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Assessment of Meteorological Drought in Main Climatic Zones of Kenya

John Nyangena

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Abstract

This paper presents a spatio-temporal assessment of meteorological drought in four counties of Kenya using Standardized Precipitation Index (SPI). Monthly rainfall data from the Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) dataset from 1981 to 2015 was transformed into a Gamma Distribution Function to characterize drought at 1, 3, 6, 9 and 12 months temporal scale. During the entire period, dry zones recorded 29 extreme and severe seasonal drought conditions compared to 18 in very dry zones. Generally, seasonal SPI declined in very dry zones but increased in the dry zones although March-April-May (MAM) period experiences more extreme droughts. In dry zones, the number of extreme and severe droughts more than doubled from 7 to 16 between 1980 and 1990 and 2000-2010, while in very dry zones it reduced by more than half from 5 to 7. The findings of 3 months SPI compared favourably to observed drought over the country, buttressing the use of SPI to monitor drought conditions. Differences in drought patterns across main climatic zones challenges the one size fits all approaches used to drought management in Kenya. Replicating drought analysis at lower spatial scale and assessing associated sectoral impacts is essential in effective drought management.

Abbreviations and Acronyms

ASALs	Arid and Semi-Arid Lands
CHIRPS	Climate Hazards group InfraRed Precipitation with Stations
CPF	Common Programme Framework
DRM	Drought Risk Management
EDE	Ending Drought Emergency
GDP	Gross Domestic Product
MAM	March-April-May
NDMA	National Drought Management Authority
OND	October-November-December
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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1. Introduction

1.1 Background

Climate-induced drought remain a global challenges affecting water supply, food production and the environment with severe consequences on economies and livelihoods (Wang et al., 2011; Sheffield et al., 2012). Notable droughts include the millennium drought in Southeast Australia (Kiem et al., 2016), the once-in-a-century droughts in Southwest China (Qiu, 2010; Zuo et al., 2015) and the Horn of Africa drought (Masih et al., 2014; Lyon, 2014). Under climate change, the frequency, duration and intensity of drought is expected to increase particularly in drought prone areas (Dai, 2016; Fu and Feng, 2014; Kelley et al., 2015; Ault et al., 2016). An understanding of drought characteristics and their impact on socio-economic systems is essential in designing appropriate adaptation actions.

The international community under the United Nations Framework Convention on Climate Change (UNFCCC) committed to limit global temperature increase to 1.5^{o}C above pre-industrial levels, considered a tipping point for catastrophic effects ((UNFCCC Conference of the Parties, 2015). Yet, the most recent report of the International Panel on Climate Change concluded that the world had only a dozen years to meet the target, beyond which even half a degree Celsius will significantly worsen the risks of drought, floods, extreme heat and poverty for hundreds of millions of people. Africa would bear the brunt of the drought effects due to low adaptive capacity and dominance of climate sensitive sectors in the economy (Government of Kenya, 2016). Already, in Sub-Saharan Africa, drought has become more frequent and more intense over the past decades (Paeth et al., 2010; Taylor et al., 2017) because temperature has increased higher than the global mean temperature (Weber et al., 2018). Even if the mean global temperature is kept below the 1.5°C threshold, regions between 15°S and 15°N are projected to experience more hot nights and longer and more frequent heat waves (Kharin et al., 2018).

Despite being located in the equator, Kenya is prone to drought due to vast areas of arid and semi-arid lands (ASALs) where rainfall is highly variable. Over the last half of the 20th century, the country experienced a number of drought episodes including 1951, 1952-55, 1957-58, 1957-58, 1974-76, 1980-81, 1983-85, 1987, 1992-93, 1995-96, 1999-2000, and 2004-06, 2009, 2010-2011, and more recently 2016-17 (Ngaira, 2004, Uhe et al., 2017). The severe drought of 2008-2011 had overall effect of about Ksh 968.6 billion (Ksh 64.4 billion for the destruction of physical and durable assets and Ksh 904.1 billion for losses in the flows of the economy across all sectors) (Government of Kenya, 2012). Failure of the long rains (March-May) in 2004 caused a severe drought, which led to crop failure where over 2.3 million people were in need of humanitarian assistance (Kandji, 2006). Other droughts that had significant impact include the 1999-2000 La Niña drought that led to power rationing causing loss of approximately US$ 20 million to Kenya Power and Lighting Company (KPLC) and serious disruption of economic activities. The national Gross Domestic product (GDP) contracted by about 0.3% as the aftermath of the drought. By June 1999, an estimated 1.7 million people were in dire need of food assistance with the figure rising to 4 million by December 2000 (Duran, 2005). Drought frequency increased from once in every 10 years in 1960/70s to 5 years in 1980s and 2–3 years in 1990s (Huho and Mugalavai, 2010; Nkedianye et al., 2011).

The Government of Kenya has pursued policies to build resilience to drought among society. Following the 1979-1980 drought, the government developed a Sessional Paper No. 4 of 1981 on national food policy with a focus on strengthening self-sufficiency in food production and achieve a calculated degree of food security across climatic zones (Government of Kenya, 1981). Subsequently, the Food and Nutrition Planning Unit under the then Ministry of Planning and National Development was mandated to coordinate food security issues across the various players. Thereafter, the government recognized that drought compromised prospects for food sufficiency particularly in the pastoral ecosystems and established various structures such as drought contingency planning and monitoring mechanism within its administration to address this matter. In 1992 a drought contingency action plan was implemented through the national disaster management programme under the then Department of Relief. In 2007, the Sessional Paper No. 8 on National Policy for Sustainable Development of Arid and Semi-Arid Lands was formulated as framework to protect economic, environmental and social facets of communities affected by drought. The essence of the policy was to reduce vulnerability of poor people to climate shocks by strengthening adaptation capacities (Government of Kenya, 2007). This policy resonated well with the needs of communities residing in dryland areas but weak implementation compromised its effectiveness, necessitating its revision.

An important milestone in addressing drought in Kenya was the formulation of the Sessional Paper No. 8 on National Policy for the Sustainable Development of Northern Kenya and other Arid Lands 2012. A key output of the document is the establishment of the National Drought Management Authority (NDMA), with mandate to ensure that drought does not result in disaster and to exercise general supervision over all matters concerning drought management in Kenya's Arid and Semi-Arid Lands (ASALs). NDMA is further responsible for overseeing implementation of the Ending Drought Emergency (EDE) Common Programme Framework (CPF), the national initiative folded into the larger regional efforts to better manage the underlying causes of drought. In 2015, a common programme framework for ending drought emergency (EDE CPF) was developed to address drought emergencies in ASAL counties by facilitating cooperation and synergy across sectors, actors, geographical areas and levels of operation. EDE has six pillars: peace and security, climate-proofed infrastructure, human capital, sustainable livelihoods, drought risk management and institutional development and knowledge management (Government of Kenya, 2015). The first four pillars aim to accelerating investment in drought-prone areas to foster development, while the second two aim to strengthen institutional and financing frameworks for Drought Risk Management (DRM). EDE is built on the premise that investing in the foundations for development upon which other interventions can be implemented, and strengthening institutions for DRM creates sustainable results beyond project interventions (Carabine et al., 2015). The National Drought Management Authority (NDMA) was established as an institutional framework to oversee implementation of the EDE CPF.

The sector plan for drought risk management and the (EDE) 2013-2017 were developed as a government response to the 2008-2011 drought and the need to roll of the Kenya Vision 2030 Development Strategy for Northern Kenya and other Arid Lands developed in 2012. An object of the Vision was to ensure food and nutrition security in areas that are susceptible to drought, where people's access to and control over critical livelihood resources such as land is insecure, and where climate change will increase unpredictability (Government of Kenya, 2012). The plan sets to eliminate the worst effects of drought by strengthening people's resilience to drought, improving monitoring of, and response to drought emergency. It recognizes the unique characteristics of ASALs to cruel climatic conditions that diminish or degrade natural resources. Scarcity of pasture and water undermine productivity of pastoral and agro-pastoral livelihoods and exacerbate food insecurity (Government of Kenya, 2012). The Plan is cognizant to the fact that pastoral system is undergoing transformation towards more commercialization and individualization, resulting to widening the gap between wealthier and poorer households. Transformation is further aided by changes in the rangelands, resulting from disruption of traditional seasonal transhumance patterns, the expansion of community conservancies, human population pressure, and the spread of invasive species. However, the Plan fails to recognize the transformation of pastoral systems due to adoption of different livelihood systems through diversification.

These frameworks and instruments spell out broad outlines for disaster risk reduction at the international, national and local levels. Implementation of these frameworks demands that governments consider their national and local circumstances in designing response measures. Although biophysical and livelihood are important elements in determining local circumstances, they have not been explicitly addressed by these frameworks.

Despite progress in combating drought, drought management has continued to be reactive, with crisis management approach as opposed to anticipatory. Response measures tend to be untimely while contingency plans are activated too late to prevent the widespread loss of assets (Government of Kenya, 2012). Most drought assessments in Kenya have focused on macro drought analysis, while those at local level are based on climate data from a single station. For example, an annual drought index was used to monitor drought events and captured drought events in 1983/1984, 1987; 1992-1994, 1999/2000, 2001, 2002, 2004, 2006, 2010/2011 (Balint et al., 2015), although this did not take into account the spatial distribution using key agro-climatic zones. Effective response to drought require a better understanding of the occurrence and severity of drought taking into account the country's main climatic zones, namely: the very dry, dry and wet zones. Very dry areas receive very low and irregular rainfall with temperatures ranging from 20°C to 40°C year-round. These regions are sparsely populated by pastoral people who keep camels, cattle and goats and mainly cover the northern part of Kenya. Dry areas receive regular rainfall every year, but in very small quantities and are dominated by small thorn bushes and scattered baobab trees. Wet regions receiving good reliable rainfall and are confined to the narrow coastal belt and the highlands. They are primarily used for cultivation of crops such as tea, pyrethrum, horticulture, maize, and dairy farming. It is expected that drought patterns in these regions vary greatly, influenced by rainfall amounts. This paper sets out to assess the drought patterns in selected counties representing the main climatic zones of Kenya.

1.2 Problem Statement

Kenya's physiographic characteristics make it highly vulnerable to drought. Over three quarters of the country is categorized as arid and semi-arid, which receives erratic rainfall. The government has put in place policy and institutional frameworks to reduce the adverse impact of drought, yet rising episodes of drought have been witnessed in 2008/2009, 2010/2011 and 2016/17. In particular, the drought of 2016-2017 caused suppressed rainfall of October-December 2016 resulting in government declaring it a national emergency. It is evident that drought affects environmental, social and economic spheres with health and local food security particularly prone. Previous drought management efforts adopted a uniform approach to drought without regard to its varying characteristics across climatic zones, thus reducing their effectiveness. Understanding drought behaviour across main climatic zones is necessary in informing development of effective response strategies. Yet, overwhelming studies have relied on observed data from a single weather station to assess drought over a large area, ignoring the heterogeneous nature of climate. Despite advances in geospatial data, use of satellite-based climate data in drought monitoring and assessment in Kenya has remained very low. Studies that have used geospatial data have been limited to a single climate zone, making it difficult to draw inferences across the various climatic zones. The study sought to elucidate drought characteristics in Kenya's main climatic zones to inform drought management policy.

1.3 Research Objectives

The broad objective of this paper is to assess drought patterns in Kenya's main climatic zones with a view to informing drought management measures.

Specifically the paper addressed the following two objectives:

(i) To examine the trends in drought occurrence across Kenya's main climatic zones

(ii) To assess the magnitude of drought across Kenya's main climatic zones.

(iii) To assess the severity of drought across Kenya's main climatic zones.

2. Literature Review

There are four types of droughts, namely: meteorological, hydrological, agricultural and socio-economic. *Meteorological drought* is a deficiency of precipitation (intensity) from expected or normal that extends over a season or longer period and is insufficient to meet the demands of human activities and the environment. *Hydrological drought* is a period of below normal stream flow and depleted reservoir storage during which flow is inadequate to supply established uses under a given system, often persisting long after a meteorological drought has ended. *Agricultural drought* links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, soil water deficits, reduced ground water or reservoir levels needed for irrigation, and so forth. A decline of soil moisture depends on several factors that are affected by meteorological and hydrological droughts, together with differences between actual and potential evapotranspiration. *Socio-economic drought* occurs when the demand for socio-economic goods exceeds supply because of a weather-related shortfall in water supply (combination of meteorological and hydrological drought impacts) or human-induced factors (from increased population and poor production from deficiency or poor technology) (Hulme, 1993, Wilhite and Glantz, 1985; Schuman, 2006; Ayoade, 2004). Meteorological drought explain the primary causes of drought, while other types of drought explain the secondary impacts of meteorological drought (Balint et al., 2013).

Several indices exist to measure the extent to which precipitation for a given period has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index (PDSI) (Palmer, 1965) has been widely used as a means of providing a single measure of meteorological drought severity, for example for the previous 30 years. It is based on a monthly water balance accounting scheme involving precipitation, evapotranspiration, run-off and soil moisture. The PDSI has been used in making operational water management decisions and planning drought monitoring. Basic drought phenomena and drought preparedness studies are presented by Wilhite and Glantz (1985) and Wilhite (1996).

Combating drought requires a good understanding of its occurrence and characteristics through use of indices, a single number assimilating a large amount of data. These broadly fall into two: (a) drought indices based on water balance calculation; and (b) statistical drought indices based on time series analysis (Ji and Peters, 2003; Morid et al., 2006). The water balance methodology requires application of several climatic and physical variables at a given time and space. Some of these variables might be calculated using some time series analysis, but overall, their final goal is to determine the water deficit of the crop at a given time and space based on a distributed parameter model. Examples of these types of indices include the Palmer Drought Severity Index (Palmer, 1965) widely used as a means of providing a single measure of meteorological drought severity, for example for the previous 30 years. It is based on a monthly water balance accounting scheme involving precipitation, evapotranspiration, run-off and soil moisture. The PDSI has been used in making operational water management decisions and planning drought monitoring.

Reclamation Drought Index. Statistical indices are based on one or maximum two parameters, mostly rainfall and sometimes temperature deficiency/excess. Commonly, indices in this category include the Percent Normal Drought Index, the Precipitation Decile Index and the Weighted Anomaly Standardized Precipitation, the China Z-Index (CZI) (Wu et al., 2001), the Standardized Precipitation Index (SPI) (Mckee et al., 1993), and the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010).

Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) to understand whether a deficit of precipitation has different impacts on the ground, reservoir storage, soil moisture, snow pack, and stream flow. The SPI was designed to quantify the precipitation deficit for multiple time scales, which reflect the impact of drought on the availability of different water resources. It gives the standard deviations that the observed cumulative rainfall at a given time scale deviates from the long-term mean. The index uses precipitation and is designed to quantify the precipitation deficiency for multiple time scales. These time scales reflect the impact of drought on the availability of different water resources. Computation of SPI for any locations based on the long-term precipitation record of a certain period. SPI is computed by first building a frequency distribution from time series of precipitation data of more than 30 years at a given location and time, with an interval greater than a month but less than 24 months (McKee, 1993; Wu et al., 2001; Bordi and Sutera, 2007; WMO, 2012). A gamma probability density function is then fitted to the precipitation data and transformed into a normal distribution with mean zero and standard deviation one. SPI has advantages over other drought indices because of its relative ease and flexibility that allows observation of water deficits at different agro-climatic zones (Szalai and Szinell, 2000; Wu et al., 2001). In addition, users can choose the time scale most appropriate for computing the SPI (Edwards and McKee, 1997). SPI can monitor dry and wet conditions over a wide spectrum of time from one to 72 months (WRCC, 2000).

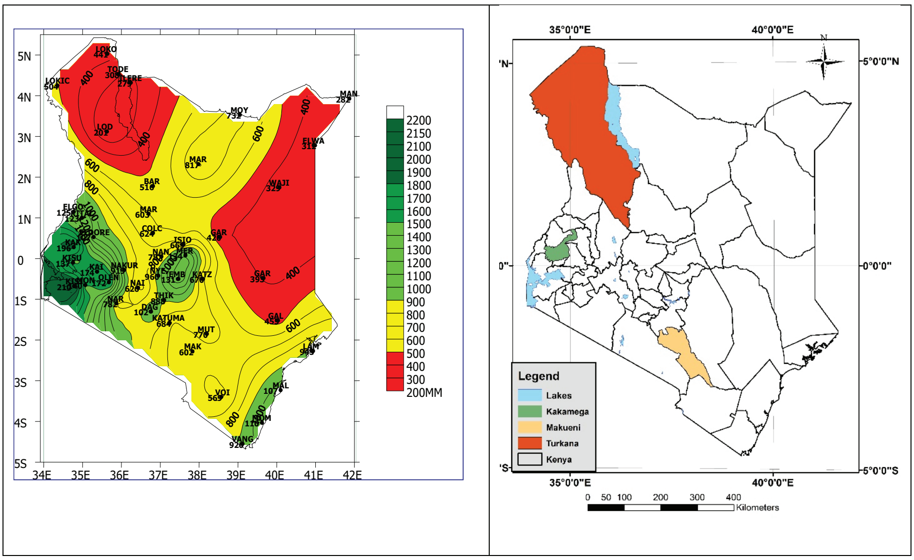
SPI is founded on the probability of an observed precipitation deficit occurring over a given prior accumulated time period. It measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest (e.g. 1, 3, 12, 48 months), with the long-term historic rainfall record for that period. The historic record is fitted to a probability distribution (the "gamma" distribution), which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero. For any given region, increasingly severe rainfall deficits (i.e. meteorological droughts) are indicated as SPI decreases below 1.0, while increasingly severe excess rainfall are indicated as SPI increases above 1.0. Because SPI values are in units of standard deviation from the long-term mean, the indicator is used to compare precipitation anomalies for any geographic location and for any number of time-scales. The indicator can be modified to include the accumulation period. Thus, SPI-3 and SPI-12, for example, refer to accumulation periods of three and twelve months, respectively. Opiyo et al (2015) using standardized precipitation index identified severe drought in Turkana County in 1990, 1995, 2000, 2008 and 2009.

3. Methodology

3.1 Description of the Study Area

Kenya is broadly divided into three climatic zones: very dry, dry and wet. Very dry climates are characterized by arid bushlands of northern and eastern Kenya. The average rainfall is very low and irregular with temperatures ranging from 20°C to 40°C year-round. These regions are sparsely populated by pastoral people who keep camels, cattle and goats. A greater part of Kenya falls within semi-arid dry climatic zones where rain falls regularly every year, but in very small quantities. Vegetation is small thorn bushes and scattered huge baobab trees. Wet climate falls in the highlands and near large water bodies including Lake Victoria and Indian Ocean. Those regions receive regular rainfall with above 200 mm pee year in some locations. In this study, four counties of Makueni, Turkana, Garissa and Kakamega were selected to respectively represent Kenya's main agro-climatic zones (Figure 1).

Figure 1: Kenya's main agro-climatic zones and study counties



Turkana County has a total area of 77,000 km² and lies between Latitudes 1° 30' and 5° 30'N and Longitudes 34° 30' and 36°40' E. Physiographically, the county has low-lying open plains, mountain ranges and river drainage patterns. The main mountain ranges of the county are Loima, Lorengippi, Mogila, Songot, Kalapata, Loriu, Kailongol and Silale mountains. The mountain ranges, because of their high elevation, are normally green, covered with dense bushes and high woody cover.

The ranges support important economic activities such as honey production and grazing. The temperatures range between 20°C and 41°C with a mean of 30.5°C. The rainfall pattern and distribution is erratic and unreliable with both time and space. There are two rainfall seasons. The long rains (*akiporo*) usually occur between April and July and the short rains between October and November and ranges between 52 mm and 480 mm annually with a mean of 200 mm. The driest periods (*akamu*) are January, February and September (Turkana County, 2013).

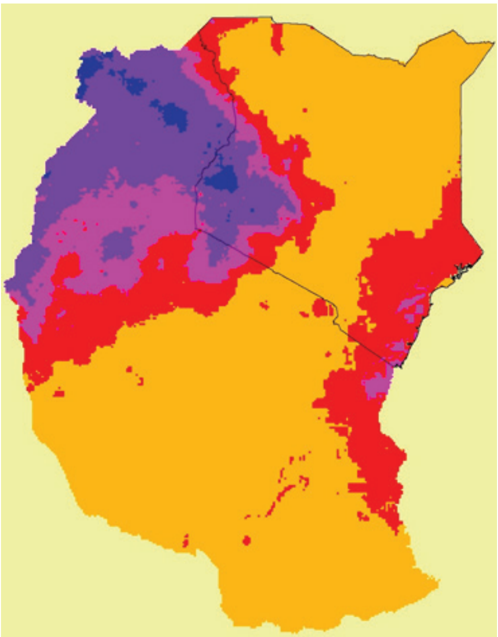
Makueni County lies between Latitudes 1°35′ and 3° 00 S and Longitudes 37°10′ and 38°30′ E coverings an area of 8,034.7 km^2. The county is predominantly semi-arid and prone to frequent droughts. The lower side is very dry and receives little rainfall ranging from 300 mm to 400mm. The depressed rains in the lower part of the county hardly sustain the major staple food of maize and beans. Thus, livestock is the most common livelihood activity in the country. Athi River and its numerous tributaries is the main river in the country, and drains various parts of the county. The county experiences two rainy seasons, the long rains occurring in March/April while the short rains occur in November/December (Makueni County, 2013).

Kakamega country lies in western Kenya between 00°08′–00°23′ N and 34°18′ – 34°57′ E. It hosts Kakamega forest, a remnant of the equatorial forests which cover 183 km^2, 100 km^2 of which consists of closed canopy. The rest is comprised of grassy and bushed glades, tea, cultivation and plantations of softwoods and commercially valuable hardwoods. Rainfall performance is above average, exhibiting a bimodal distribution with two distinct wet seasons occurring in March-April-May and October-November-December (long and short rain seasons). Long rains average at 1000-1200 mm per year while short rains average at 500-800 mm per year, which is good for production of most of the staple crops in the county. It also helps recharge both ground and surface water sources in the county. Average air temperatures range between 15°C and 30°C while evaporation ranges from 400-800 mm per year, which is favourable for crop and animal production. Climatic conditions result in attendant fluctuation in water levels in river and steams hence affecting water supply (Kakamega County, 2013).

3.2 Dataset

Poor spatial distribution of weather station and gaps in available data complicate drought analysis in Kenya' dry regions. In this study, monthly rainfall data from January 1981 to December 2015 for Makueni, Turkana, Garissa and Kakamega counties was downloaded from the Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) dataset, a 0.05° (~5 km) spatial resolution global gridded dataset of daily precipitation available from 1981 to 2015 http://chg.geog.ucsb.edu/data/chrps/ (Funk et al., 2015).

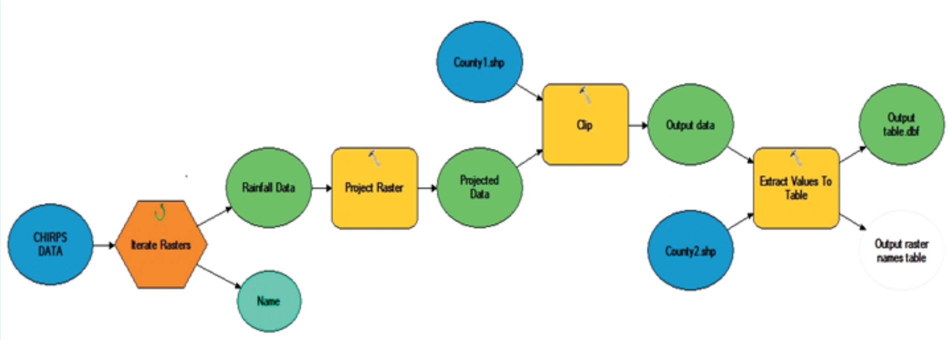
Figure 2: CHIRPS data spatial data



CHIRPS data (Figure 2) is derived by merging satellite observations, weighted average precipitation from stations for a given pixel, and precipitation predictors such as elevation, latitude and longitude (Funk et al., 2015). It has been compared with other satellite precipitation estimates and observed rain gauge data (Dembélé and Zwart, 2016; Toté et al., 2015) and has been used in previous studies in East Africa (Ayana et al., 2016).

Figure 3: Flow chart for data acquisition from CHIRPS database

Precipitation data extracted using ARCMAP 10.5 and exported to excel 2016 following the flowchart shown in Figure 3.



3.3 Data Analysis

In the study, SPI was computed for a period of 1, 3, 6, 9 & 12 months to Kenya's dominant seasons when rainfall deficit is expected to have implications of economic and environmental systems. World Meteorological Organization recommend National Meteorological and Hydrological services to use SPI to characterize meteorological drought (World Meteorological Organization, 2012).

Mathematically SPI is derived as:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad for\ x, \alpha, \beta > 0 \ldots\ldots (1)$$

Where:
α shape parameter
β scale parameters
x is the precipitation amount

$\Gamma(\alpha) = \int_0^{\infty} e^{(-t)}\, t^{(\alpha-1)}$ dt is the gamma function……(2)

α and β are optimally estimated using the maximum likelihood solutions

$\dot{\alpha} = 1/4A\ (1+\surd(1 + 4A/3)$……(3)

$\beta = \ddot{x} / \dot{\alpha}$……(4)

Where, A is a measure of skewness given as:

$A = ln\ (\ddot{x}) - (\sum ln(x))/n$……(5)

n = number of rainfall observations.

The cumulative probability of rainfall totals is given as:

$G(x) = (\int_0^{x} x^{(\dot{\alpha}-1)} e^{(-x/\beta)} dx)/(\beta\, \Gamma(\dot{\alpha}))$……(6)

By substituting t=x/β , the equation becomes the incomplete gamma function:

$$G(x)=(\int_0^x t^{(\alpha-1)} e^{(-x/\beta)} dx)/(\beta\Gamma(\alpha)) \quad (7)$$

Since the gamma function is undefined at x=0, the final cumulative probability becomes:

$$H(x)=q+(1-q)G(x) \quad (8)$$

q is the empirical probability of a zero monthly precipitation.

Conversion of precipitation to SPI was performed using the National Drought Mitigation Center software available at https://drought.unl.edu/droughtmonitoring/SPI/SPIProgram.aspx. The resulting SPI values were used to categorize drought using a scheme developed by the World Meteorological Organization - WTO (Table 1).

Table 1: Drought categorization using Standardized Precipitation Index

SPI range value	Drought category
>2.00	Extreme wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderate wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Mild drought
-1.50 to -1.99	Severe drought
<-2.00	Extreme drought

Source: Mckee et al., 1993

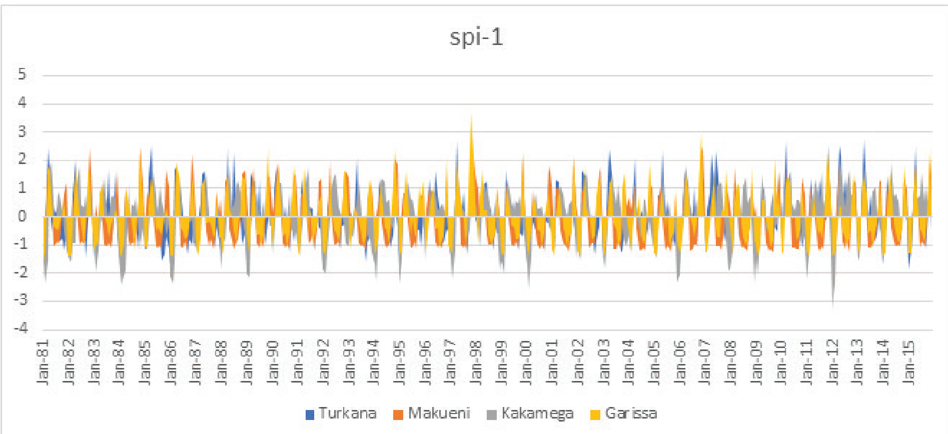
Other drought measures used in this paper are drought intensity, duration, magnitude and frequency (Figure 2). Intensity annotates departure of a climate index from its normal value when the SPI is continuously negative and SPI reaches a value of –1.0 or less. The lesser the value the more intensity will be the drought. Drought duration is the period when the SPI value falls below -1.0 (start) until it rises above it (end).

A drought event starts when the SPI is continuously negative and reaches an intensity of –1.0 or less, while the event ends when the SPI becomes positive. The magnitude of a drought corresponds to the cumulative water deficit over a drought period given by the absolute value of the sum of all SPI values during a drought event. Frequency is expressed by return period - the average time lag between two drought events (Saravi et al., 2000).

4. Results and Discussion

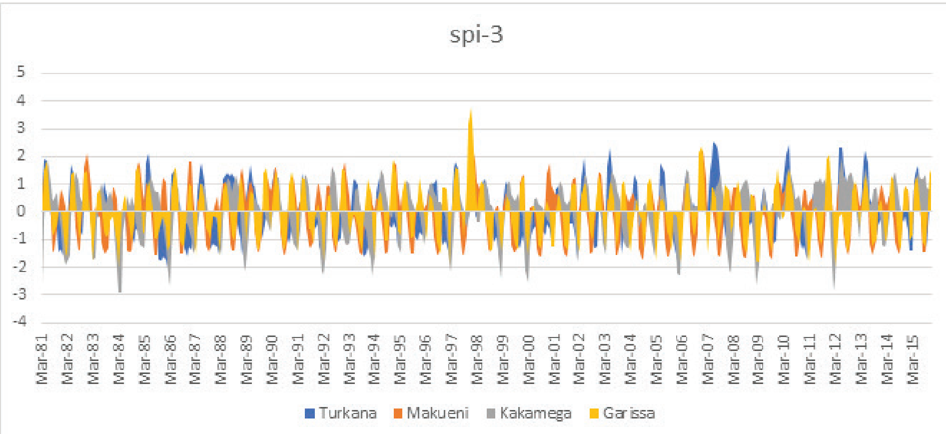
This section presents results of the analysis of drought in the study area between January 1981 and December 2015 based on Standardized Precipitation Index (SPI) for 1, 3, 6, 9 and 12 months. Overall, the SPI values for all the counties for spi-1 and spi-3 are stationary with equal distribution of extreme dry and wet periods. Those for spi-6 were more stable for the period prior to 1998 but showed higher degree of fluctuation thereafter. Drought indices for spi-9 and spi-12 show high degree of fluctuation for most of the period. For spi-1, month analysis, apart from Garissa, which recorded an extreme dry month in January 1981, all extreme months were experienced in Kakamega County (Figure 2). January 2012 was the extreme month in the county with a drought index of -3.29. Other extreme months were February 1981 (-2.37), February 1984 (-2.4.2), February 1986 (-2.35), February 1989 (-2.16), February 1992 (-2.00), February 1994 (-2.33), January 1995 (-2.38), February 1997 (-2.23), February 2000 (-2.58), December 2005 (-2.33), and February 2009 (-2.04). Severe droughts were experienced in February 1982, February 1983, February 1999, February 2002, February 2005, January 1988, January 2008 and December 1998. These results show severe and extreme months are concentrated between December and February; a dry season in most parts of Kenya. Interpretation of 1-month SPI can lead to misleading assessment, as there are many examples where there is no perfect agreement between rainfall deviations and SPI values (Kumar et al., 2009).

Figure 4: Trends in Standardized Precipitation Index for 1-month time scale



Results for the three-month Standardized Precipitation Index (spi-3) show that compared with spi-1, the selected counties experienced less extreme droughts with Kakamega County experiencing the highest number of extreme events followed by Garissa County. The driest periods were recorded in April 1984 (SPI = -2.89), February 2012 (SPI = -2.84), March 1986 (SPI = -2.71) and February 2009 (SPI = -2.65) all in Kakamega county. However, few events were recorded in the county in the period after 2009. On the contrary, Turkana County experienced the highest number of wet periods, while Garissa County recorded the wettest period in January 1998 with SPI value of 3.79. An important finding from this assessment is that while drought has traditionally been associated with arid and semi-arid lands, wet regions that on average receive high precipitation are equally prone to this phenomenon.

Figure 5: Trends in Standardized Precipitation Index for 3-month time scale



The six-month SPI trend for the four counties is presented in Figure 5, which shows a more spread of extreme drought across the counties compared with spi-3. The corresponding severe and extreme droughts are shown in Figure 6.

Figure 6: Trends in standardized Precipitation Index on a 6-monh time scale

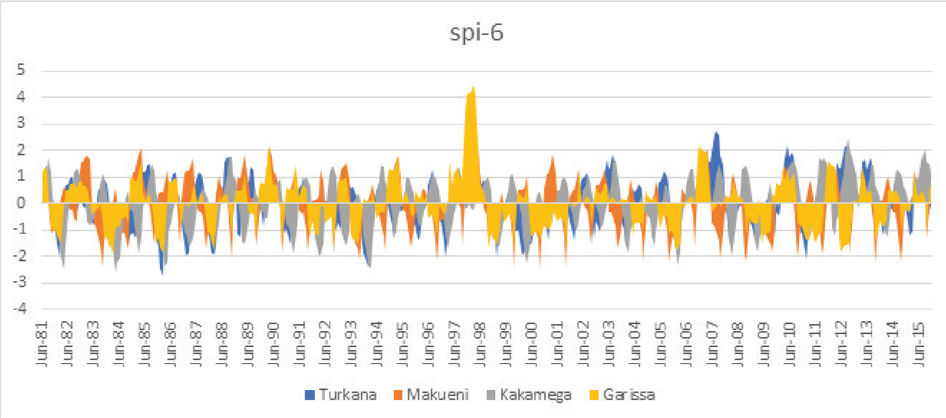
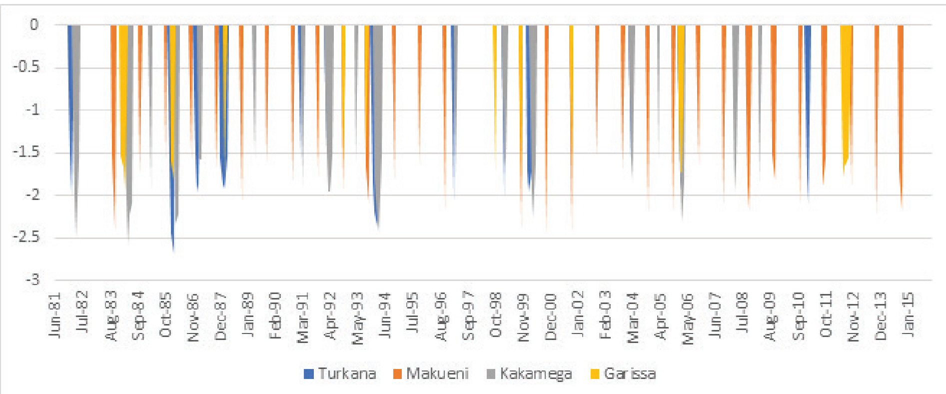


Figure 7: Magnitude of severe and extreme drought events on 6-month time scale



From the analysis, extreme droughts often tend to affect all the four counties at the same time, although there are cases when only a single county is affected. For example, the droughts of 1982, 1984, 1992, 1997, 2000, 2006, 2009 and 2011 affected multiple counties mostly Kakamega, Turkana and Garissa while those of 1989, 1990, 1995, 1996, 2002, 2013 and 2015 were unique to Makueni County (the distribution of all severe and extreme droughts are shown in Figure 6). Kakamega County had the largest drought magnitude with an absolute value of 8.42 that occurred in March-June 1984, followed by that of January-April in the same County with a magnitude of 8.03. Other intense droughts were those in Kakamega between February-May 1993 (6.93), Turkana County between March and May

1994 (6.93), and Garissa County between June-September 2012 (6.57). Based on these results it may be deduced that apart from differences in intensity, droughts can be widespread, affecting vast regions, or highly localized, affecting a given area. The implication of this drought characteristic is that drought monitoring should be robust enough to enable assessment within small spatial dimension particularly if they exhibit uniqueness in agro-climatic factors.

SPI values for a 9-month time scale follow similar trend as those of the 6-month time scale, although the magnitude is amplified. The distinctive wet season between 1997-98 in Garissa, Turkana and Makueni correspond to the El Niño phenomenon that affected most parts of Kenya. None of the regions experienced a severe drought event between 2000-2006 (Figure 7). There were also changes in the spread of drought, with Garissa recording an increase in drought with more events in post-2000 period. In this time scale, the largest drought of 19.29 happened in Turkana in 2000 covering January-October. Other droughts with large magnitude occurred in Kakamega (7.21) between January-September 1984 and again in the same county in February-April 1994 with a magnitude of 6.47 (Figure 8). A careful examination of the spi-9 values show that extreme wet conditions followed almost immediately with an extreme dry event. This knowledge implies that policy makers and practitioners should strengthen drought-monitoring system to inform the design of drought contingency measures.

Figure 8: Standardized Precipitation Index for 9-month time scale

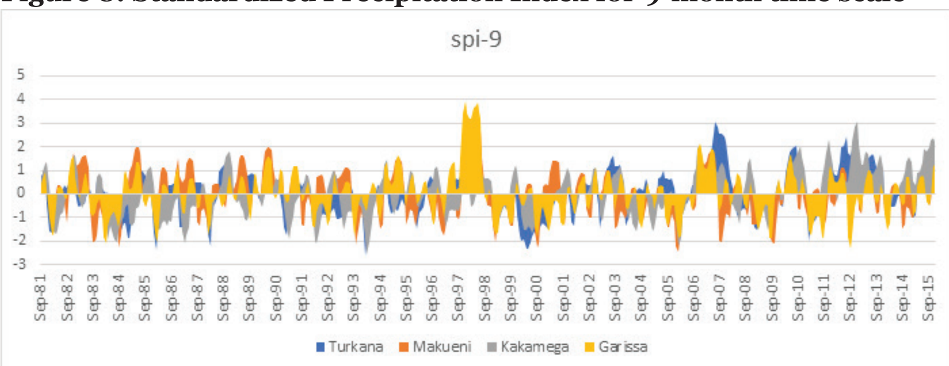
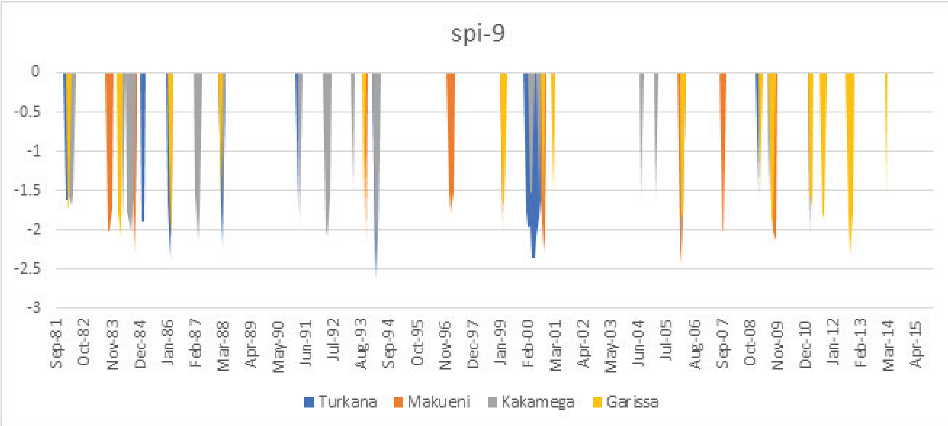
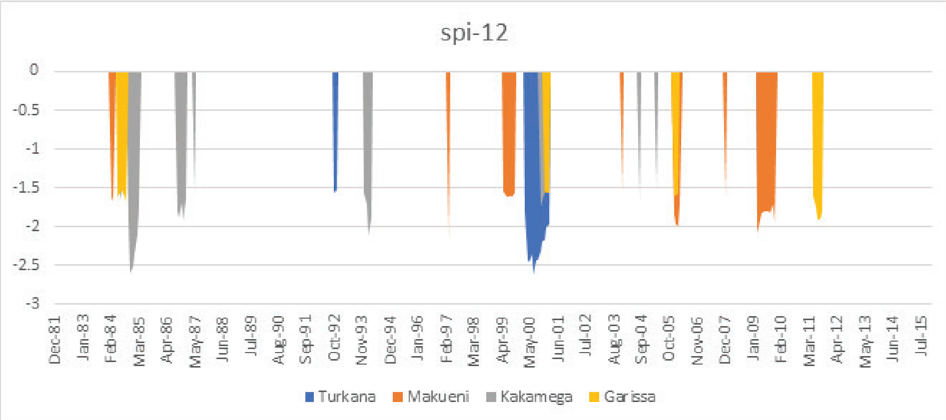


Figure 9: Magnitude of severe and extreme drought on 9-month time scale



The spi-12 gives drought characteristics within one year, useful in understanding drought behaviour in a complete season. The results show that extreme dry conditions were experienced in 1985 in Kakamega and Turkana in 2000.

Figure 10: Trends in seasonal Standardized Precipitation Index on a 12-month time scale



Severe droughts were recorded in 1984, 1986, 2006, and 2011 while extreme drought occurred in 1994, 2000/01 and 2009 with varying spatial distribution. The largest drought (19.29) was reported in Turkana County dring January-October 2000. A detailed analysis of the occurrence of severe and extreme droughts for all the counties is contained in Appendices 1- 4.

The results so far presented in this study amplify earlier studies conducted in Kenya. Studies in Turkana County conclude that droughts have become more common particularly in the past three decades (Huho and Mugalavai 2010), without specificity of the time scale being assessed. On their part, Huho et al. (2016) and Uhe et al. (2017) using SPI documented extreme drought events in 1990, 1995, 2000, 2008, and 2009 and 2010/2011. These studies further found that although the 2010/2011 drought affected most parts of the country it was less intense in Turkana. A major weakness in existing studies is treatment of drought as a generic phenomenon ignoring its slow and creeping nature and that it has a long life span.

Table 2: Comparison of drought categories with recorded drought

Drought event	Affected area	Reported effect	Study findings
2016-17	23 counties affected	More than 2 million people in need of famine relief, Government declared national emergency	N/A
2011-2012	Widespread	4.3 million affected	Extreme drought in Makueni in June, Severe drought in September

2009	Widespread	70-90% livestock loss in Maasai pastoralists	Extreme drought in Makueni
2007-2008		4.4 million people 70% loss of livestock	Extreme drought in Makueni; severe drought in Makueni
2006	Widespread	40 human deaths 40% loss of cattle, 27% sheep, 17% goats	
2005		3 million people in need of famine relief for 8 months, Government declared a "national catastrophe"	Severe drought Makueni
2004		2.3 million people in need of assistance, 70% loss of livestock in some pastoral communities	Extreme and severe drought in Makueni
1999-2001		4.4 million people affected	Severe drought in Makueni; Extreme drought in Turkana; Severe drought Turkana
1995-96			Severe drought Makueni
1992-93	Widespread		Severe drought in Makueni
1983-85	Widespread		Extreme and severe drought in Makueni and Turkana

Source: Huho et al. (2016); Uhe et al. (2017); Government of Kenya (2012)

This study captured all recorded droughts in Kenya except 2006, with SPI-3 for Makueni corresponding to most of national droughts. Thus, results of drought analysis at the county level reflect better drought conditions in Kenya compared to using Standardized Precipitation Evapotranspiration Index (SPEI) for the entire country as reported by Mutsoto et al. (2018).

5. Conclusion and Policy Implications

The primary objective of this study was to assess meteorological drought patterns in Kenya's main climatic zones. From the analysis, drought was a common phenomenon in dry and very dry zones, while wet zones did not experience any drought during the entire period. Dry zones had, on average, lower monthly and seasonal SPI values, pointing to more intense droughts compared to very dry zones. In total, dry zones recorded 29 extreme and severe seasonal drought conditions compared to 18 in very dry zones. This suggests that dry zones exhibited high variability in rainfall patterns compared to other agro-climatic zones, and therefore are most important in monitoring drought in Kenya.

Trend analysis of seasonal SPI showed that, generally, drought declined in very dry zones but increased in dry zones. Drought occurrence was fairly distributed between the two main seasons of March-April- May (MAM) and October-November-December (OND). MAM tended to experience more extreme droughts in both zones. One drought event extended for a period of six months in dry zones and four in very dry zones. This period is long term to dramatically affect social and environmental systems in these fragile ecosystems.

Seasonal drought index gave accurate reflection of observed drought conditions in the country than monthly index, and is therefore suitable for monitoring drought in the country. In dry zones, the number of extreme and severe droughts more than doubled from 7 to 16 between 1980-1990 and 2000-2010, while in very dry zones it reduced by more than half from 5 to 11. Based on the study findings, drought in Kenya varies according to space and time.

Results show great variation in drought patterns across climatic zones suggesting that drought response measures including contingency plans should take into account variations in both frequency, magnitude and severity of drought. Given the poor network of weather stations in the country, policy makers should integrate satellite-based precipitation data to inform policy and programme design.

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Appendix

Table A1: Duration on severe and extreme drought events in Makueni County

spi-3	spi-6	spi-9	spi-12												
Start	dur	peak	sum	Start	dur	peak	sum	Start	dur	peak	sum	Start	dur	peak	sum
Sep-83	3	-1.51	-2.99	Oct-83	6	-2.39	-5.51	Sep-84	14	-2.29	-15.27	Mar-84	9	-1.67	-12.85
Sep-85	3	-1.57	-3.68	Oct-84	1	-1.72	-1.72	Oct-93	6	-2.14	-6.78	Feb-94	10	-1.56	-10.4
Sep-86	2	-1.52	-2.4	Oct-85	2	-1.56	-1.82	Feb-97	4	-1.78	-4.97	Mar-97	8	-2.12	-8.47
Sep-90	2	-1.55	-2.56	Oct-86	1	-1.54	-1.54	Feb-99	9	-2.03	-8.52	Jul-99	7	-1.61	-9.73
Sep-93	2	-1.56	-2.54	Oct-87	5	-1.66	-4.69	Feb-99	4	-2.28	-6.38	Feb-06	11	-1.99	-15.3
Sep-95	2	-1.51	-2.02	Oct-88	2	-2.06	-2.59	Feb-06	4	-2.43	-6.36	Mar-09	27	-2.08	-28.99
Sep-96	2	-1.56	-2.82	Oct-89	2	-1.59	-2.16	Sep-09	6	-2.03	-8				
Sep-00	2	-1.55	-2.38	Oct-90	2	-1.82	-2.41	Oct-09	7	-2.13	-8.3				
Sep-01	3	-1.59	-4.24	Oct-91	2	-1.76	-2.62								
Aug-02	3	-1.63	-4.31	Oct-92	2	-1.92	-2.43								
Aug-03	3	-1.5	-3.72	Oct-93	5	-2.09	-5.04								
Sep-03	3	-1.53	-4.14	Oct-94	1	-1.8	-1.8								
Sep-04	3	-1.7	-4.26	Oct-95	5	-1.62	-3.43								
Sep-05	4	-1.62	-4.48	Oct-96	6	-2.14	-4.92								
Aug-06	3	-1.62	-3.94	Oct-99	1	-2.36	-2.36								
Sep-07	3	-1.6	-4.33	Oct-00	2	-2.41	-2.76								

Sep-08	3	-1.64	-4.16	Oct-01	2	-2.39	-2.41								
Sep-09	3	-1.72	-4.02	Oct-02	2	-1.52	-1.98								
Sep-10	3	-1.63	-4.42	Oct-03	4	-1.68	-3.92								
Sep-11	3	-1.64	-3.75	Oct-04	3	-2.17	-3.19								
Sep-12	2	-1.54	-2.57	Oct-05	6	-2.16	-7.27								
Aug-13	3	-1.56	-3.98	Oct-06	1	-1.62	-1.62								
Sep-14	2	-1.52	-2.53	Oct-07	5	-2.08	-3.68								
				Oct-08	7	-2.18	-5.96								
				Oct-09	3	-1.82	-4.33								
				Oct-10	4	-2.07	-3.14								
				Sep-11	3	-1.89	-3.47								
				Oct-12	2	-1.87	-2.69								
				Oct-13	2	-2.2	-3.01								
				Oct-14	5	-2.18	-4.71								
				Oct-14	5	-2.18	-4.71								

Table A2: Duration on severe and extreme drought events in Makueni County

Spi-1				Spi-3				Spi-6				Spi-9				Spi-12			
start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum
Jan-81	2	-1.65	-2.15	Jan-82	3	-1.56	-3.22	Feb-82	3	-1.98	-4.73	Jan-82	6	-1.62	-5.14	Nov-84	6	-2.14	-9.54
Jan-83	3	-1.52	-2.73	Feb-84	13	-1.52	-9.85	Feb-86	4	-2.68	-7.61	Jan-85	8	-1.89	-12.08	Oct-92	26	-1.56	-19.37
Jan-84	3	-1.59	-2.88	Feb-86	5	-2.02	-8.8	Jan-87	5	-1.95	-6.69	Feb-86	5	-2.37	-6.67	Jul-00	26	-2.62	-35.13
Jan-86	6	-1.74	-7.69	Nov-86	5	-1.59	-5.62	Feb-88	4	-1.92	-6.9	Mar-87	3	-1.8	-2.98	Mar-09	12	-1.56	-10.97
Jan-89	1	-1.58	-1.58	Feb-88	2	-1.53	-2.48	Feb-91	3	-1.54	-2.3	Mar-88	5	-2.21	-5.11				
Jan-92	2	-1.71	-2.82	Jan-89	2	-1.56	-2.46	Feb-92	15	-1.51	-9.69	Feb-91	4	-1.75	-3.83				
Jan-93	6	-1.63	-6.71	Feb-92	2	-1.52	-2.55	Feb-94	6	-2.35	-9.41	Feb-94	5	-2.61	-6.94				
Jan-95	2	-1.7	-2.41	Feb-94	6	-1.77	-8.05	Feb-97	2	-2.03	-3.27	Apr-00	21	-2.35	-26.6				
Jan-99	2	-1.65	-3.05	Feb-97	2	-1.63	-2.27	Feb-99	2	-1.99	-2.52	Feb-06	6	-1.76	-4.58				
Jan-00	6	-1.63	-4.29	Feb-99	1	-1.74	-1.74	Feb-00	15	-1.96	-17.6	Feb-09	10	-1.52	-7.79				
Jan-03	2	-1.63	-2.72	Mar-00	12	-1.58	-8.46	Feb-04	2	-1.64	-2.64	Feb-11	6	-2.01	-6.44				
Jan-06	2	-1.63	-2.33	Feb-02	1	-1.69	-1.69	Feb-06	4	-1.93	-4.87								
Jan-11	2	-1.64	-2.63	Nov-03	5	-1.51	-4.21	Feb-11	5	-2.09	-5.61								
Jan-12	2	-1.82	-3.03	Jan-06	4	-1.77	-5.14												
Jan-14	2	-1.67	-2.36	Feb-09	2	-1.68	-2.67												
Jan-15	3	-1.85	-3.2	Jan-11	3	-1.62	-3.27												

Table A3: Duration on severe and extreme drought events in Kakamega County

spi-1				*spi-3*				*spi-6*				*spi-9*				*spi-12*			
start	*dur*	*peak*	*sum*	*start*	*dur*	*peak*	*sum*	*start*	*dur*	*peak*	*sum*	*start*	*dur*	*peak*	*sum*	*start*	*dur*	*peak*	*sum*
Feb-81	*3*	*-2.37*	*-5.52*	*Mar-81*	*2*	*-2.47*	*-2.76*	*Apr-82*	*4*	*-2.49*	*-6.34*	*Apr-82*	*6*	*-1.7*	*-7*	*Nov-84*	*14*	*-2.6*	*-21*
Feb-82	*3*	*-1.58*	*-3.44*	*Feb-82*	*4*	*-1.9*	*-5.42*	*Apr-84*	*6*	*-2.58*	*-10.19*	*Aug-84*	*16*	*-2*	*-19*	*Dec-86*	*20*	*-1.9*	*-23*
Feb-83	*3*	*-1.94*	*-3.78*	*Mar-83*	*3*	*-1.69*	*-3.7*	*Mar-85*	*3*	*-1.9*	*-3.31*	*Mar-87*	*20*	*-2.1*	*-20*	*Feb-94*	*12*	*-2.1*	*-13*
Feb-84	*4*	*-2.42*	*-8.35*	*Mar-84*	*5*	*-2.9*	*-8.76*	*Mar-86*	*5*	*-2.32*	*-6.59*	*Mar-88*	*4*	*-1.6*	*-3.2*	*Oct-00*	*8*	*-1.7*	*-7.4*
Feb-86	*3*	*-2.35*	*-6.03*	*Mar-86*	*3*	*-2.71*	*-5.96*	*Mar-87*	*4*	*-1.58*	*-5.41*	*Mar-91*	*6*	*-1.9*	*-5.1*	*Aug-04*	*27*	*-1.7*	*-26*
Jan-88	*3*	*-1.88*	*-3.52*	*Mar-88*	*2*	*-1.57*	*-1.88*	*Apr-89*	*4*	*-1.54*	*-3.62*	*Apr-92*	*6*	*-2.1*	*-6.8*				
Feb-89	*3*	*-2.16*	*-4.64*	*Feb-89*	*3*	*-2.1*	*-4.68*	*Mar-91*	*3*	*-1.89*	*-4.14*	*Mar-94*	*16*	*-2.6*	*-16*				
Feb-92	*3*	*-2*	*-5.07*	*Mar-92*	*3*	*-2.28*	*-5.72*	*Mar-92*	*5*	*-1.95*	*-7.4*	*Jul-00*	*9*	*-1.7*	*-11*				
Feb-94	*3*	*-2.33*	*-4.12*	*Feb-94*	*4*	*-2.33*	*-5.88*	*Apr-93*	*3*	*-1.59*	*-2.84*	*Jul-04*	*15*	*-1.6*	*-11*				
Jan-95	*2*	*-2.38*	*-3.9*	*Mar-95*	*2*	*-1.51*	*-1.64*	*Mar-94*	*5*	*-2.43*	*-8.57*	*Feb-06*	*6*	*-2.2*	*-6.1*				
Jan-96	*2*	*-1.56*	*-2.15*	*Mar-97*	*3*	*-2.17*	*-4.59*	*Mar-97*	*4*	*-1.74*	*-4.27*	*Jul-09*	*4*	*-1.5*	*-3.3*				
Feb-97	*2*	*-2.23*	*-3.41*	*Feb-99*	*3*	*-2.44*	*-5.32*	*Feb-99*	*4*	*-1.67*	*-4.98*								
Feb-99	*3*	*-1.99*	*-5.37*	*Mar-00*	*4*	*-2.54*	*-6.14*	*Apr-00*	*5*	*-2.26*	*-7.59*								
Feb-00	*3*	*-2.58*	*-5.76*	*Feb-02*	*2*	*-1.81*	*-2.73*	*Mar-04*	*6*	*-1.83*	*-6.19*								
Feb-02	*1*	*-1.56*	*-1.56*	*Mar-03*	*2*	*-1.55*	*-1.83*	*Mar-05*	*4*	*-1.55*	*-3.01*								
Feb-03	*2*	*-1.88*	*-2.22*	*Feb-05*	*3*	*-1.62*	*-3.06*	*Feb-06*	*4*	*-2.31*	*-6.52*								
Feb-05	*2*	*-1.51*	*-1.57*	*Jan-06*	*3*	*-2.3*	*-5.29*	*Mar-08*	*4*	*-1.96*	*-4.65*								
Dec-05	*3*	*-2.33*	*-5.32*	*Feb-08*	*4*	*-2.22*	*-5.5*	*Mar-09*	*5*	*-1.84*	*-4.96*								
Jan-06	*3*	*-1.89*	*-4.93*	*Feb-09*	*4*	*-2.65*	*-6.23*												
Dec-07	*4*	*-2.35*	*-6.58*	*Feb-11*	*3*	*-1.76*	*-4.31*												
Jan-11	*2*	*-2.19*	*-3.54*	*Feb-12*	*2*	*-2.84*	*-5.22*												
Jan-12	*3*	*-3.29*	*-6.21*																
Jan-13	*2*	*-1.54*	*-2.94*																
Jan-14	*3*	*-1.65*	*-2.27*																

Table A4: Duration on severe and extreme drought events in Garissa County

spi-1				spi-3				spi-6				spi-9				spi-12			
start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum	start	dur	peak	sum
Jan-81	2	-1.57	-2.82	Mar-82	1	-1.61	-1.61	Mar-84	10	-1.9	-9.96	Mar-82	3	-1.73	-3.9	Sep-84	6	-1.68	-9.3
				Mar-83	2	-1.77	-2.08	Feb-86	3	-1.82	-4.89	Mar-84	9	-2.08	-11.18	Jan-01	16	-1.56	-16.99
				Mar-84	2	-1.99	-2.25	Feb-88	2	-1.75	-2.59	Feb-86	3	-2.07	-4.35	Jan-06	11	-1.59	-11.83
				Mar-87	2	-1.59	-1.64	Oct-92	2	-1.6	-1.94	Feb-88	9	-1.77	-4.96	Jul-11	6	-1.91	-9.71
				Feb-88	2	-1.55	-1.89	Sep-93	3	-1.53	-3.1	Sep-93	8	-1.8	-5.37				
				Mar-92	1	-1.77	-1.77	Oct-99	13	-1.84	-12.79	Feb-99	9	-1.69	-9.49				
				Mar-94	1	-1.66	-1.66	Oct-01	2	-1.64	-1.78	Sep-00	14	-1.82	-14.06				
				Feb-97	2	-1.92	-2.45	Feb-06	5	-1.74	-5.17	Feb-06	8	-1.87	-6.27				
				Mar-00	2	-1.55	-2	Jun-12	6	-1.79	-8.46	Aug-09	8	-1.87	-8.05				
				Mar-05	2	-1.74	-2.19					Sep-11	9	-1.85	-11.68				
				Feb-06	2	-1.84	-3.16					Sep-12	8	-2.34	-7.78				
				Mar-09	3	-1.84	-4.23					Feb-14	3	-1.5	-2.96				
				Mar-11	2	-1.83	-2.26												
				Mar-12	8	-1.96	-6.91												

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