1991-2013 for Turkana, Marsabit, Samburu, and Isiolo Counties. Figure 16 presents the total annual rainfall distribution for the four study Counties.

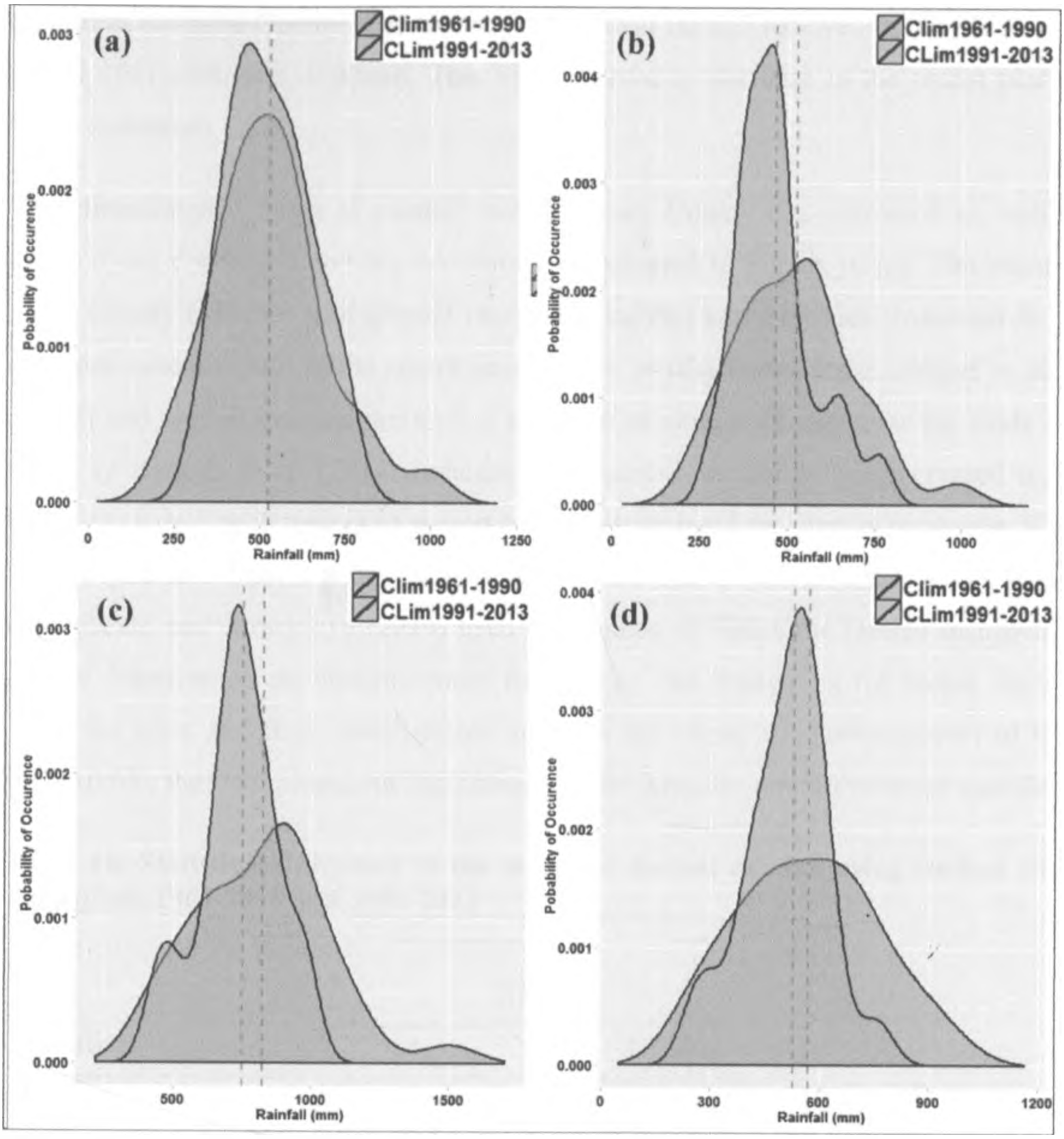

Figure 16: Total annual rainfall distribution over (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties for different climatic periods, 1961-1990 and 1991-2013.

The rainfall distribution over Turkana County (Figure 16 (a)) showed a slight decrease in variability and extreme events in the period 1991-2013 from the period 1961-1990. The maximum annual rainfall received over Turkana County for the period 1961-1990 was 1200mm, this was observed to decrease for the period 1991-2013 to approximately 950mm, and thus rainfall has decreased over this County. The distribution for Marsabit County indicates an increase in rainfall variability in the recent past (1991-2013) with a negative change in climatological mean of annual total rainfall as shown in Figure 16 (b) thus reduced rainfall in Marsabit County. The highest annual total rainfall received in this County for the period 1961-1990 was 1100mm. This was observed to decrease in the recent past (1991-2013) to 860mm.

The climatological mean of rainfall over Samburu County has decreased as well as the extreme wet conditions and dry conditions as indicated in Figure 16 (c). The situation for Isiolo County indicates a significant increase in rainfall variability and reduction in rainfall extremes (wet and dry) in the recent past (Figure 16 (d)). Thus, these changes in the mean rainfall and rainfall extreme are a clear evidence of climate change over the study area. A study by Darkoh *et al.* (2014) indicated that rainfall variability has increased in Kenya leading to a decline in long rains season and a positive trend for short rainy season. Kingwell (2006) used this type of analysis to detect climate change in Australia, while a study by Ogungbenro and Morakinyo (2014) used the method to assess the rainfall distribution and change detection across climatic zones in Nigeria. The changes in the means were tested using the t-test and their result shown in Table 10. Using a significant level of 0.05 (p-value=0.05), the study found out that changes in the mean for rainfall were not significant.

Table 10: Statistical difference in the mean for annual rainfall using student t-test for the periods 1961-1990 and 1991-2013

	Rainfall	
Counties	**t**	**p-value**
Turkana	1.168	0.2523
Marsabit	1.88	0.07018
Samburu	1.6957	0.1007
Isiolo	0.7467	0.4613

4.3.6 Annual Distribution of Maximum and Minimum Temperature over the Study Area

Figure 17 shows the mean annual maximum surface air temperature distribution for the four study counties using 1961-1990 and 1991-2013 climatic period. The result for Turkana County (Figure 17 (a)) indicates a positive change in the mean from 32.3 (1961-1990) to 33.2 (1991-2013) and an increased variability leading to extreme high temperatures. The highest temperature observed in the period 1961-1990 was 33.7^0C while the period 1991-2013 recorded an annual maximum surface air temperature of 34.8^0C (Figure 17 (a)). The same changes in the mean and variability were observed for Marsabit and Samburu Counties (Figure 17 (b) and (c) respectively). The highest maximum annual air temperature recorded for Marsabit County in the period 1961-1990 was 31.8^0C while that of the period 1991-2013 was 32.1^0C. Samburu County recorded a highest annual temperature of 30.8^0C for the period 1961-1990 and 31.5^0C for the period 1991-2013. The mean of annual maximum temperature have also increased in Isiolo County but the variability has decreased (Figure 17 (d)).

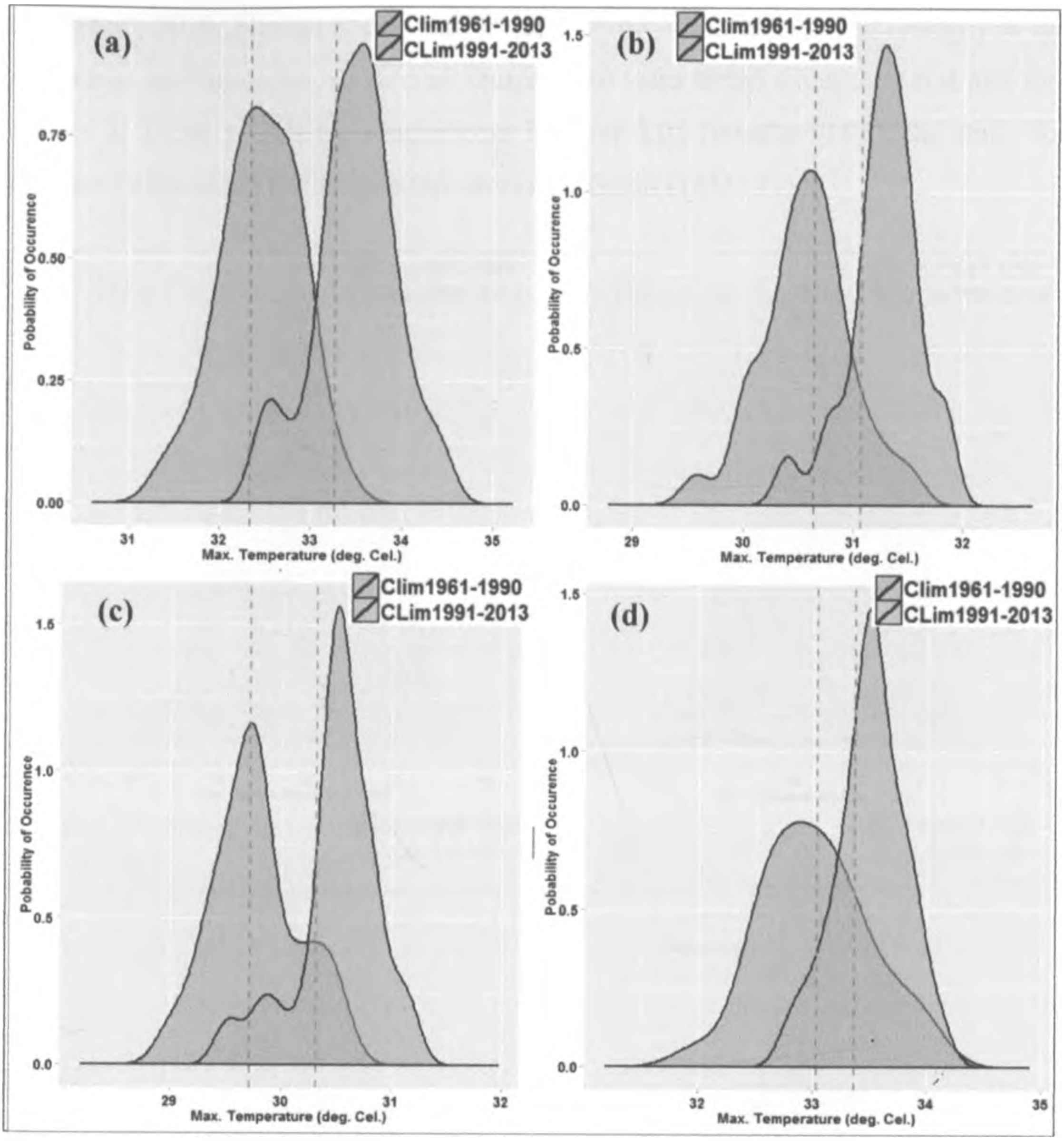

Figure 17: Mean annual maximum surface air temperature distribution for (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties using different climatic periods (1961-1990 and 1991-2013)

Figure 18 indicates the mean annual minimum surface air temperature distribution for the four study counties using 1961-1990 and 1991-2013 climatic periods. The mean for minimum surface air temperature for the four Counties have increased while the variability has decreased. Based on Figure 17 and Figure *18*, there is clear evidence of climate change over the study area and temperature has increased by approximately 1.2^{0}C. Other studies have also indicated that the mean annual temperature for Kenya has increased by 1^{0}C since 1960 particularly in the ASAL regions (Orindi *et al.*, 2007; Christensen *et al.*, 2007;

Hoffmann, 2010; Ngaina and Mutai, 2013; Darkoh *et al.*, 2014). The changes in the means maximum and minimum surface air temperature were tested using the t-test and their result shown in Table 11. Using a significant level of 0.05 (p-value=0.05), the study found out changes in the mean for temperature were significant (Table 11).

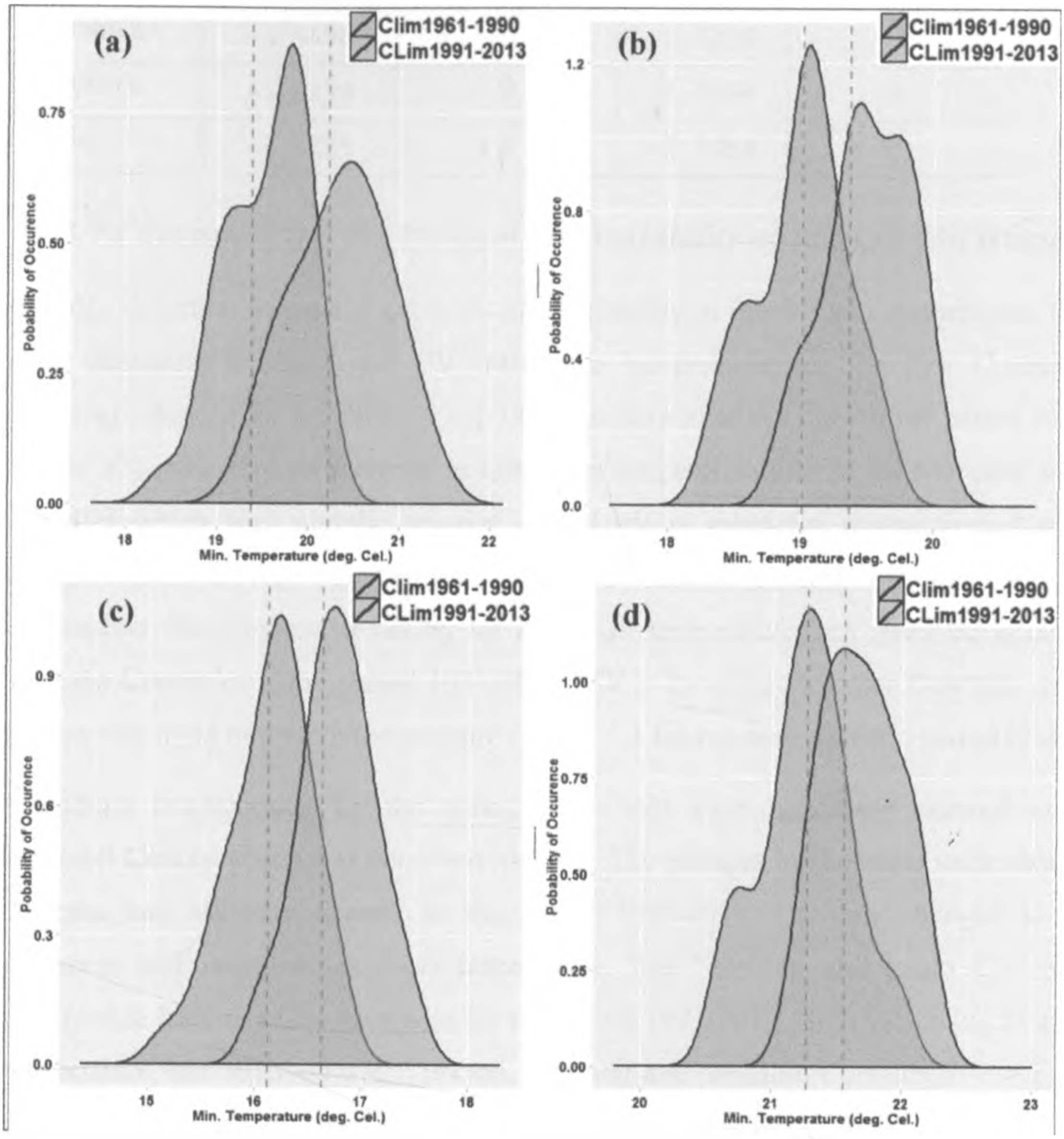

Figure 18: Mean annual minimum surface air temperature distribution for Turkana (a), Marsabit (b), Samburu (c), and Isiolo (d) Counties using different climatic periods (1961-1990 and 191-2013)

Table 11: Statistical difference in the mean for surface air temperature using student t-test for the periods 1961-1990 and 1991-2013

Counties	Max. Temperature		Min. Temperature	
	t	p-value	t	p-value
Turkana	-8.3976	0	-8.4496	0
Marsabit	-3.5598	0	-3.3299	0
Samburu	-5.7298	0	-4.9064	0
Isiolo	-3.2035	0	-2.7463	0

4.3.7 Characterizing the location and variability of rainfall and temperature

In order to further assess the extremes and variability in rainfall and temperature, the study used skewness, Kurtosis and CV. Minimum temperature for the four Counties were negatively skewed for the period 1961-1990 but skewed to the right in the period 1991-2013 (Table 12) indicating an increase in minimum temperature except for Marsabit and Isiolo Counties which was slightly negative. The kurtosis value for minimum and maximum temperature for the four Counties were found to be positive (kurtosis > 0) indicating a peaked distribution. The highest variability for minimum temperature was observed to occur over Turkana County over the period 1991-2013 (CV > 1) while the other Counties recorded a low variability in minimum temperature i.e. CV < 1 for the same climatic period (Table 12).

Maximum temperatures for the period 1961-1990 were negatively skewed except for Marsabit County which was positively skewed. The changes in skewness were observed for Turkana and Marsabit County in the period 1991-2013, i.e. they changed to positive skewness and negative skewness respectively. But Samburu and Isiolo Counties were observed to have negative skewness for the period 1991-2013. High variability in maximum temperature was observed over Turkana, Marsabit and Samburu Counties (CV > 1) but low for Isiolo County for the period 1991-2013 as shown in Table 12. On the other hand, rainfall was observed to be positively skewed in all the Counties for the two climatic periods (Table 12) with a variability of one in the period 1961-1990 and variability below one in the period 1991-2013.

Table 12: Analysis of Skewness, kurtosis and coefficient of variability for temperature over the study area for the periods 1961-1990 and 1991-2013

			1961-1990	1991-2013
Minimum Temperature	Skewness	Turkana	-0.4709	0.424
		Marsabit	-0.8298	-0.0122
		Samburu	-0.4009	0.2127
		Isiolo	-0.4591	0.0043
	Kurtosis	Turkana	2.6097	2.3706
		Marsabit	3.7035	2.0708
		Samburu	2.5733	2.5539
		Isiolo	3.1001	2.4879
	CV	Turkana	1	1.6909
		Marsabit	1	0.7235
		Samburu	1	0.9263
		Isiolo	1	0.7611
Maximum Temperature	Skewness	Turkana	-0.2388	0.0321
		Marsabit	0.1195	-0.5863
		Samburu	-0.4508	-0.4675
		Isiolo	-0.2435	-0.5771
	Kurtosis	Turkana	3.4418	2.4395
		Marsabit	3.0221	2.7799
		Samburu	4.6116	2.4815
		Isiolo	3.891	2.7409
	CV	Turkana	1	2.0602
		Marsabit	1	1.0204
		Samburu	1	1.2259
		Isiolo	1	0.7682

Analysis for rainfall totals over the four Counties indicates a positive skewness for the entire study area (Table 13). The highest positive skewness of 1.86 was observed in Isiolo County for the period 1991-2013. The variability of rainfall have reduced over the four study location (CV<1) for the period 1991-2013 compared to 1961-1990 (Table 13)

Table 13: Analysis of skewness, kurtosis and coefficient of variability for rainfall over the study area for the periods 1961-1990 and 1991-2013

Total rainfall	Skewness	Turkana	1.14	0.23
		Marsabit	0.57	0.75
		Samburu	0.68	0.45
		Isiolo	0.30	1.86
	Kurtosis	Turkana	5.05	2.67
		Marsabit	3.42	3.27
		Samburu	4.09	3.91
		Isiolo	2.32	9.28
	CV	Turkana	1	0.93
		Marsabit	1	0.54
		Samburu	1	0.65
		Isiolo	1	0.79

4.3.8 Trends in rainfall, maximum and minimum temperature

Trend analysis in annual and seasonal rainfall and temperature were done using Mann Kendall trend test methods. The results from the trend analysis show that rainfall trends are not significant at all locations. MAM season indicated a negative trend at all study Counties (Figure 19 (a) and Table 14). JJA season Figure 19 (b) JJA season has a positive trend except for Isiolo County which are not significant over the study area. A summary of trends in rainfall, minimum and maximum surface temperatures are shown in Table 14. A trend was determined to be significant if the p-value is equal to or less than 0.05. Trend in rainfall for all the season in all station were not significant. A study by Ngaina and Mutai (2013) showed that the long rains (MAM) over the Lodwar County have a negative trend which was not significant. Other studies on observed rainfall have also shown that there is no significant trend in rainfall since 1960 (Eriksen and Lind, 2009; Schilling *et al.*, 2011; Tutiempo, 2014), but the events of heavy rainfall have increased.

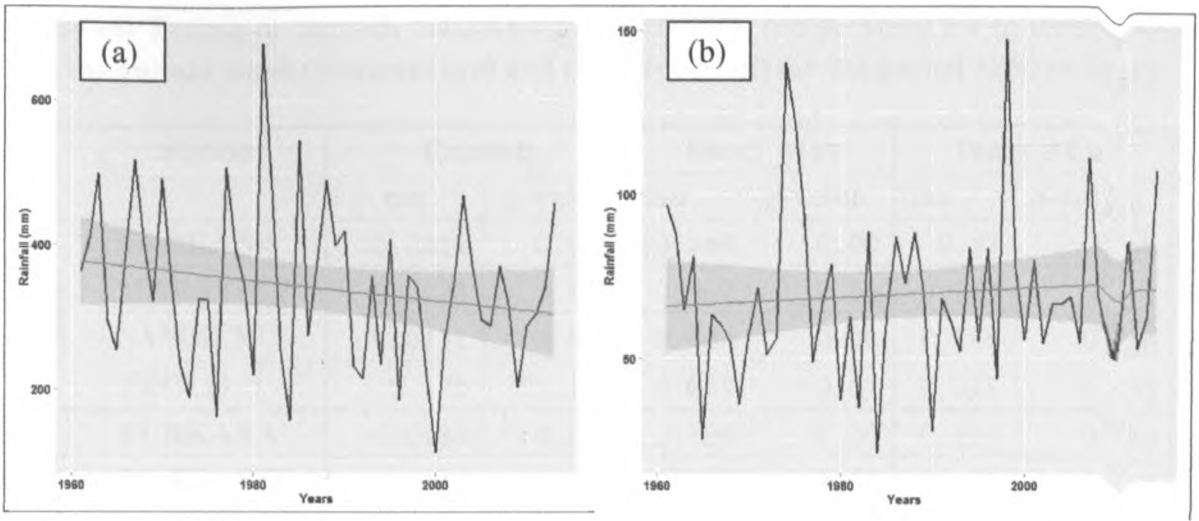

Figure 19: Trend in (a) March, April, and May and (b) June, July, and August rainfall season for Samburu County for the period 1960-2013.

Temperature on the other hand showed a significant increasing trend for all the seasons and annual mean for both maximum and minimum temperature (Table 14). This is in line with the findings of the study by Omondi *et al.* (2014) which indicated that the temperature in Kenya is on the rise. A study by Ngaina and Mutai (2013) also concluded that there is an increase in maximum temperature extremes. Over the study area, the highest significant increasing trend for maximum temperature was 0.556 for JJA and SON seasons. The trend for minimum temperature was 0.644 observed in Turkana County. Temperature increase over the ASALs leads to severe thermal heat discomfort for the cattle.

Table 14: Trends in rainfall, maximum and minimum temperature for different season and the annual mean (temperature) and totals (rainfall) for the period 1960 to 2013

	Stations	Rainfall		Temp_Max		Temp_Min	
		tau	p-value	tau	p-value	tau	p-value
DJF	TURKANA	-0.0414	0.668	0.544	0.00	0.37	0.00
	MARSABIT	0.0428	0.656	0.362	0.00	0.144	0.14
	SAMBURU	0.0131	0.896	0.427	0.00	0.369	0.00
	ISIOLO	0.139	0.143	0.245	0.01	0.225	0.02
MAM	TURKANA	-0.0588	0.539	0.486	0.00	0.497	0.00
	MARSABIT	-0.115	0.228	0.356	0.00	0.408	0.00
	SAMBURU	-0.131	0.170	0.36	0.00	0.385	0.00
	ISIOLO	-0.0958	0.315	0.315	0.00	0.344	0.00
JJA	TURKANA	0.053	0.581	0.556	0.00	0.6	0.00
	MARSABIT	0.0363	0.707	0.515	0.00	0.573	0.00
	SAMBURU	0.0312	0.747	0.469	0.00	0.538	0.00
	ISIOLO	-0.0137	0.903	0.301	0.00	0.383	0.00
SON	TURKANA	0.0922	0.334	0.556	0.00	0.644	0.00
	MARSABIT	-0.0319	0.742	0.409	0.00	0.479	0.00
	SAMBURU	-0.0261	0.788	0.452	0.00	0.529	0.00
	ISIOLO	-0.0537	0.576	0.32	0.00	0.361	0.00

4.4 Assessing the changes in livestock population that may be associated with past and present climate extremes

4.4.1 Past and present abnormal wetness and dryness

This subsection presents the result for the analysis of the past and present abnormal wetness and dryness of the four counties based on the SPI. Figure 20 shows the SPI time series plot for Turkana County with different time steps (run3, run6, run12, run24, run36 and run48). The first three time step ((a), (b), and (c)) have noise in their time series and the patterns cannot be clearly seen. On the other hand run24, 36, and 48 have reduced noise, thus the pattern for abnormal wetness and dryness in Turkana County are clearly seen. The number of extreme wet conditions is more than the dry conditions as indicated in run36 with 1983–1986 and 1995–1996 being the extreme driest year in Turkana County. The periodicity of abnormal dry condition which is referred to as drought in this study and the abnormal wet conditions are 3–6 years. This can be attributed to ENSO which is an irregular phenomenon that recurs every 2–7 years (Diaz and Markgraf, 2000; Chang and Zebiak, 2003; Rourke, 2011; IPCC, 2013).

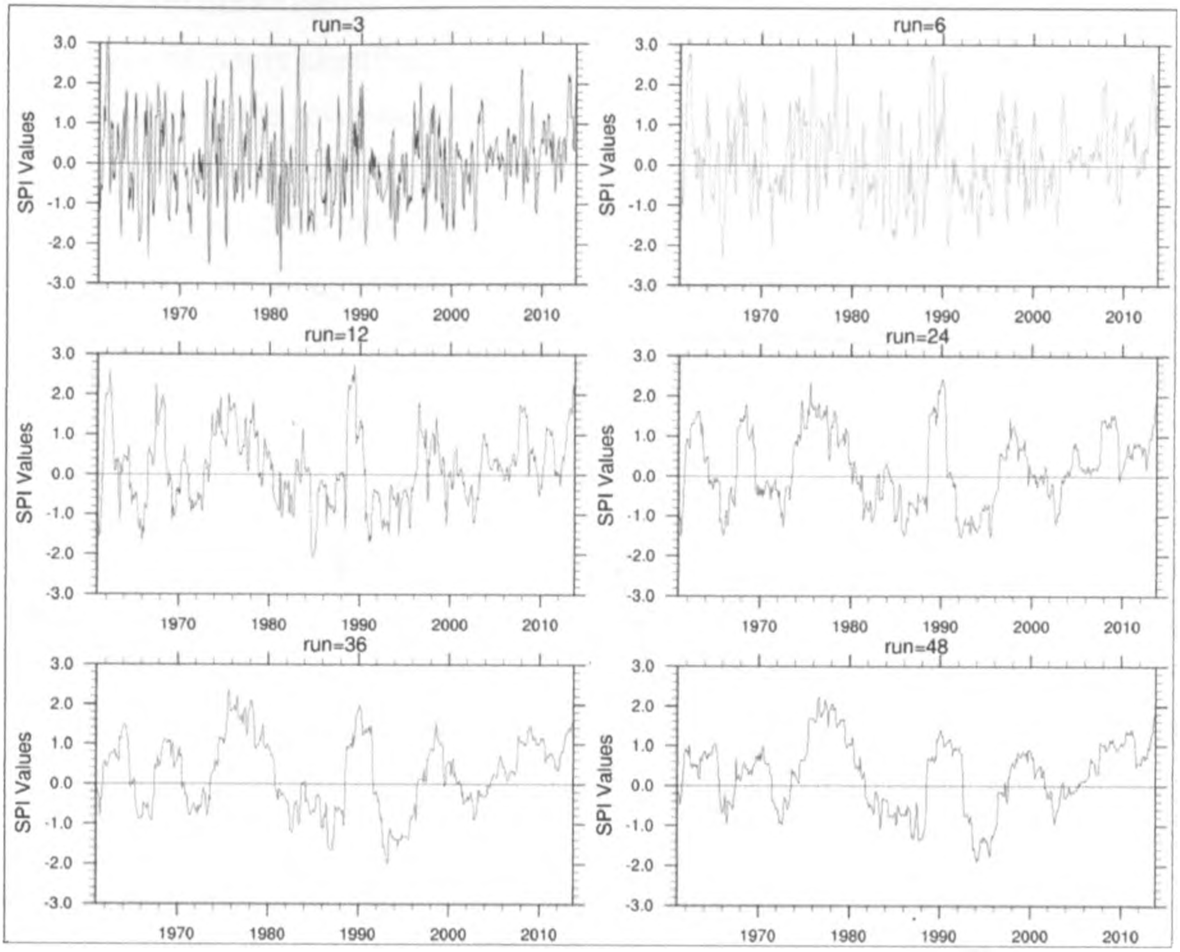

Figure 20: SPI time series over the Turkana County for the period 1961-2013 using (a) run=3, (b) run=6, (c) run=12, (d) run=24, (e) run=36 and (f) run=48.

In the recent past, Marsabit County was affected more by drought than abnormally wet conditions. Extreme droughts that affected Marsabit County were the 1974-1975 followed by 2000–2001 droughts. These results are in line with the study by Makishima (2005) who reported that the 2000 was the driest year in Kenya. The 2000 to 2001 drought was also observed in Samburu County. The 1974–1975 and 2000–2001 droughts can be attributed to the negative phase of ENSO that occurred during the years 1973 to 1976 and 1998 to 2001. The worst drought that affected Isiolo County spanned the period 1973 to 1976. The historical data of El Nino/La Nína episode can be obtained at the Climate Prediction Center (CPC) (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.

shtml). The magnitudes of extreme wet conditions over Samburu County were higher than the magnitudes of extreme dry conditions.

Therefore SPI can be used as a tool for monitoring abnormal wetness and dryness of a region to improve the timely identification of the emerging drought and abnormal wet conditions to be acted upon by the government (Wu *et al.*, 2005; Dutra *et al.*, 2013; Di Lena *et al.*, 2014). CERF (2009) and Rourke (2011) reported that there was drought in Northern and Eastern Kenya in the year 2005-2006 which was attributed to the failure of the short rains in 2005 leading to 70% death of livestock in some areas in northern Kenya (CERF, 2009). However, this study analyses indicated that this period was within the range of normal condition The difference may be attributed to the difference in data used.

4.4.2 Cattle population against climate extremes

The results in this subsection are linked to the observed abnormal wetness and dryness in SPI time series for Turkana, Marsabit, Samburu, and Isiolo Counties (Figure 20). The cattle populations for the years that were indentified to be abnormally wet were compared with those of the years that were identified to be abnormally dry for all the four counties (Table 15). The study found that cattle populations were higher during the abnormal wet conditions than during the dry conditions for all the four Counties. Therefore, it can be concluded that cattle populations are related to climate variability and change. It is important also to note that cattle population is also affected by migration, government destocking in times of drought and cattle rustling from outside and within the Counties.

Table 15: Comparison between years of abnormal wetness and dryness with the corresponding cattle population for Lodwar, Marsabit, Samburu and Isiolo Counties

TURKANA						SAMBURU					
Abnormal wetness	Classificati on level	Cattle Population in 1000s	Abnormal dryness	Classificati on level	Cattle Population in 1000s	Abnormal wetness	Classificati on level	Cattle Population in 1000s	Abnormal dryness	Classificati on level	Cattle Population in 1000s
1975	Extremely wet	180	1973	Moderately dry	180	1979	Extremely wet	250.78	1975	Moderately dry	232
1990	Very wet	417	1985	Severely dry	158	1990	Moderately wet	187.18	1985	Severely dry	100.8
1997	Moderatel y wet	200	1995	Severely dry	165	1998	Very wet	223.17	1993	Moderately dry	119.3
2008	Moderatel y wet	198	2002	Near normal	194				2001	Severely dry	171

MARSABIT						ISIOLO					
Abnormal wetness	Classification level	Cattle Population in 1000s	Abnormal dryness	Classification level	Cattle Population in 1000s	Abnormal wetness	Classification level	Cattle Population in 1000s	Abnormal dryness	Classification level	Cattle Population in 1000s
1978	Very wet	464	1976	Severely dry	434	1979	Very wet	287.32	1976	Extremely dry	250
1983	Moderately wet	420	1985	Extremely dry	260	1998	Very wet	139	1986	Moderately dry	135.57
			1996	Severely dry	132				1994	Moderately dry	100.8
			2001	Extremely dry	128				2001	Severely dry	119

4.5 Assessing the future climate change scenarios and their potential impacts on pastoral systems in the ASALs of Kenya

4.5.1 Models skill in simulating the observed data

In order to determine the model with better skills, this study used; graphical method, model bias, correlation, standard deviation, and root mean square to analyze the performance of the models in relation to observed data. Figure 21 shows the result for time series analysis of normalized rainfall over the study area.

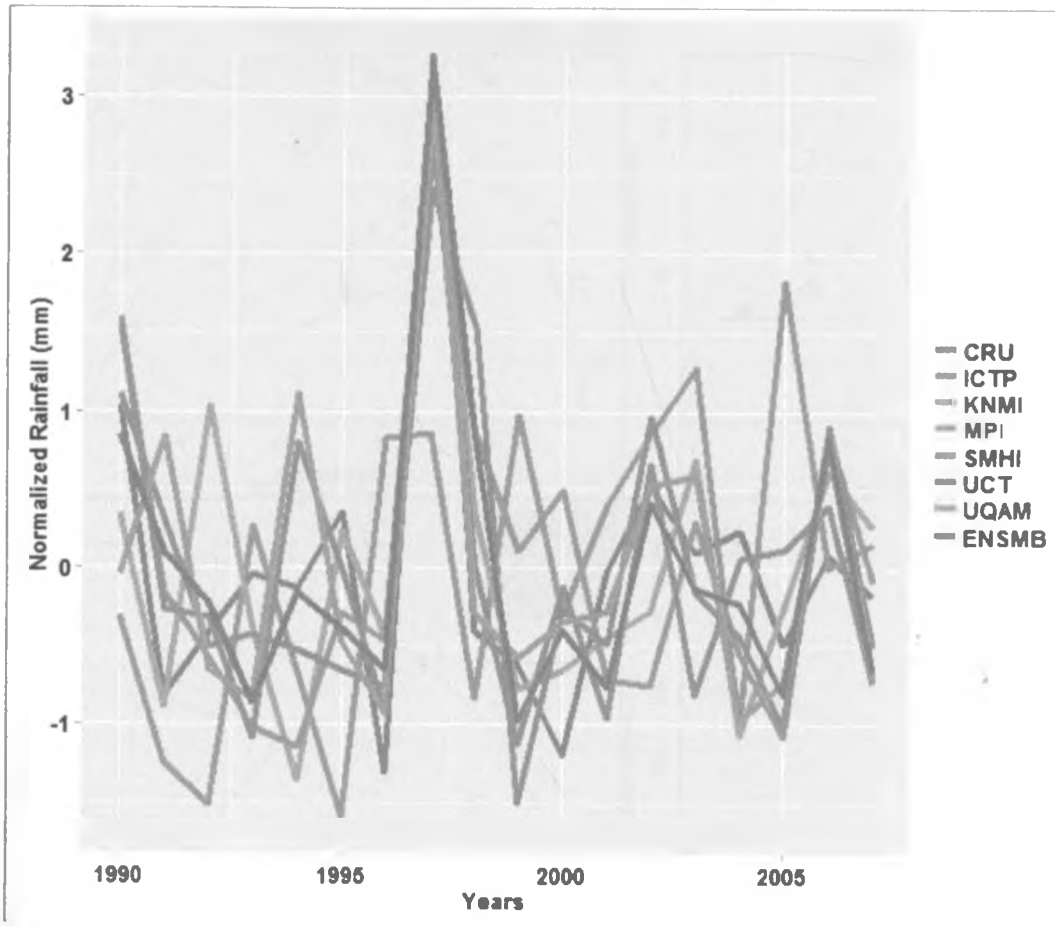

Figure 21: Time series of the CRU representing the observation data, the CORDEX RCMs and average of all the RCMs for the period 1990-2008 over the study area.

Therefore, other robust methods which are; correlation, standard deviation, and root mean square difference were used. These were summarized in a Taylor diagram as shown in Figure 22. From Figure 22, the multi-model ensemble mean abbreviated as ENSMB in the legend was identified to have higher skill than the individual models. This is in line with a similar study by Endris *et al.* (2013) that assessed the performance of CORDEX in East Africa, and reported that the multi-model ensemble mean can be used for assessing the future climate projections for the region because it sufficiently simulates well the Eastern Africa rainfall. The individual model that performed worst for the four Counties (Turkana, Marsabit, Samburu and Isiolo) was the International Centre for Theoretical Physics (ICTP) model from Italy and the individual model that had better skill for the four Counties was the Max Planck Institute (MPI) model from Germany.

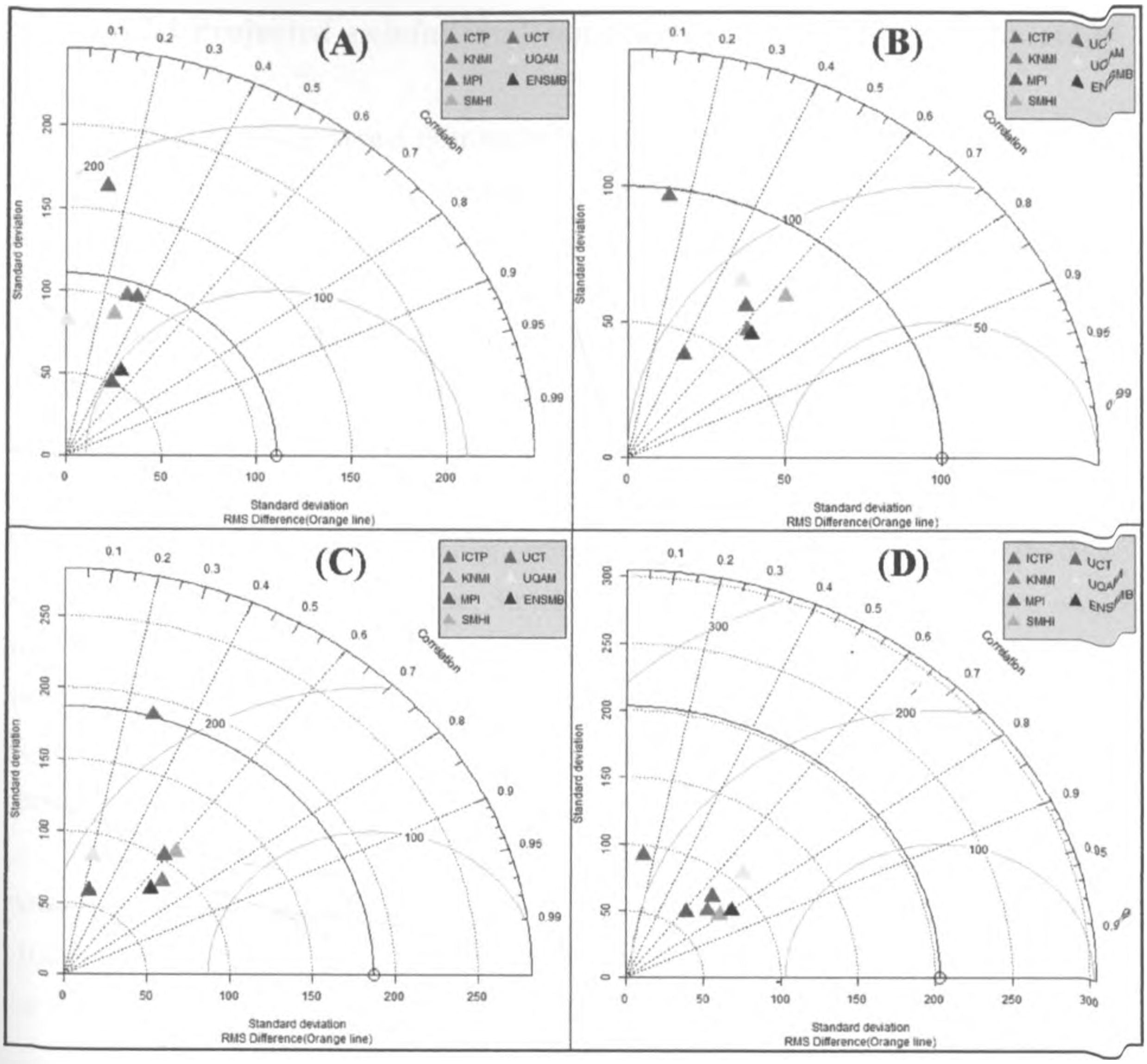

Figure 22: Taylor diagram representing the performance of the CORDEX models and ensemble of the models against observation for Turkana, Marsabit, Samburu and Isiolo Counties A, B, C and D respectively.

4.5.2 Potential impact of future climate change on cattle farming

This subsection presents future scenarios of annual rainfall and temperature distribution for three future climatological periods (2017-2046, 2047-2076, and 2077-2100), abnormal wetness and dryness for the period 2017 to 2100 and thermal heat comfort for cattle for both RCP 4.5 and RCP 8.5 for Turkana, Marsabit, Samburu, and Isiolo Counties using the multi-model ensemble (2030, 2050, and 2070).

4.5.2.1 Projected rainfall and temperature extremes over the study area

The study used Gaussian kernel distribution to analyze the future changes in rainfall and surface air temperature using the non-overlapping climatic periods i.e. 2017-2046, 2047-2076, and 2077-2100. Figure 23 shows the projected total rainfall distribution under the RCP 4.5 scenario Turkana, Marsabit, Samburu and Isiolo County. Figure 23 (a) indicates likelihood of a positive shift in mean annual total rainfall for Turkana County with reduced variability in the period 2047-2076 and reduced extremes under the RCP 4.5 scenario. Extremes are also projected to increase with increase in variability by the period 2077-2100 for Turkana County which may result to more droughts in the future. The maximum annual rainfall over Turkana County was also projected to decrease (less than 700mm) for the three climatic periods. Changes in the mean, variability, and extreme rainfall are likely to occur over Marsabit, Samburu, and Isiolo Counties as shown in Figure 23 (b), (c), and (d) respectively. The distribution observed for Turkana County was also projected for Marsabit County Figure 23 (b). Reduced rainfall variability for Marsabit and Samburu are projected to occur in the period 2047-2076 and high variability is likely to occur in the period 2077-2100. Low variability in rainfall for Isiolo County is likely to occur in the period 2017-2046 with extreme wet conditions, while high variability was projected to occur in the period 2077-2100 (Figure 23 (d)). The projected annual rainfall total is likely to reduce in the future over the study area

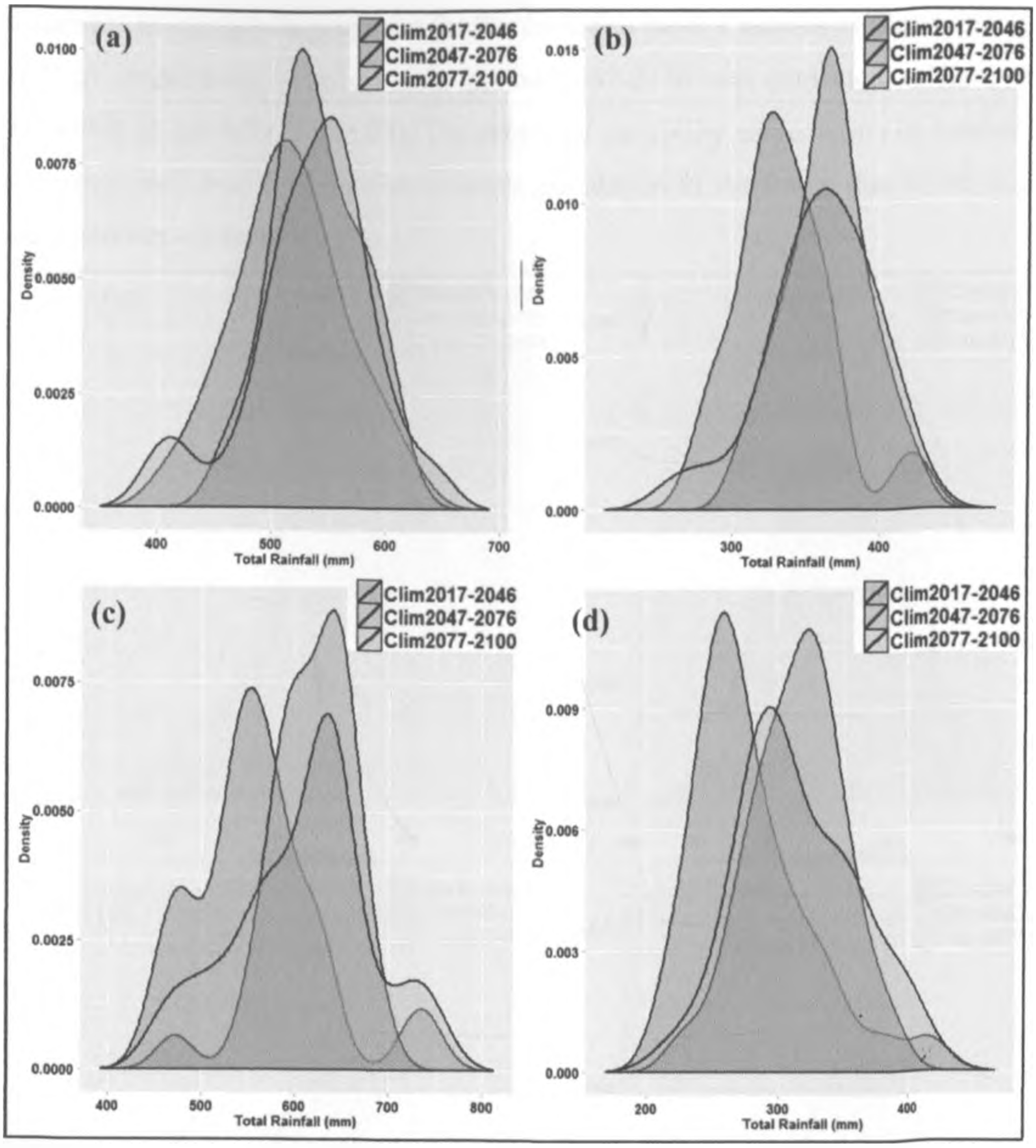

Figure 23: Gaussian kernel distribution for the annual rainfall distribution under RCP 4.5 scenario for (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties for different climatic periods.

Under the RCP 8.5 scenario, climatogical mean rainfall was projected to increase over the study area while the maximum total annual rainfall was projected to decrease compared to the current observations. Turkana County (Figure 24 (a)) is likely to have the smallest change in the mean compared to Marsabit, Samburu, and Isiolo Counties (Figure 24 (b), (c), and (d)) respectively. Highest variability in rainfall for the four Counties is likely to occur in the period 2017-2046 (Figure 24). Increase in extreme wet conditions are likely to occur in the period 2077-2100 for the all the Counties (Figure 24) and within the same period, increased variability in rainfall are projected for Samburu and Isiolo Counties as shown in Figure 24 (c) and (d) respectively. The climatic period 2047-2076 was projected to have the lowest variability in rainfall (Figure 24). The projected variability and extreme in rainfall under this scenarios, may lead to reduction in cattle population in the future due to the likelihood of increased dry conditions.

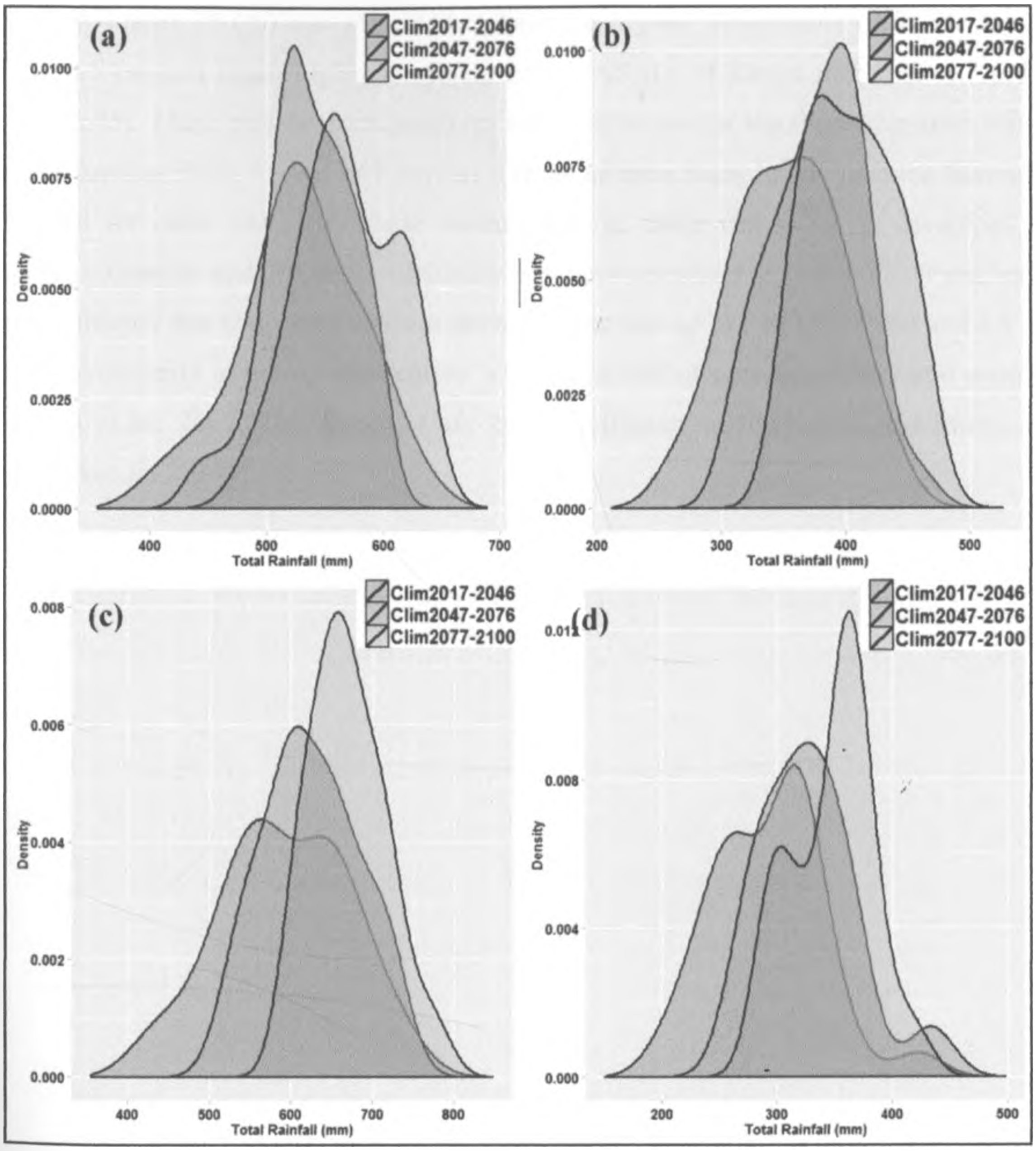

Figure 24: Gaussian kernel distribution for the annual rainfall distribution under RCP 8.5 scenario for (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties for different climatic periods.

As it has been observed under objective one, that temperature is significantly rising, the projected temperature under this objective still indicates that there are likelihood of high temperature in the future over the ASALs of Kenya under the RCP 4.5 and RCP 8.5 scenario as shown in Figure 25 and Figure 26. Under the RCP 4.5 scenario, maximum annual air temperature was projected to increase progressively in the climatic periods (Figure 25). Isiolo County (Figure 25 (d)) was projected to have the highest temperature of 35 7^{0}C by 2100 RCP 8.5 projects much higher temperature over ASALs of Kenya than RCP 4.5 scenario (Figure 26). These projected temperatures are likely to have a significant negative effect on cattle farming in the ASALs of Kenya as a result of them being higher than the thermal heat comfort for cattle i.e. 32^{0}C. These assume that the cattle will not have developed some adaptive capacity and that cattle variability will have remained the same. Other studies have also indicated that temperatures are projected to increase up to 2.8 ^{0}C by 2060 and 4.5 ^{0}C by 2090 particularly in the ASALs regions with a potential of decreasing the cattle population (Orindi *et al.*, 2007; Christensen *et al.*, 2007; Hoffmann, 2010; Ngaina and Mutai, 2013; Darkoh *et al.*, 2014).

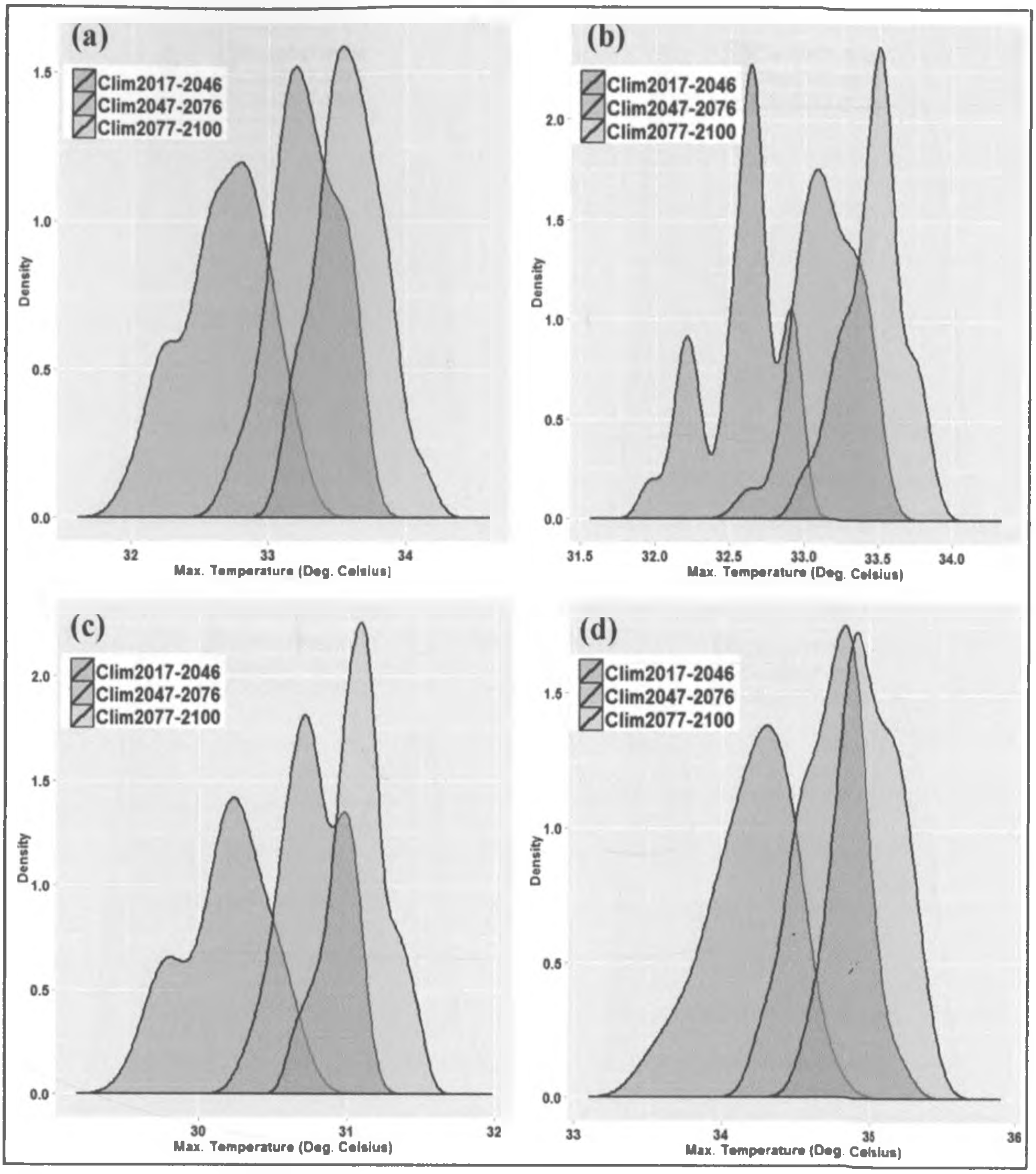

Figure 25: Gaussian kernel distribution for the annual mean of maximum surface air temperature distribution under RCP 4.5 scenario for (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties for different climatic periods.

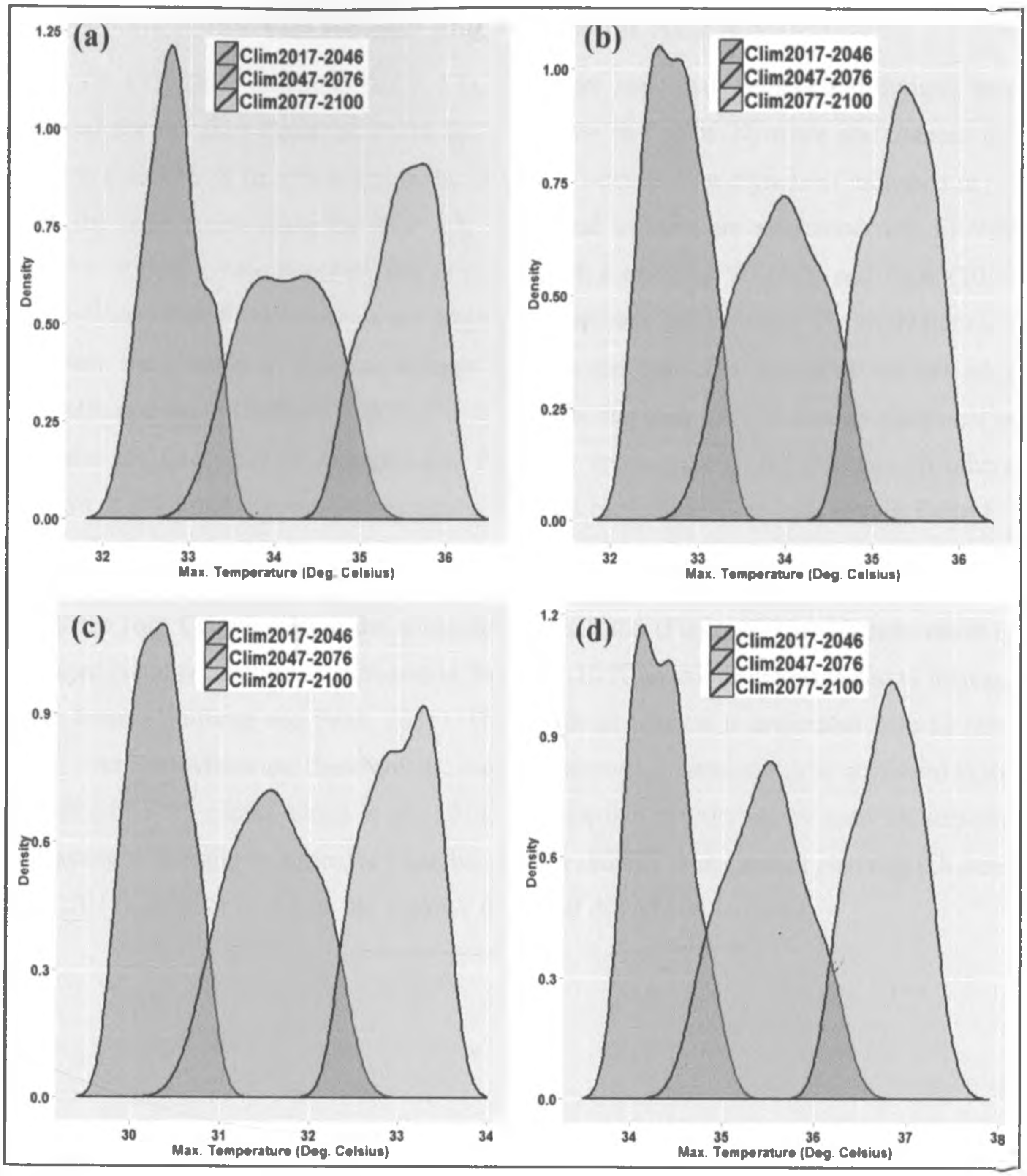

Figure 26: Gaussian kernel distribution for the annual mean of maximum surface air temperature distribution under RCP 8.5 scenario for (a) Turkana, (b) Marsabit, (c) Samburu, and (d) Isiolo Counties for different climatic periods.

4.5.2.2 Abnormal wetness and dryness for RCP 4.5

Using the CORDEX ensemble (RCP 4.5), the future abnormal wetness and dryness were analyzed for the four Counties. From the projection in Figure 27, there are chances that Turkana County will be affected more by abnormal wetness than dryness as indicated in run 24 in the same figure using the RCP 4.5. Abnormal wetness are associated with El Niño events over east Africa therefore, this is in line with a study by Williams and Funk (2011) who indicated that, El Niño events are projected to increase in the future. The study indicates that there are chances of frequent drought between the year 2020 and 2040 for Marsabit, Samburu, and Isiolo Counties. IPCC (2013) predicts that over the 21st century there will be increases the frequency of droughts and floods in some regions and decrease in others. Drought or abnormal dryness has a negative effect on cattle farming as indicated in Table 15.

From the year 2040, there are likelihoods of more abnormal wetness than abnormal dryness for all the four Counties using the ensemble for RCP 4.5 (Figure 27) which may result to increased cattle population as indicated in Table 15. El Niño events are projected to increase in the future (Williams and Funk, 2011). The abnormal wetness is associated with El Niño events over East Africa and therefore, the projected abnormal wetness can be attributed to the projected El Niño events. Dutra *et al.* (2013) reported that the SPI can be used for seasonal forecasting of drought in Africa. SPI can be used for drought management planning (Di Lena *et al., 2014*), in order to reduce the negative impact of drought on livestock.

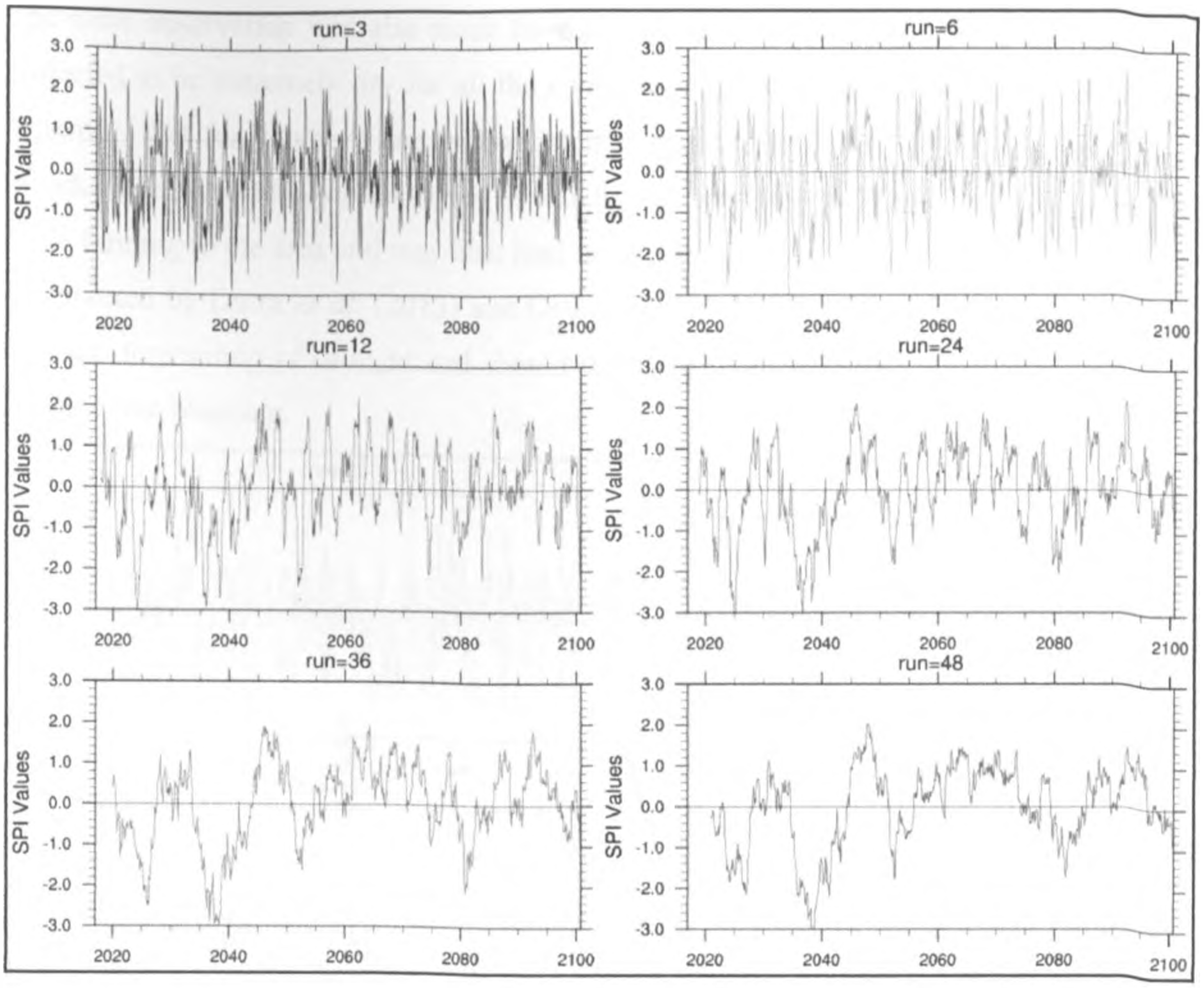

Figure 27: SPI time series over the Turkana County for the period 2017-2001 using (a) run=3, (b) run=6, (c) run=12, (d) run=24, (e) run=36 and (f) run=48 for RCP 4.5 scenario.

4.5.2.3 Abnormal wetness and dryness for RCP 8.5

Using the RCP 8.5 scenario, Turkana County is likely to experience extremely severe drought in the 2020 and 2070 as indicated in Figure 28 run 24. The ensemble model (RCP 8.5) also projects that there are chances of reduction in extremes for the period 2040 to 2060, followed by frequent abnormal wet and dry conditions. The frequency of extreme climate conditions projected for this County will have a negative effect on cattle farming. The extreme dry condition in the year 2020 projected for Turkana County is also the same for Marsabit County. But the RCP 8.5 ensemble model for Marsabit indicated that the frequencies of abnormal dryness are projected to decrease while the abnormal wetness is projected to increase. IPCC (2013) also predicted that over the 21st century there will be increases the in frequency of droughts and floods in some regions and decrease in others.

The same observation was also made for Samburu and Isiolo Counties with the year 2020 projected to be extremely dry for all the counties while 2075 and 2090 are projected to be extremely wet for Samburu and Isiolo Counties respectively**Error! Reference source not found.**. The projected extremes over the study area are likely to have a negative effect on cattle farming in the area and may also lead to conflict over the limited resources in the area. As reported by Dutra *et al.* (2013) and Di Lena *et al.* (2014), SPI is an important tool for seasonal forecasting of drought and should therefore be incorporated in drought and flood management planning.

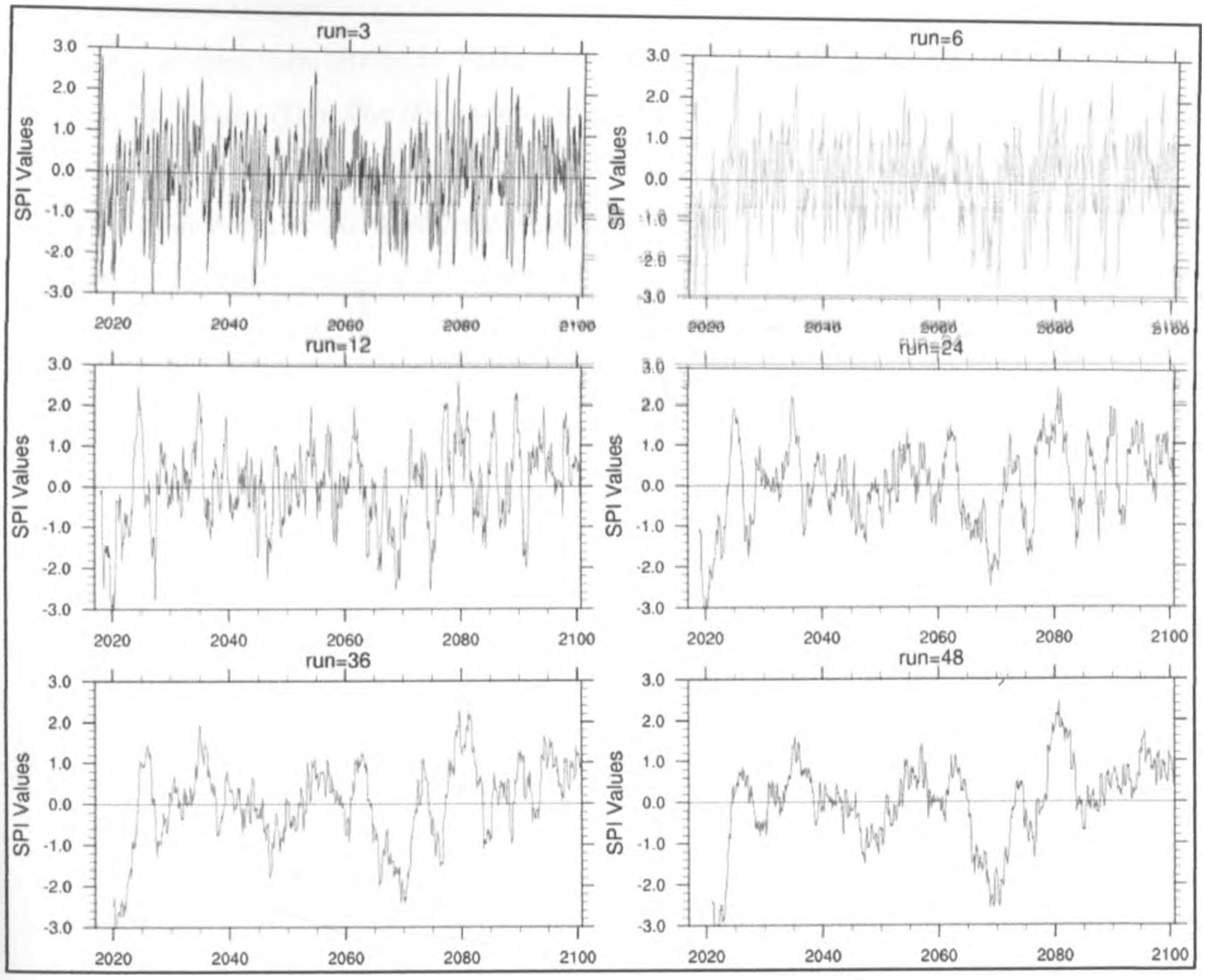

Figure 28: SPI time series over the Turkana County for the period 2017-2001 using (a) run=3, (b) run=6, (c) run=12, (d) run=24, (e) run=36 and (f) run=48 for RCP 8.5 scenario.

4.5.2.4 Thermal heat comfort for cattle using ensemble model for RCP 4.5

By 2030 under the RCP 4.5 scenario, the heat comfort projected for DJF and MAM seasons were observed to be the severe for Turkana, Marsabit, and Isiolo Counties while Samburu Country indicates a favorable for cattle farming as shown in Figure 29 (A) and (B). JJA and SON seasons indicate a likelihood of favorable thermal heat comfort for cattle by the year 2030 (Figure 29 (C) and (D)). The same observation DJF and MAM was also made for the 2050 projection (Figure 30 (A) and (B)). It was also projected that severe heat stress on cattle are likely to start manifesting in Turkana and Isiolo Counties during JJA and SON seasons (Figure 30 (C) and (D)). The observed change in JJA and SON seasons were attributed to the projected increase in temperature by the IPCC (2013). The area covered by severe heat stress is likely to increase by 2070 over the study area for all the seasons as indicated in Figure 31. Studies by Klehmet (2009) and Christensen *et al.* (2007) reported that temperatures of East African are consistently increasing throughout the models; this is line with the observation made in this study.

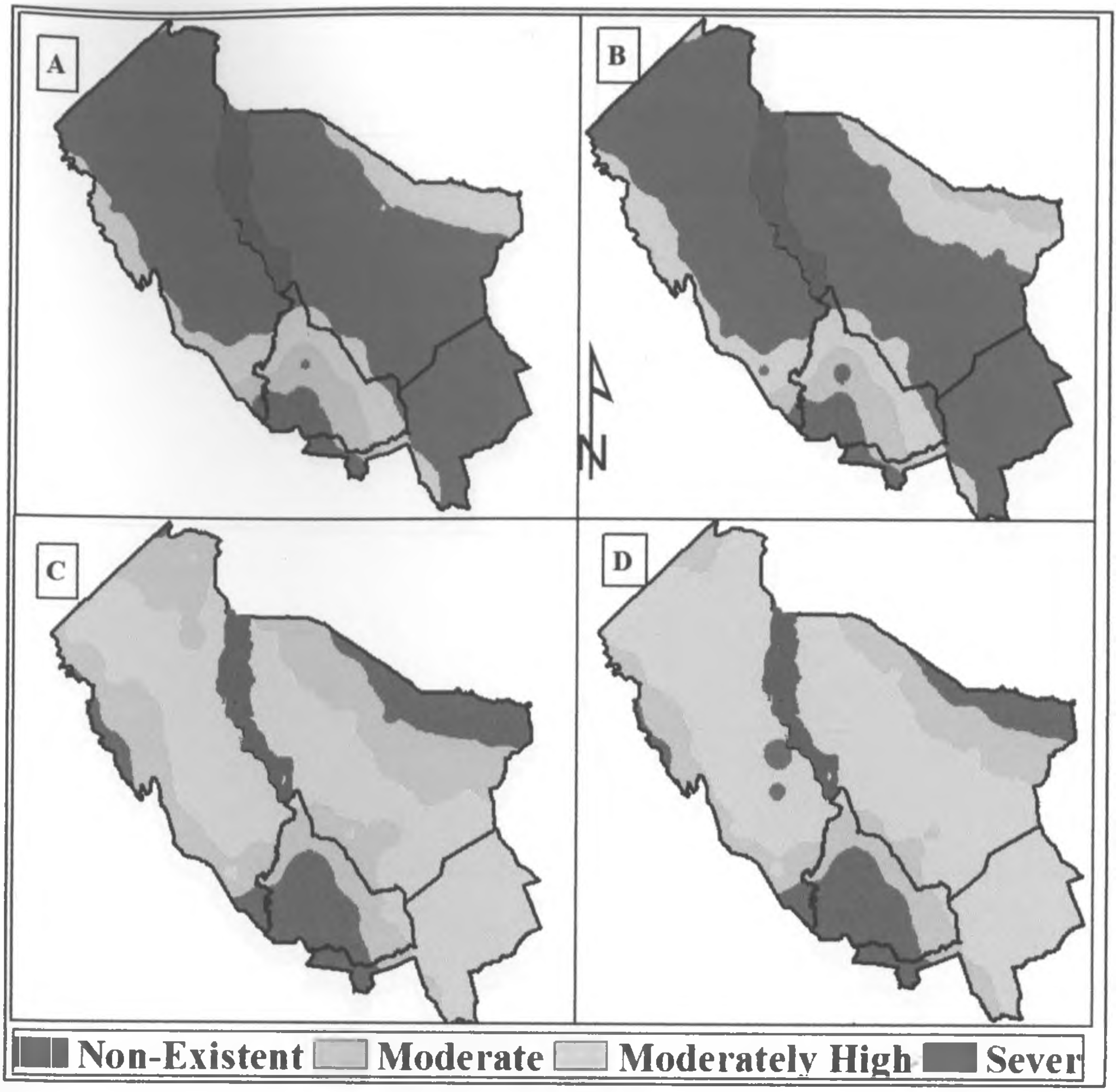

Figure 29: Cattle thermal heat comfort using maximum temperature from RCP 4.5 ensemble model for the year 2030 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

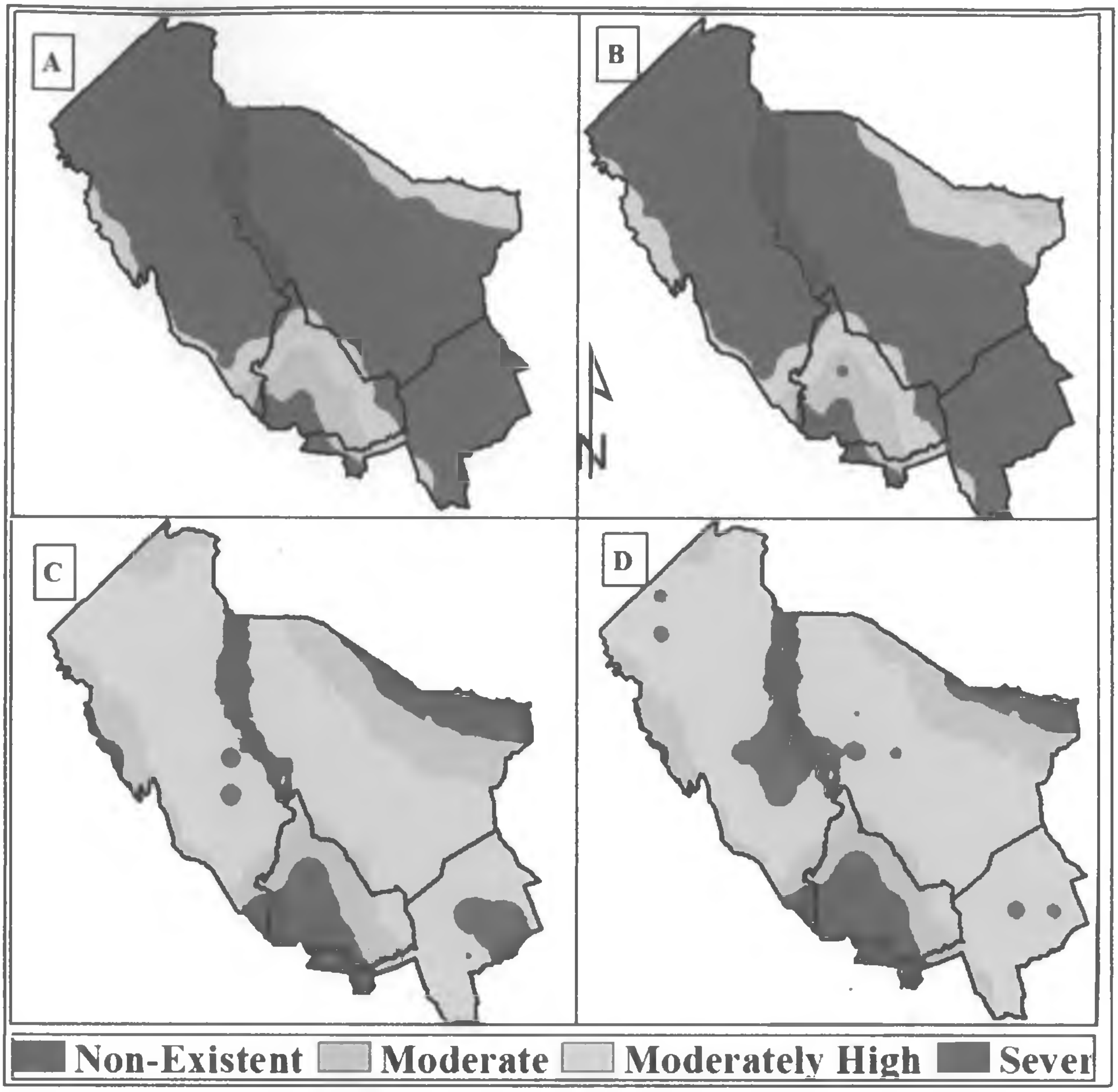

Figure 30: Cattle thermal heat comfort using maximum temperature from RCP 4.5 ensemble model for the year 2050 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

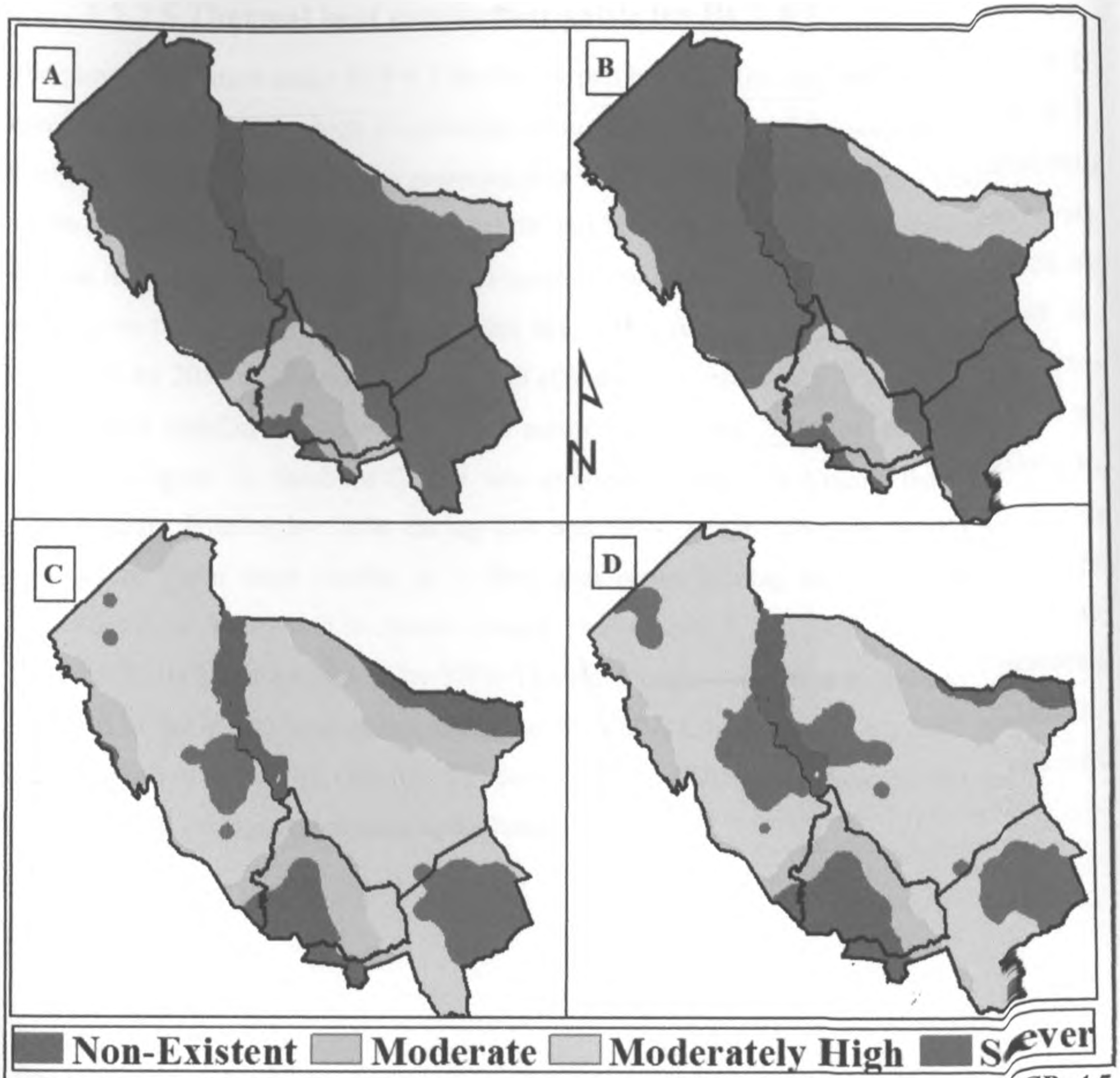

Figure 31: Cattle thermal heat comfort using maximum temperature from RCP 4.5 ensemble model for the year 2070 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

4.5.2.5 Thermal heat comfort for cattle for RCP 8.5

The same observation under RCP 4.5 for the thermal heat comfort for cattle by the year 2030 was also made under the high emission scenario (RCP 8.5) for all the seasons as shown in Figure 32. By the year 2050, it is projected that Turkana, Marsabit, and Isiolo Counties will not be favorable for cattle farming during DJF and MAM seasons due to the projected severe thermal heat comfort in these Counties (Figure 33 (A) and (B)). The study also projects an increase on the area covered by the severe heat stress for JJA and SON seasons over the study area by 2050 as indicated in Figure 33 (C) and (D) respectively. The impact of severe thermal heat comfort is likely to be more severe by the year 2070 for all the seasons as evident in Figure 34. Samburu County was projected as the only County that is likely to support cattle farming by 2070 during JJA and SON seasons (Figure 34 (C) and (D)) respectively. From these results, it is likely that cattle farming may experience several challenges in the future due to climate change. Temperature is also projected to increase by 1.0 to 2.8 ^{0}C by 2060s and 4.5 ^{0}C by 2090. Therefore, cattle population is likely to decreased as shown in Table 4 in chapter two (Orindi *et al.*, 2007; Christensen *et al.*, 2007; Klehmet, 2009; Darkoh *et al.*, 2014). Over the 21st century, IPCC (2013) has predicted that there will be increases in average temperature and extreme heat.

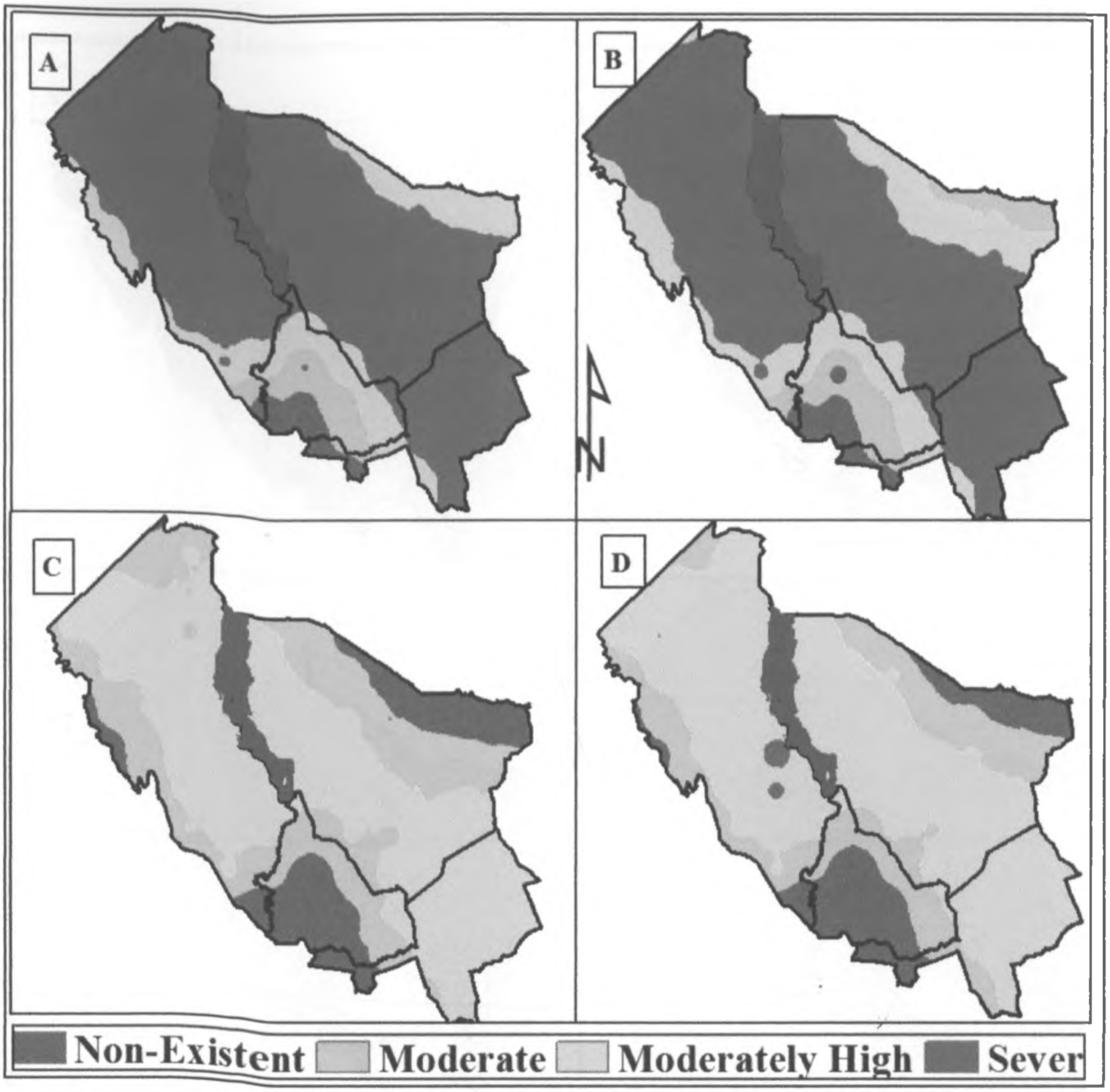

Figure 32: Cattle thermal heat comfort using maximum temperature from RCP 8.5 ensemble model for the year 2030 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

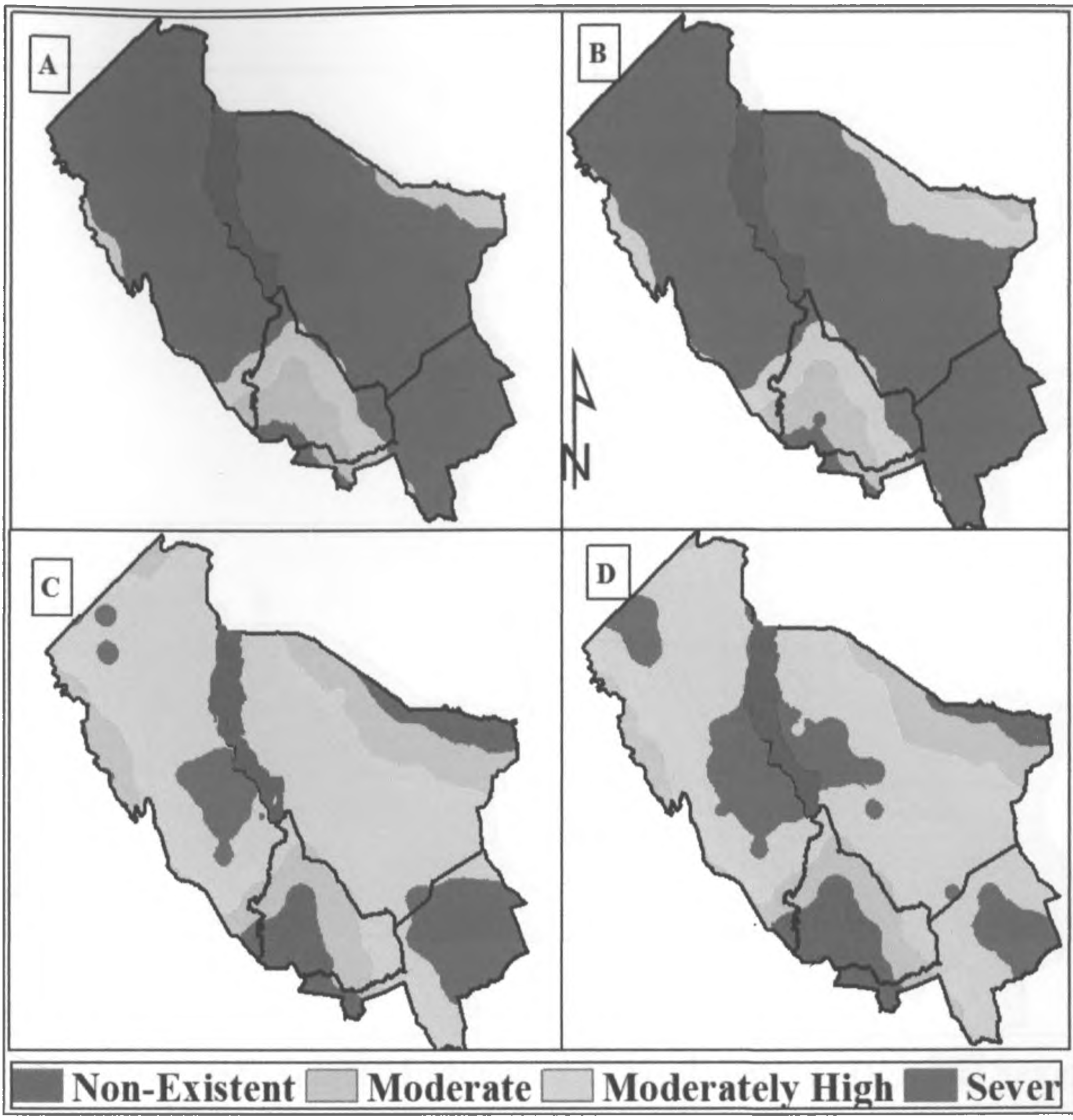

Figure 33: Cattle thermal heat comfort using maximum temperature from RCP 8.5 ensemble model for the year 2050 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

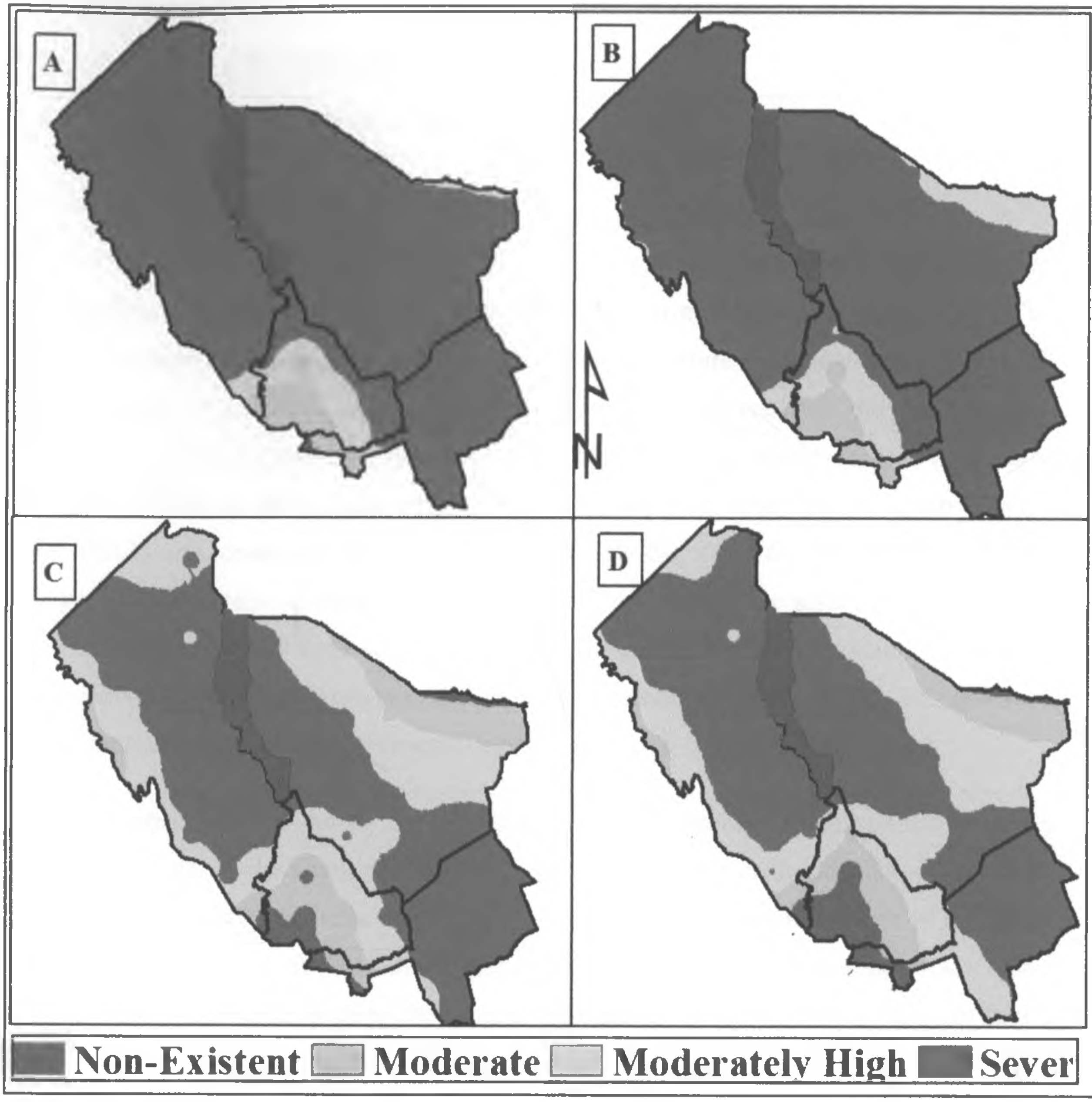

Figure 34: Cattle thermal heat comfort using maximum temperature from RCP 8.5 ensemble model for the year 2070 for December, January, February (A), March, April, May (B), June, July, August (C), and September, October, November (D) seasons.

CHAPTER FIVE

5.0 Conclusion and Recommendation

This chapter presents the conclusion and recommendation of the study.

5.1 Conclusion

It is evident from the study that both maximum and minimum temperatures are increasing at all study locations as has been observed at many locations worldwide. The highest increase in seasonal mean of surface air temperature ranging from 0.33-1.45^{0}C was observed for June-August season. Results from rainfall analyses did not delineate homogenous changing patterns at all locations and seasons, however increase in drought risk was evident at most locations within the study area when recent mean rainfall (1991-2013) was compared with the means of 1901-30, 1931-60, and 1961-90. Some changes in the pattern of temperature and rainfall extremes were also evident from the patterns of higher order time series moments which included skewness and kurtosis. It was observed that the recurrences of extremes were centered on 2.3, 3.5, 5.5, and 9-10 years which were attributed to different climatic systems.

The study observed that during the period of abnormal wetness, cattle populations were higher than those of the abnormal dryness thus climate affects cattle population. From the projections, the study concludes that there are chances of high negative effect of abnormal dryness for the period 2030-2040 over the study area. An ensemble of the models was found to have a better skill in replicating the observation and hence was used for analysis of future climate. The extremes in rainfall and temperature were projected to increase in the future with a significant change in the mean of temperature in all the scenarios used in this study. Cattle farming are likely to be affected by high temperature resulting to severe thermal heat comfort thus cattle that can adapt to high temperature are recommended in the arid and semi-arid lands of Kenya. Cattle that can adapt to these projected temperature, abnormal wet and dry conditions should adopted in the ASALs of Kenya.

5.2 Recommendation

5.2.1 To the livestock sector

The result from this study can be used in the planning and management of the livestock sector in the ASALs of Kenya and support national sustainable development planning. The SPI tool can be adopted by the livestock sector for monitoring and forecasting abnormal wetness and dryness of a region to improve the timely identification of the emerging extreme conditions to be action by the government.

5.2.2 To the policy makers

The information from this study can be used by the policy makers to develop policies that can address the problem of high livestock mortality due to extreme weather and climate conditions in the country.

5.2.3 To the climate scientists

Further studies on the effect of climate change on other aspects of livestock such as forage as well as a methodology way to distinguish human factors from climate factors that affect livestock farming are recommended.

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