Rainfall Variability and Extreme Hydrological Events in Kenya Since 1845-2012 Driven from Documentary Evidence and SPI Analysis

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ABSTRACT

The study investigates the chronology of rainfall extremities in Kenya and their inter-relationship with the external climate factors since the years 1845-2012. It is the first study in Kenya to evaluate a long-term temporal evolution of the droughts and wet extremities using documentary evidences and Standardized Precipitation Index (SPI) analysis. The statistical procedures for this study involved the establishment of drought and wet events indices using MATLAB R 2009a and Instat Plus (Instat+ v3.36) statistical software programs. The study findings show that the 19th century was much drier than the 20th and 21st centuries, marked by great desiccation, especially towards the end of the century. In the 20th century, very severe long droughts were also experienced in 1940s and 1970s but there were also very wet years which moderated the situations in 1960s and 1990s. Based on the (SPI), results droughts were not uniformly severe in all areas of the country. The strongest impacted stations were those located in the arid and semi-arid lands, some parts of the highlands and the coastal region.

Keywords: Rainfall variability; Rainfall extremities; Documentary evidence; SPI analysis; Droughts; Wet events; Rainfall seasons; Climate change

INTRODUCTION

Given the current interest in climate change, considerable scientific efforts are being invested to establish the sequence of climate variability to provide a long term benchmark against which to compare global warming trends [1,2]. Consequently, periods with highly anomalous weather conditions, notably temperature and/ or precipitation extremes and their impacts on the ecosystems, economic systems, and the societal responses, have greatly attracted scientific attention during recent times [3-6]. For instance, in the East African region, the El Niño Southern Oscillation (ENSO) phenomenon, which has been linked to climate variability in many parts of Sub-Saharan Africa, has been a great concern for most researchers, with the interest of disentangling the phenomenal influence and those of the expected climate changes in the region. The region usually experiences persistent anomalous rainfall patterns during strong and persistent ENSO events [7,8].

Meteorologically equatorial eastern Africa is one of the most complex regions in the African continent [9,10]. Compared to other African countries, East African countries such as Uganda, Tanzania, and Kenya have a complex climate, with variations occurring within relatively small geographical space. Some areas have desert and semi-arid conditions, while others experience subhumid and wetter climatic conditions especially at the highlands and lake basins. Rainfall seasonality is quite complex changing within tens of kilometres. Consequently, the region has been previously subdivided into 6-26 homogenous zones of rainfall variability [11,12]. Empirical researches postulate that the region's inhomogeneity in rainfall variability is attributable to the complex topography, the effects of inland lakes, the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) and the influence of Indian Ocean SST variations [12,13].

The seasonal climate patterns in Eastern Africa follow the seasonal North-South movement of the ITCZ, which follows the seasonal migration of the sun from the Northern to the Southern Hemisphere resulting in binomial rainfall distribution patterns [7,14]. These patterns are modified by the Northeast (NE) and Southeast (SE) monsoon winds [15]. During the Southern Hemisphere Summer, the NE Monsoon occurs, they traverse over Egypt and Sudan, losing their moisture and becoming warm and dry thus, being associated with aridity in much of the East African region [14]. On the other hand, the SE Monsoon air stream occurs when the sun is north of the Equator. This airstream is cool and moist as it picks maritime moisture from the Indian Ocean and

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is responsible for heavy precipitation near the coastal and Northwestern parts of Lake Victoria [16,17].

Greater inter-annual rainfall variability in eastern Africa is portrayed during the short rain seasons [8]. The main contribution to this being the large-scale anomalies such as ENSO-induced SSTs anomalies in the Indian Ocean, which inter modulate inter-annual variability in Africa [11,13,18]. However, ENSO as measured by the Niño 3 index, only accounts for 20 percent of the December to January rainfall variability, while Indian Ocean SST anomalies, particularly in the western and South-western Tropical Indian Ocean, account for up to 60 percent of the rainfall variance [19]. Therefore, these anomalies result from a dipole reversal in atmospheric circulation and Indian Ocean sea surface temperatures over Eastern and Southern Africa [11,18].

During the warm ENSO events, there is enhanced evaporation and therefore, moisture availability associated with build-up warm SST anomalies over the Indian Ocean. When this happens the short rains extend resulting in El-Niño extremities for most of the East African region with an exception of Sudan [20]. However, horizontal convergence anomaly motion associated with Higher SSTs over the Indian Ocean during warm ENSO events tend to reverse sign when cooling of the southern Indian Ocean SSTs occur leading to the occurrence of La Nina conditions which result in severe droughts [21,22].

Climate models suggest that the enhanced greenhouse effects may result in less frequent intense rainfall events in the mid-latitude regions [21,23]. Thus, drawing greater concern for most researchers trying to understand the role of the El Niño Southern Oscillation (ENSO) phenomenon and the changes associated with climate change effects in the eastern African region. Moreover, the recently noted extremities in rainfall variability are also proving to be a great challenge to the agricultural-based economies of the East African countries and Kenya in particular, where irrigation systems are undeveloped and agriculture is entirely rain-fed [14]. In line with this, accurate seasonal and inter-annual climate monitoring and forecasting, which could be used to improve the planning and management of climate-sensitive activities involving agriculture, water resource, and other development sectors in this region are very important, specifically at localized level [24].

In recent years, increased incidences of droughts and flood extremities have been noted in the East African region and Kenya in particular [21]. This has consequently, attracted a concerted effort in research and establishment of institutions such as early warning systems to address climate-related challenges in this region [25,26]. In order to enable such institutions to formulate evidencebased policies, there is a need for reliable long-term and welldistributed rainfall station networks and quantified information on the magnitude of rainfall variability at the local level, which are rarely available in Kenya.

The rainfall projections in Kenya are inconsistent with a range of models and scenarios suggesting both an increase and a decrease in total precipitation [27]. Moreover, most of the rainfall based research has been on a recent decadal-scale, which is insufficient for establishing long-term rainfall variability [28,29]. The current study thus focuses on establishing a longer (168 years) rainfall chronology for Kenya, using historical and instrumental records, which will be a more detailed climatic record for this country.

DATA SOURCES AND METHODS

Documentary data

The study has utilized documentary sources to generate the rainfall variability for Kenya during the period 1845-1976. The primary data sources for the study were the archived, published and unpublished documentary evidence such as letters, journals, memoirs, diaries, travelogues, reports, monographs, and newspaper articles written by explorers, travellers, missionaries and colonial officials who lived in and travelled through Kenya and neighbouring countries such as Tanzania and Uganda during the 19th century. Early travellers in the East African region, such as Dr. David Livingstone, Rev. Charles Ludwig Krapf and Rebmann expedition records dating from c1845 were useful in providing earlier information before the settlement of the missionaries and colonial government in Kenya.

The most resourceful materials were the collection of unpublished letters from the missionary stations, established by the Church Missionary Society (CMC) in Kenya. Most of these letters were very detailed because they were written by missionaries who had stayed in Kenya for many years, therefore can be considered reliable for climate interpretations. They were also place specific, thus showing long-term spatio-temporal variations for different parts of the country. In contrast, there was a need for a more careful analysis of the quarterly colonial government reports or annual summaries to identify the specific timing of the climatic events and the impacts they had on the environment. The quarterly and annual reports and letters from the Ministry of Agriculture and the East African Protectorate Meteorological Department were also consulted. These contained annual, seasonal, and in some cases quarterly accounts of rainfall, temperature, and harvests reports of different parts of the country. Letters and reports sent to and from colonial government offices during the colonial period also contained valuable information of harvests, droughts, floods, and other weather occurrences written by the District commissioners.

The documentary records were retrieved from University libraries in South Africa and Kenya, the Kenya National Archives (Nairobi and Mombasa), Kenya National Museum (Nairobi), McMillan library, and Kenya national library services in Mombasa and Nairobi (Table 1). The main objectives during data retrieval were identification of documentary series that may offer climatic information with an acceptable density, optimum reliability, precise dating, homogeneity over time, and the possibility of being quantified [30].

Instrumental data

The rare East African protectorate instrumental weather records dating from 1876-1955 in the annual and monthly bulletins, government official reports, and any unpublished records were retrieved from the archival records. The remaining instrumental records dating between the years 1956-2012 were sourced from the Kenya Meteorological Services Department in Nairobi. The database comprises twelve meteorological stations identified for the study, which are representative of the main climatic divisions/ regions in Kenya. These are the coastal region (Mombasa and Malindi), arid and semi-arid lands (Machakos, Garissa, and Marsabit), the central and Rift valley highlands (Nyeri, Meru, Nairobi, Thika, and Embu) and the lake basin region (Kisumu,

Location	Details of sources			
	Published and unpublished colonial government records such as annual and monthly reports, government gazette, blue books, monographs, journals, diaries, and memoirs.			
Kenya National Archives	Explorers, travellers, and missionary records such as travelogues, diaries, incoming letters from various districts, and outgoing letters from government offices and reports.			
Kenya National Archives (Nairobi and Mombasa)	East African protectorate instrumental weather records which included; DC/ Coast/1/1/1-16 DC/NBI/1/1/1-23, DC/NYA/4/4/3, CQ/2/2, PC/RVT/2 MSS/10/1-63, DC/BAR/3/1-4, MSS/61/ 1-47 MFN Class no. 912.EAS			
McMillan library	Newspapers, such as East African Standard 1901-1906, Kenya Times 1953-1968 Daily Nation 1940-1976, The leader 1908-1922 Official Gazette of Eastern Africa and Uganda 1899-1956, Annual reports, books, journals, diaries.			
Kenya National Museum (Nairobi)	Books and historical records written by explorers and travellers, such as diaries and journals. These included: Books: Class no. 050.9676YEA,946.9box,967.6JOE,910.202bri, 960.liv, 967.KRA Diaries: Class no. STA no. 967BEL,923.2 WIL, 800.BAN Letters: Class no. 960.2325.42 Correspondences: Class no. 960.SCH, GP. 551.6, GP.551.57, GP.916 PAT			
University libraries in South Africa and Kenya	All available books showing climatic conditions in East African region, particularly the conditions for Kenya, diaries, and journals written by the colonial government, explorers, travellers, and missionaries in Kenya or any other East African country.			

Table 2: Rainfall stations and the dates of the data.

Coastal region	Highlands region	Arid and semi-arid lands	Lake basin region
	Central and rift valley highlands		
Mombasa 1891-2012	Thika 1913-2012	Machakos 1895-2012	Kakamega 1913-2012
Malindi 1891-2012	Nyeri 1908-1962	Marsabit 1918-2012	Kisumu 1905-2012
	Nairobi 1905-2012	Garissa 1903-2012	Kitale 1914-2012
	Meru 1910-2012		
	Embu 1908-2012		

Kitale, and Kakamega). The selection of the stations considered not only the optimum availability of the conserved documents but also their representation within the climatic configuration of Kenya. Table 2 shows various geographical regions of Kenya with their respective stations considered for the study and their available instrumental records.

These are stations identified with full records representative of the recording period up to the year 2012. Whenever possible, the records gap especially in the 19th century was 'plugged' using descriptive records.

DATA ANALYSIS

Determination of rainfall variability using documentary records

The methodology used to identify the climatic conditions from documentary sources in this study was adapted from different studies [2,30-34,36]. Whenever possible, all references were read and noted in chronological order, with all information related to seasonal weather phenomenon, environmental conditions, and human societal responses recorded verbatim. Observations from each year were subsequently compiled in chronological order along with details of the author, dates and location captured [30,34].

In the case of most letters, journals and quarterly reports were

relatively straightforward processes although some annual records only permit the identification of seasonal patterns [36]. Considering the fact that some authors are both times and place specific in their observations, all comments about the environment (observations about weather, harvest quality, and hydrological conditions) or description of unusual events such as droughts, famines, floods or pest infestations and the human societal responses since c1850 were used in determining the timing of the rainfall seasons (onset and cessation dates). In cases where time lags between the occurrence and documentation of an event or phenomenon are suspected, relevant contextual material was noted to allow the timing to be more tightly constrained [34,37]. All materials were scrutinized to minimize bias from external factors such as war, slave trade, pestilences, and land-use changes, which are not products of climate variability [2,38].

To determine variations in the relative amounts of seasonal and annual precipitation, the ordered documentary records were analysed according to 'rain-year' between march-may (long rainfall season) and October-December (short rainfall season) with the seasonal and annual rainfall amounts being qualitatively categorized into one of the five classes: 'very wet/floods', 'relatively wet', 'normal', 'relatively dry' and 'very dry' (Table 3). This method is identical to that used by many other researchers [34-36,39,52,53]. During the classification process, preference was given to the climate-related phenomenon that provides the strongest indication

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Table 5: Rainfail events indexation in relation to documentary interpretations.				
Event	Index	Description		
Very dry	-2	Drought accompanied by reports of dry rivers and springs, if being impossible to sow or very bad harvests, rise of prices, great famine associated with death of people, lack of pastures and livestock deaths		
Dry	-1	Records of meteorological drought, involving lack of rainfall without the explicit mention of deficits in the runoff of rivers and springs		
Normal	0	Events in which the author did not comment on weather conditions and where other non-meteorological events are found		
Wet	+1	A strong and continuous rainy period which affects agricultural and other socio-economic activities		
Floods	+2	Rains accompanied by floods		

Table 3. Rainfall events indevation in relation to documentary interne

of relative and actual rainfall occurrences, such as reports of rainfall intensity, wind and storms/lightning, hail, fog, river levels, floods, description of crops and vegetation cover, information of droughts, famines and societal coping strategies [4,6]. The content analysis and discourse analysis was used to assess the information and rank the observations in terms of severity.

Each of the classes was assigned an ordinal index relative to the documentary descriptive rainfall intensity within a given season or a 'rain-year'. Indexation ranged between -2 to +2 based on the impact of the events and the community responses [30,40]. Therefore, positive or negative indices indicated unmistakably extreme conditions [30]. Because the documentary information does not have regional sub-divisions, these indices were used to develop an annual time series representative of the whole country over the documentary period c1845-1976. These series were useful for verification of seasonal and annual rainfall anomalies identified in the instrumental time series, especially when there were gaps in the instrumental records. Descriptive information on seasonal and annual anomalies was quoted wherever possible to emphasize the extremities of events over the study period.

Assessment of rainfall variability using instrumental records

Determination of drought and wet events indices: Drought is an inevitable and recurring feature, which occurs due to precipitation deficiency over a pre-determined period, often resulting in significant societal, economic and ecological impacts [41,42]. Based on different empirical findings, a holistic approach to drought monitoring requires an investigation of multiple indicators (precipitation, soil moisture, runoff, evapotranspiration among others). Usually, a drought is identified by quantitative indices and over the years, several indices have been developed to measure drought and wet spell intensities. Among these indicators, Percentage of Normal Precipitation (PNP), Bhalme-Mooley Drought Index (BMDI), Standard Precipitation Index (SPI), Effective Drought Index (EDI) and deciles are the most commonly used. The majority of these indices apply precipitation in drought quantification [42]. Additionally, droughts can be predicted using vegetation Indices based on remote sensing data such as normalized difference vegetation index [24,43].

A drought index is typically a single value used to indicate the severity, duration, and place of drought occurrence. The drought and wet events indices for this study within the period of precipitation recording have been determined using Standardized Precipitation Index (SPI) method. SPI was developed in Colorado, based on the probability for the time scale of interest and is relatively simple to compute [43,44]. The method primarily quantifies precipitation

deficit and may be applied in areas with different climates for various time scales [45].

The SPI is based on the long-term precipitation data for the desired time step and is mainly based on precipitation only unlike other indices such as Crop Moisture Index (CMI) and Palmer Drought Severity Index (PDSI) indices. The analysis involves taking the difference of the precipitation from the mean for a particular time step and then dividing it by the standard deviation. It is a dimensionless Index, in which negative values indicate drought, while positive value represents wet conditions. It is the most suitable drought analysis method because it requires fewer input data and calculation efforts.

In this study, a 6 months' time scale SPI derived by non-parametric SDAT has been adopted to examine anomalous rainfall events occurrences in Kenya since the year 1904-2012 for monthly rainfall data derived from twelve stations nation-wide. Through this method, the climatology of floods and droughts of different intensities for both long and short rain seasons are reviewed. Precisely, the SPI is the number of standard deviations that the observed value deviates from the long-term mean for a normally distributed random variable [46]. In this case, the positive SPI value indicates greater than mean precipitation and negative values indicate less than mean precipitation. This method is also suitable for monitoring both dry and wet conditions. The "drought" part of the SPI range is arbitrarily split into the following categorizations as shown in the Table 4.

Table 4: Categorization of rainfall events based SPI nominal classification.

SPI value occurrence	% occurrence	Normal SPI class
>1.645	≤ 5	Extremely wet
1.644 to 1.282	6-10	Severely wet
0.842 to 1.281	11-20	Moderately wet
-1.281 to -0.842	11-20	Moderate drought
-1.644 to -1.282	6-10	Severe drought
< −1.645	≤ 5	Extreme drought

A drought event starts when the SPI value reaches -1.0 and ends when SPI becomes positive again. The positive sum of SPI for all the months within a drought event is referred to as "drought magnitude" [47]. The advantage of Standardized Precipitation Index indices is that they offer the opportunity to create statistically consistent indices based on precipitation (SPI), soil moisture (CMI), relative humidity, or even evapotranspiration.

The study region: Kenya is located at latitude 4°North to 4°South and longitude 34°East to 41°East in Eastern Africa. The country

covers an area of 582,650 sqkm including 13,400 sqkm of inland water and 536 km coastline straddling the equator, which cuts across the country about 90 miles north of Nairobi. Kenya's boundaries are defined in the east by the Indian Ocean and Somalia, in the west by Lake Victoria and Uganda, in the south by Tanzania and to the north by Ethiopia and Sudan [48]. According to the 2009 population and housing census, Kenya has a population of 38,610,097 [49]. Being an equatorial country, there is only a small variation in mean monthly temperature. Most of the country experiences a semi-arid to sub-humid climate, with the highlands and lake areas being wetter compared to other parts of the country. The temperature ranges between 21°C and 25°C in most parts of the country. However, in the highland regions, the mean monthly temperature is usually 17°C between January and April [50]. The diurnal temperature ranges in nearly the whole of the country is in the range 9°C to 13°C except above 2200 m in the highlands where it is about 14°C to 17°C and at the coast on the islands where it is between 5°C and 9°C [51]. Kenya has diverse geographical features; the coastal region, Nyika Plateau, highlands regions, and the lake basin region.

The coastal region: The coastal belt along the Indian Ocean is a fertile agro-ecological zone, mainly dominated by rain forests and mangrove swamps. The coastal region usually experiences a mean daily temperature of 25°C, as experienced within the Rift Valley region. A bimodal rainfall regime exists within the coast, with some additional precipitation in most months of the year [52]. However, it has been noted that it is only the months of April and May, which experience a positive net moisture regime. In all other months, predicted evaporation exceeds received precipitation. The annual June winds also create a cyclic depression in rainfall amounts during the long rains season, resulting in decreased soil moisture and therefore adverse effects on annual field crops [53]. Consequently, the region experiences chronic food insecurity and is heavily dependent on relief food with a large number of populations living below the poverty level [49]. Nevertheless, most of the inhabitants of this region are predominantly subsistence farmers. This study focuses on Mombasa and Malindi, which have the longest data recordings for this country.

The Nyika Plateau-Arid and Semi-Arid Lands (ASALs): Moving from the coastal region the terrain gradually rises changing from the low coastal plains to a vast dry savannah land, which includes the Nyika Plateau extending to the eastern and the northern frontier. The Tana and Athi Rivers pass across this vast land, discharging their waters into the Indian Ocean. While other major rivers, such as the Nzoia, Yala, and Gori flow across the country before draining into Lake Victoria. This region is primarily occupied by pastoralists and a few agro-pastoralists [54]. It covers approximately 83% of the country's total area, where rain-fed agriculture and pastoralism are central to livelihoods and food security [24]. And about 20% of the Kenyan population and 60% of the country's livestock are to be found in these zones [35].

The population density reflects the agricultural potential and ranges from about 15 people km² in the lowland to as high as 250 people km² in the upper mid-land areas [55]. The major environmental factors limiting crop production in these ASALs of Kenya are high potential evaporation and rainfall unreliability. The temperature and evaporation rates are generally high with

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February and September being the hottest months of the year. The minimum mean annual temperatures vary from 14°C to 22°C, while maximum mean annual temperatures vary from 26°C to 34°C [55]. Rainfall variability is inherently large and severe, accompanied by recurrent droughts [24]. The mean total annual rainfall ranges from as low as 500 mm in the lowlands to over 1050 mm in the hilltops [55]. The identified zones of study within this region are; Marsabit, Garissa, and Machakos.

The highland regions: The highlands which occupy the southwestern quarter of Kenya are plateau raised at 4000 feet, with the highest altitude being the peak of Mount Kenya 5,199 m.a.s.l [48]. The Great Rift Valley dissects the highlands into east and west stretching from the central to the western region. Along it are several rivers flowing into Lakes Turkana, Naivasha, Nakuru, and Victoria [56]. The rainfall amount in the highlands ranges from 1,016 mm-2540 mm per annum [29]. The region has fertile soils and cooler temperatures compared to other areas in the country, hence being one of the major agricultural zones in the country [54]. The gauged rainfall data for Nyeri, Thika, Nairobi, Meru, and Embu represent this region in the study.

The lake basin region: It is also another geographical feature, which is typically semi-tropical with relatively high humidity and an annual rainfall of 1000 mm-1778 mm [48]. It is the most densely populated Lake Basin in Africa, occupying an area of 194,000 km² and a population of more than 3 million people. This region forms the watershed for Lake Victoria, which is the largest lake (about 68,800 km²) in Africa and the second largest lake in the world. It is located in continental sag between the two arms of the Great Rift Valley system, with high mountain ranges (Kilimanjaro, Kenya, and Rwenzori) on the east and west. The altitude of the lake surface is about 1,135 m.a.s.l, while the basin is made of a series of stepped plateaus with an average elevation of 2,700 m but rising to 4,000 m or more in the highlands. The climate of the lake basin is somehow different, ranging from a modified equatorial type with substantial rainfall occurring throughout the year, especially over the lake and its vicinity to a semiarid type characterized by intermittent droughts over some areas located even within short distances from the lakeshore [14]. Records of Kisumu, Kakamega, and Kitale have represented this region.

RESULTS

The temporal evolution of extreme events variability is very important, especially when considering place vulnerability to natural disasters such as droughts and floods. In this study, the temporal evolution of rainfall events in Kenya was determined using over a century-long data series derived from documentary evidence and the mean monthly aerial precipitation for the selected 12 stations, dating from 1895-2012. The time series of the mean monthly aerial precipitation represented nationwide SPI evolution over this period showing occasions of anomalous dry conditions as well as the extreme wet spells. These evolutionary serial events were essential in establishing how different rainfall events were temporarily distributed in order to particularly identify when a given category of drought occurred, how frequent and intense the events were, and which period was particularly vulnerable to droughts or floods.

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Dry and wet events derived from documentary evidence

Using documentary evidence, the current study was able to establish the rainfall events, which occurred from mid-19th century until the end of the century in Kenya. Some of the events for the years which had instrumental records have been proven using SPI analysis. Then, instrumental rainfall data was used in quantifying the events in the 20th and 21st centuries. Using indexation analysis method, the study got a glimpse of the rainfall distribution during 19th century [2,34,36,38,39]. It should be noted, however, that the analyses were limited to only the years, which had rainfall records. The analysis showed that there were unusual events in the first three years (1845-1849), but towards the end of the decade, very intense drought conditions were experienced in both the years 1849 and 1850. The records show that the two rainfall seasons begun late in 1849, and then the situation was further aggravated by a lack of rainfall in both rainfall seasons in 1850 resulting to migrations of the arid and semi-arid lands of Kitui and Tharaka inhabitants to Mbeere and Meru agriculturally potential zones.

In the following decade, only one drought is noted in 1868 due to the failure of both rainy seasons. This must have been an extreme drought for the whole country. Such a drought was experienced in 1836 as orally suggested by Kitui people [57]. After the 1868 drought, the following year was normal and there were no other droughts reported for that decade. In the following decade, a relatively dry year occurred 1876 and then, a severe drought followed in 1879. In 1880s, very severe droughts occurred in 1887 and 1888. Although, these were considered as severe droughts the severest of all droughts in this century was experienced in 1897 (SPI-1.5235). Moderate rainfall reined in the country until the year 1895 then, a severe drought struck the country lasting for four years (1895-1898). Documentaries note great devastation in the whole country. There was a great scarcity, animals had disappeared from the forests and caves, people hunted "alligators" for food, and all wild fruits and berries became dietary staples. This drought ended with heavy rainfall in 1899 (SPI 1.5325), the only extreme wet event in that decade, which extended until 1900 (SPI 1.2481).

Evolution of the dry and wet spells derived from SPI analysis

The study through the application of SPI analysis method

established a series of mean monthly aerial precipitation, which represented a nationwide SPI evolution over a period of 117 years. Firstly, the monthly precipitation indexes were established (Figure 1), and then these indexes were converted into cumulative monthly indexes, which presented the evolutionary identity of the rainfall events. The cumulative monthly indexes were employed in order to determine how subsequent SPI_6 values reveal tendencies of drought/wet events in certain epochs to forming prolonged dry/ wet spells during successive months.

Using the method, it was easy to identify the general trends in rainfall occurrences with periods of distinct trends and their turning points vividly portrayed in the resultant national cumulative SPI_6 series cycles which revealed the evolution of wet and dry spell patterns over many decades (Figure 1).

Generally, the analysis shows that the early twentieth century was characterized by stable, almost normal, or moderately wet rainfall events in 1904-1905, 1911-1912, 1916, and 1922. Although, the year 1905 and 1922 were intensely wet all other years had moderate rainfall with the majority of the years being normal. There were only two cases of severe and moderate droughts occurrences in 1917 and 1920 respectively until when dry conditions encroached in the early 1940s lasting for 5 years (1942-1945), and (1947-1948), but 1946 had normal precipitation. Such severe drought epochs recurred in the early 1970s between (1972-1975) and later in (1984-1985). Most of these droughts were either severe or moderate, the only extreme drought episode occurred in 1948 with SPI_6 (-1.71498), Table 5 shows these drought epochs.

Table 5: Severe and moderate droughts experienced in Kenya from 1904-2012.

Severe drought	Moderate drought		
1917	1920	1960	
1928	1924	1966	
1932	1938	1979	
1943-1945	1942	1991	
1972-1975	1947	2007	
1984-1985	1952	2008	
1998	1954	2010	

Wet periods prevailed intensely in the early decades of the 20th century between the years 1900-1916.Although later decades such



Figure 1: Temporal evolutions of cumulative SPI_6 months time series for the period 1904-2012.



Figure 2: The temporal distribution of excess and deficient years occurrences over the country from the year 1904-2012.

as 1960s and 1990s were also wet, the events were not as prolonged as earlier years were. More specifically, severely wet spells were experienced in 1899, 1912, 1916, 1922, 1929, 1955, 1962, 1977, 1978, 1989, 2006, and 2009. While, moderately wet years included 1900, 1904, 1911, 1935-1936, 1939, 1941, 1950, 1956-1957, 1963, 1976, 1980, and 2001. Extremely wet events occurred in 1905 SPI_6 (1.67354), 1961 SPI_6 (1.987014), and in 1997 SPI_6 (1.70551). As noted above some decades had very intense events, while others were devoid of any or either experienced only one incidence.

The century-long cumulative SPI_6-time series reveals that relatively short wet and dry spells without major systematic turning points prevailed in the early twentieth century, and then later in the mid-1930s, a considerable change in the rainfall pattern with conspicuous prolonged dry spell interspaced with extended wet spells encroached. Afterward, periods of fast and sustained rainfall increase or decrease, demonstrating a tendency of relatively more intense drought spells alternating with equally rapid and sustained increase of stronger wet spells prevailed until 2012 (Figure 2).

These analyses show a near decadal cycle pattern of dry epochs interspaced by equally intense and protracted wet spells of almost similar duration. It is evident from Figure 2 that unprecedented rainfall decrease occurred in Kenya from the year 1933 to 1940. Then later another turning point occurred between the years 1957 to 1967, which portrays an intensive rainfall increase in 1960s and then a fall back in the early 1970s. The frequency of occurrence of excess (SPI 1.282 to \geq 1.645) and deficient (SPI-1.282 to \leq -1.644) years experienced over this period are vividly demonstrated (Figure 2) and (Table 5).

The analysis shows that great desiccation reigning mainly in two decades, in 1941-1950 when three droughts struck the country, one being a moderate drought year, seconded by a severe drought, which lasted for three years, and then an extreme drought, which occurred in 1948. In 1971-1980 two drought episodes occurred, one lasting for four years. These were the driest periods over the study period seconded by the last decade 2001-2010, which experienced three moderate drought epochs. Most of the severe droughts tend to concentrate in the mid and near the end of the time series. In the early decades of the 20th century, droughts were fewer and less pervasive until the year 1940. Each decade had two occurrences, a moderate, and a severe drought. Severe droughts were dominant in 1940s and 70s, while moderate events dominated the 1950s and the last decade (2001-2010) of the study period.

It has been noted that the first decade of the 20th century had almost normal rainfall occurrences. It is the only decade, which had

no drought occurrence; at least each other decade experienced one drought episode during the study period. These findings confirm the IPCC report description of the increased climate variability in the last two decades of the twentieth century, characterized by disastrous droughts worldwide [23]. Also, less drought occurrences were established in Zimbabwe during early years of the twentieth century and increased episodes towards the end of the century [46]. The analysis shows that severe droughts were being experienced in all stations. This evidently explains why such extremities are usually destructive to agricultural sector, other ecosystems, and human livelihoods as well because they are usually intense and spatially spread.

On the other hand, viewing the excessive rainfall occurrences, the study establishes that intensive rainfall epochs occurred in three consecutive decades-spanning in c1951-1980. In each of these decades, at least three excessive rainfall epochs were registered. Particularly, 1960s were the wettest years during which three episodes of excessive rainfall and only one moderate drought occurred. It is essentially during this decade when the highest ever-recorded rainfall in Kenya occurred in 1961. Although 1970s were categorized as dry years, these were characteristic of the early years of that decade, in mid-70s three consecutively years registered very high rainfall from 1976-1978. Other extreme rainfall events occurred in 1905 and 1997. The 1997 event was extreme though not comparable to the 1961 episode. Again, this was the only excessive rainfall event experienced in that decade. Seasonal events occurrences were similarly analysed (Table 6).

Table 6: Representation of the frequency of excess and deficient yearsoccurrences from 1904-2012.

D 1	Annual		Long rain		Short rain	
Decade	Excess	Deficient	Excess	Deficient	Excess	Deficient
1900-1910	1	0	1	1	1	0
1911-1920	3	2	2	1	1	1
1921-1930	2	2	2	3	0	0
1931-1940	1	2	2	1	1	0
1941-1950	2	4	2	2	1	1
1951-1960	3	1	1	0	1	0
1961-1970	3	0	2	1	2	0
1971-1980	3	5	1	3	1	3
1981-1990	1	1	5	1	1	1
1991-2000	1	3	1	1	2	2
2001-2010	2	3	2	1	1	2
2011-2012	0	0	0	1	2	0

DISCUSSION

Several droughts and wetter periods emerged from the detailed study of a variety of documentary sources and analysis of the instrumental rainfall data from early 1845-2012. The droughts and wet periods identified in this study were compared with those identified by other studies conducted on the East African regional scale and Africa as a whole. The study established that the 20th century experienced more drought occurrences in comparison to the 19th century. However, a lack of documentary data for the early 19th century restricted the analysis to the available years only. In accordance to this, in the 19th century, the country experienced severe droughts in 1849/50/51, 1868, 1875/76, 1879, 1883, 1887/88, 1897/98, and 1899. The severest of all these droughts experienced during this century was the 1887/1888 due to the great scarcity experienced because there was nothing available, fit for both human and animal consumption. Then, during the 20th century, both documentary and SPI analysis reveals there were several droughts in the years 1901/2, 1917/18/19/20, 1932/33/34/35, 1942/43/44/45, 1947/48, 1972/73, 1975/76, 1983/84, and 1998. Majority of these droughts were either severe or moderate. The severe and prolonged drought epochs prevailed in 1940s, 70s, and 80s, with some lasting for more than four years. The century-long SPI_6-time series shows that some decades had very intense events, while others did not have any event at all. In the present century, over the last decade, there has been no severe drought occurrence, only a few moderate events experienced in 2000/2001, 2005/2006 and 2010.

Extreme droughts usually occur twice or thrice over a period of about 100 years [44,58]. And in line with that, the study establishes that most of the droughts experienced in the 19th and 20th century was either severe or moderate, the only extreme drought episode established by SPI_6 analysis occurred in 1948 with SPI_6 (-1.71498). Documentary narratives however show there were some other extremities revealed by the intensity of human devastations such as the famines experienced in 1897 and 1902 when there was a great scarcity in most of the country causing massive migrations. Additionally, the extreme devastation felt in the East African region in 1918/19, resulting in many deaths in Kenya and other East African countries such as Tanzania also places this year in the extreme drought category.

The temporal evolutions of rainfall events from both narrative documentaries and the SPI series have less evidence of wet rainfall events in the 19th century due to scarcity of data, especially in the early decades. A strong peak occurred around 1878, characterized by extremely high Niño 3.4 SST anomaly and all India rainfall [59]. The documentary evidence shows one incidence of a moderately wet event in 1899. From the analysis in the National SPI_6 series, it is evident that normal rainfall events accompanied by moderately wet spells dominated the early twentieth century until the encroachment of the drought conditions in the early 1940s.

During this period, there were relatively short wet and dry spells without major systematic turning points, then thereafter a more conspicuous prolonged dry spell interspaced with extended wet spells begun in mid-1930s. The findings show that unprecedented rainfall decline occurred from the year 1933-1940, and then a turning point of heavy, intensive rainfall events occurred in 1960s, followed by a fall back in 1970s and 80s. The SPI evidence shows

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that the 1960s and 90s were the two main epochs during the 20th century which experienced extremely wet spells, dominated by either moderately wet or severely wet rainfall events.

Generally during the study period severely wet years were; 1912, 1916, 1922, 1929, 1951, 1955, 1962, 1977,1978 and 1989, while moderately wet years were; 1900, 1904, 1911, 1935-36, 1939, 1941, 1950, 1956-1957, 1963, 1976 and 1980. The extremely heavy rainfall events occurred in 1905 SPI_6 (1.67354), 1961 SPI_6 (1.987014), and in 1997 SPI_6 (1.70551) and the current century until the year 2012 there has been no extremely wet event. The only two severely and one moderately wet events occurred in 2006, 2009 and 2001 respectively.

The current study findings confirm the robustness of the SPI results analysis and matches those of a previous studies in the African continent Tor instance the investigations on lake-level trends. Moreover, the investigations on the lake-level trends across eastern equatorial Africa confirm there was a transgression in 1890s, which led to peak levels in 1900 and 1910s, then a decline occurred in 1940s-1950s, which marked a low stand [16,17]. Then immediate recovery to intermediate levels started in the late 1950s and acceleration to higher levels after the 1961-1962 heavy rains [13].

Based on the study findings, it is clear that the historical period between mid-19th century until the beginning of the 20th century was very dry, with great desiccation for most of the years. Although there is less information about the wet events in the documentaries, description of the experienced droughts and the affirmation by the SPI indices for 1890s shows the period under analysis was dry. The 20th century begun with moderately good rains, other than the year 1905, which was exceptionally wet (SPI 1.6735) all other years were moderately wet and there was no drought occurrence in the first decade.

The next decade was comparatively wetter than the first. Although there were droughts in 1917 and 1920 (SPI -1.5552 and -1.1715) respectively, the other years were marked by heavy rainfall. Much notably, the decade begun with heavy rainfall events in 1911 (SPI 1.0022) and 1912 (SPI 1.4817), followed by three years moderate rainfall, then the 1916 severe rainfall (SPI 1.5776), which was crowned by the 1917 desiccation and two years of average rainfall as the decade ended with a moderate drought. In comparison to the first two decades, 1920s and 1930s were relatively dry, although only two droughts were being experienced in each decade, the rainfall distribution was slightly low compared to the early years.

The 1920s decade begun with above average rainfall followed by a severe rainfall event in 1922 (SPI 1.5457). Afterwards the SPI indices distribution shows the rains begun to deteriorate. Almost all years had negative SPI indices, with exception of 1925 (SPI 0.6506), which occurred after the moderate drought of 1924 (SPI-1.2355), culminating to the severe drought of 1928 (SPI-1.3633) and then desiccation relieve by heavy rains of 1929 (SPI 1.6096). The first half-decade of 1930s was remarkably dry. The SPI indices indicate that the rainfall was low until 1934. The peak drought was experienced in 1932, when a severe drought (SPI 1.4592), occurred initiating the moderately wet environs of 1935 and 1936, before a moderate drought-hit in 1938 (SPI -1.0117). The decade ended with severe rains of 1939 (SPI 1.226), which extended until 1941 (SPI

1.3858) intertwined with average rains of 1940.

This marked the end of the wet period of East African climate and ushered a decade viewed as the driest of all in the 20th century. The analysis shows that after the end of the prolonged wet event in 1941, a prolonged drought also struck the country in 1942-1948. This was the longest drought period on records for Kenya, which lasted for six years (SPIs -0.8519, -1.4273, -1.6191, -1.3314, -0.8838, and -1.7150) respectively. Nonetheless, it should be noted that 1946 was not a drought year, the country received fairly above average rainfall, thus moderating the severity of 1947 drought. The long desiccation ended with normal rains in 1950 and then a more intense rainfall in 1951 (SPI 1.1940).

As noted above, the 1950s started with good rainfall, which in contrast was followed by three consecutive devastating drought years, the worst being 1952 drought (SPI-1.1076), preceding the eminent 1960s wet epoch, which lasted until 1969. In comparison to the previous decades, 1950s were wetter than 1920s and 1930s. It is a period, which marked the start of another wet regime as that experienced at the beginning of the century. The significantly wet events during this epoch occurred in 1955, 1956, 1957, 1961, 1962, 1963, and 1967 with SPIs (1.6416, 1.0342, 1.0662, 0.6186, 1.2899, 1.2580, and 1.3219 respectively. From mid-1950s through the 1960s, the country was endowed with adequate rainfall. The only year, which was relatively dry, was 1966 (SPI-0.8838), other years had SPI ranging from 0.2300 to 0.4900. For a period of more than fifteen years, Kenya received rainfall continuously with no drought incidence after the 1940s long droughts thus, the period being the wettest period ever experienced in the country. Remember the early decades such as 1900s, 1910s, and 1920s were wet, but there were some dry "breaks" of at least two droughts (moderate and severe) in each decade, therefore not comparable to one and half decades of adequate rains with no drought at all.

These rainfall variations have been noted in other empirical researches from different perspectives [18,20]. Further confirmation of the current study findings is found in research on 1961 and 1997 rainfall extremities in Eastern Africa [13]. The study showed that the rainfall changes witnessed in the Eastern African region during the 1960s were comparable to those of 1916. In the description of the Tana River flow, the researcher also shows there was an anomalous volume increase in 1963 and 1964, generating the second-highest river flow in the record.

The current study shows that, the 1990s rainfall events cannot be equated to those of 1960s or 1980s. This period was relatively dry, comparatively similar to 1920s. The wet conditions associated to 1990s are attributable to the extreme 1997 event (SPI 1.7055), which had overwhelming consequences to the entire country.

A similar observation has been made as follows: The event was contemporaneous across the region, being the third wettest event and higher than 1961, beginning in October and lasting through until February 1998 [13].

Unlike the 1960s and 1980s, this decade had three severe drought episodes experienced in 1991, 1998, and 1999 (SPIs -1.1715, -1.2674 and -1.6830) respectively. Other years had either slightly above or below-average rainfall. Therefore, this study establishes that the rainfall deterioration currently being experienced in Kenya begun in 1990s. Since the good rains in 1960s, 70s, and 80s, there has been no other epoch of continuous rainy years in Kenya as previously experienced. The current century has been dry since the beginning, more specifically drought was experienced in the last three years of the first decade. The first two years had above-average rainfall, followed by two more years of slightly below average rains before the heavy rains in 2006 (SPI 1.1301). This being an El Niño year was followed by two severe droughts in 2007 and 2008 (SPI -1.1396 and -1.5232) then, a heavy rainfall in 2009 (SPI 1.4178) and a severe drought in 2010 (SPI -1.0756).

The question that emerge is what causes such occasional intense anomalies? Several studies have investigated the causes of rainfall variability in the East African region [13,18,20]. As earlier noted, rainfall variations in the eastern Africa region, occur on temporal intervals scale of about 2-3 years. The extremely heavy rainfall events according to the current study recur after approximately 37 years intervals, indicating a climatic shift during such extreme years. The extreme positive anomalies in Kenya occurred in 1878, 1916, 1961 and 1997.

CONCLUSION

The study concludes that the rainfall deterioration being experienced in Kenya begun in the 1990s. Apart from the good rains in the 1960s, 70s and 80s, there has been no other epoch of continuous rainy years in Kenya as previously experienced. The current century has been dry since the beginning with drought occurrences in the last three years of the first decade. The extreme rainfall events in Kenya recur after approximately 37 years indicating a climatic shift during such extreme years. The study findings confirm the robustness of the SPI analysis in establishing rainfall variability and extreme hydrological events.

NOTES

- El Niño Southern Oscillation (ENSO) is a large-scale climate moderating phenomenon which occurs in the range of 2-7 years time frame when central and eastern Pacific Ocean warms up interfering with the global atmospheric circulations [59]. El Niño is defined by the Sea Surface Temperature (SST) anomalies in the eastern tropical pacific, while the Southern Oscillation Index (SOI) is a measure of the atmospheric circulation response in the Pacific-Indian Ocean region [19]
- 2. North-East (NE) and Southeast (SE) trade winds are tropical continental air masses which includes northerly air stream from Egypt, Sudan, Arabia, and the Horn of Africa. Due to its originality from desert conditions, it is dry and brings no rain to the East African region. Its characteristics account for the aridity in northern and eastern Kenya and for dry zones of Tanzania. The South-East (SE) trade winds comprising of tropical maritime air mass bring heavy rainfall to most parts of Eastern Africa in the month of April and May [16,17]

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