Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.11, 2016

# Analysis of Spatial and Temporal Patterns of Rainfall Variations over Kenya

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**Abstract**
This paper presents analysis of spatial and temporal patterns of rainfall variability over Kenya between 1971 and 2010. Rainfall data was obtained from 26 stations in Kenya, out of total 34 synoptic stations which were analyzed at monthly, seasonal and annual scales. Monthly Climate Research Unit (CRU) and Global Precipitation Climate Centre (GPCC) data sets were used. Results showed that CRU data performs better than GPCC when subjected to evaluation and comparison with station data. The findings showed that the highest and lowest annual rainfall was recorded in 1997 (1309.1.2mm) and 2000 (609.4mm) respectively. Maximum mean annual rainfall (2087.0mm) was observed on Kisii station, while the least mean annual rainfall (203mm) was reported at Lodwar station. The highest recorded total rainfall within the analysis domain occurred at Kisii location (3673.6mm), while the least was recorded at Lodwar location (54.2mm). Further results reveal that among the seasons, a noticeable decrease in March, April and May (MAM: 95.5.0mm) and slight increase in October to December (OND: 65.3mm). Overall the findings demonstrated that there is significant decrease in rainfall over Kenya and this is in line with recent trends of global warming as reported by last intergovernmental panel on climate change report (IPCC report). The significance of these findings is that it could support various policy makers and development partners in the field of climate science working in Kenya both on local to large scale related industries.
**Keywords:** Spatial-temporal variability, Climatology, Kenya.

## 1. Introduction

Rainfall variations in both spatial and temporal scales are likely the most evident effects of the changes occurring in earth's climate system. According to the latest report by IPCC, (2014), mean global surface temperature increased and one of the most significant consequences of this increase may be the alteration of the hydrological cycle at global and local scales (Arnell, 2004; Held and Soden, 1995). The rising atmospheric moisture content associated with warming might be expected to generate an increase in mean global precipitation (Almazroui et al.,2012). Based on global averages, precipitation over land has increased by approximately 2% during the 1900-1998 period (Hulme et al., 2001), but regional variation are highly significant. Precipitation has generally increased over land north of 30°N over the period 1900-2005, while downward trends dominate the tropics since the 1970s (IPCC, 2014) .

An understanding of the temporal and spatial characteristics of precipitation is hence central to water resources planning and management, especially given the evidence of climate change and variability in recent years (Liu et al. 2015). Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling and water resource assessments (Gallego et al., 2011). Therefore, many studies on the temporal and spatial characteristics of rainfall in different parts of the world have been conducted (González-Hidalgoet al., 2011). These international literatures include several studies of rainfall trends that have been carried out at different temporal scales from daily to annual, and in different areas of the world. Also, methodologies employed in these studies are different.

According to the report by IPCC (2007) rainfall is not well approximated by normal distributions across the region. Mooley and Parthasarathy, (1984) reported that monsoon rains from Africa to India decreased by more than 50% from 1957 to 1970 and predicted that the future monsoon seasonal rainfall, averaged over 5 to 10 years is likely to decrease to a minimum around 2030.

Currently a number of studies have been focused on rainfall trends and variability over East African region since it has shown more inter-annual variability than temperature trends (Stefan et al. 2010). According to Cook and Vizy (2013), the rainfall trends over the region are linked with the strength of the Wyrtki jet in the upper tropical Indian Ocean, which is driven by the surface westerly winds that reinforce the easterly oceanic temperature gradient and form part of the equatorial zonal-vertical circulation cell. This causes the variations trends and periodicities of rainfall over the region. Over Kenya, rainfall patterns and characteristics are influenced by Inter Tropical Convergence Zone (ITCZ), jet streams, El Nino South Oscillation (ENSO), Indian Ocean Dipole (IOD) at regional and local effects (Ogwang, et al 2015). Furthermore the region is affected by Monsoon winds and Congo air mass (Ogwang et al., 2014).

Studies by (Gamoyo et al., 2015a) have projected likelihood of enhanced rainfall in East Africa. The results are supported by IPCC (2014) that this is due to global warming, which has resulted from increased anthropogenic emissions of greenhouse gases (GHGs). If the projected rainfall actualizes, it will be a recovery from the observed drying trend currently being experienced (Yang et al. 2015). However, a recent study by Cook and Vizy (2013) has added uncertainty in the future on rainfall variations and trends over Kenya by pointing out that the lateral and ocean boundaries indicate a reduction in the long rains. Hence the long term projections are very informative for planning purposes,

There is need to understand the past and current trends in rainfall patterns so as to make informed decisions in various planning processes. There is minimal literature on precipitation variations, trends and periodicities over Kenya. The aim of this study therefore was to address the question of whether there are any spatial and temporal patterns of rainfall over Kenya from 1971 to 2010 and their associated mechanisms. Long term rainfall trends at seasonal and annual time scales are evaluated, advancing the understanding of the changes in precipitation in both past and future. This study will hence add more knowledge to climate change in Kenya and also provide reference for water resources vulnerability evaluation.

Section 2 of the paper contains the description of the study area, data and methodology. Section 3 details results and discussions while the conclusions and recommendations of the paper are provided in section 4.

## 2.0 Data and Methodology

### *2.1 Study area*

Kenya is located in East Africa on the Indian Ocean coast between Somalia and Tanzania with geographical coordinates: longitude 34°E, 42°E and at latitudes of 5°S to 5°N. The total land coverage is 582,650km$^2$, and land coverage totaling to 569,140 km$^2$. The rest portion is covered by water bodies with total of 11,227 km$^2$ (Liebmann et al., 2014).

The geography of Kenya is very diverse. Kenya has a coastline on the Indian Ocean, which contains swamps of East African mangroves. Inland are broad plains and numerous hills. Central and western Kenya is characterized by the Kenyan Rift valley and home to Kenya's highest mountain which is Mount Kenya. Mt. Elgon is on the border between Kenya and Uganda. Kakamega forest in western Kenya is one of East Africa's major rain forest. Much larger is Mau forest, the largest forest complex in East Africa and one of Kenya's main water towers (Parry et al, 2012). Figure 1 shows map of Kenya and its location in the continent Africa.

The variability of rainfall has a major impact on the future sustainable socio-economic development of the region with keen interest on agriculture (Omondi et al., 2014). The failure or reduction in wet days leads to periods of severe drought, especially in the arid and semi-arid regions of northern and eastern Kenya (Sako et al., 2012).

The country has therefore four distinct weather zones which include: Western Kenya which experiences rainfall throughout the year, but heaviest in April. An average may be recorded in January. Temperature range from a minimum of 14-18°C (Camberlin and Okoola, 2003b). Rift Valley and Central Highlands experience temperate climate with temperatures ranging from 10-28°C. Rainfall varies from a minimum of 20mm in July to 200mm in April. Two different seasons of rainfall occur: long rains, which starts from March until beginning of May and short rains, which start from October until the end of December (Omondi et al., 2014). Semi-arid bush lands are located at the north and east of Kenya. Temperatures vary from 40°C daytime to 20°C. At night, violent storms occur due to the sparse rainfall. The average rainfall ranges between 250mm and 500mm (Daron, 2014). Coastal region is always humid with average temperature ranging from 22-30°C and average rainfall ranging from 20mm in February to 300mm in May. The rainfall is monsoon-dependent; this blows from the northeast from October-April, and from the Southwest for the rest of the year (Clark et al., 2003).

Because of the reduction of temperature with altitude, temperatures over much of Kenya are subtropical or temperate. The equatorial situation means that there is a very limited annual variation in temperature. Nairobi, in the southern inland highlands at 1800m altitude, has an annual mean temperature of 18°C, with a peak of 19°C in March and a low of 15°C in July. Kisumu, near the shores of Lake Victoria in the west at 1350m altitude, has an annual mean temperature of 26°C. Only the coastal lowlands experience the constant high temperatures and humidity associated with equatorial latitudes, although daytime sea breezes have a cooling effect. Mombasa has an annual mean temperature of 26°C. The northern part of Kenya is also hot throughout the year, but with lower humidity; Lodwar in the north-west has an annual mean temperature of 29°C (Christy et al 2009).

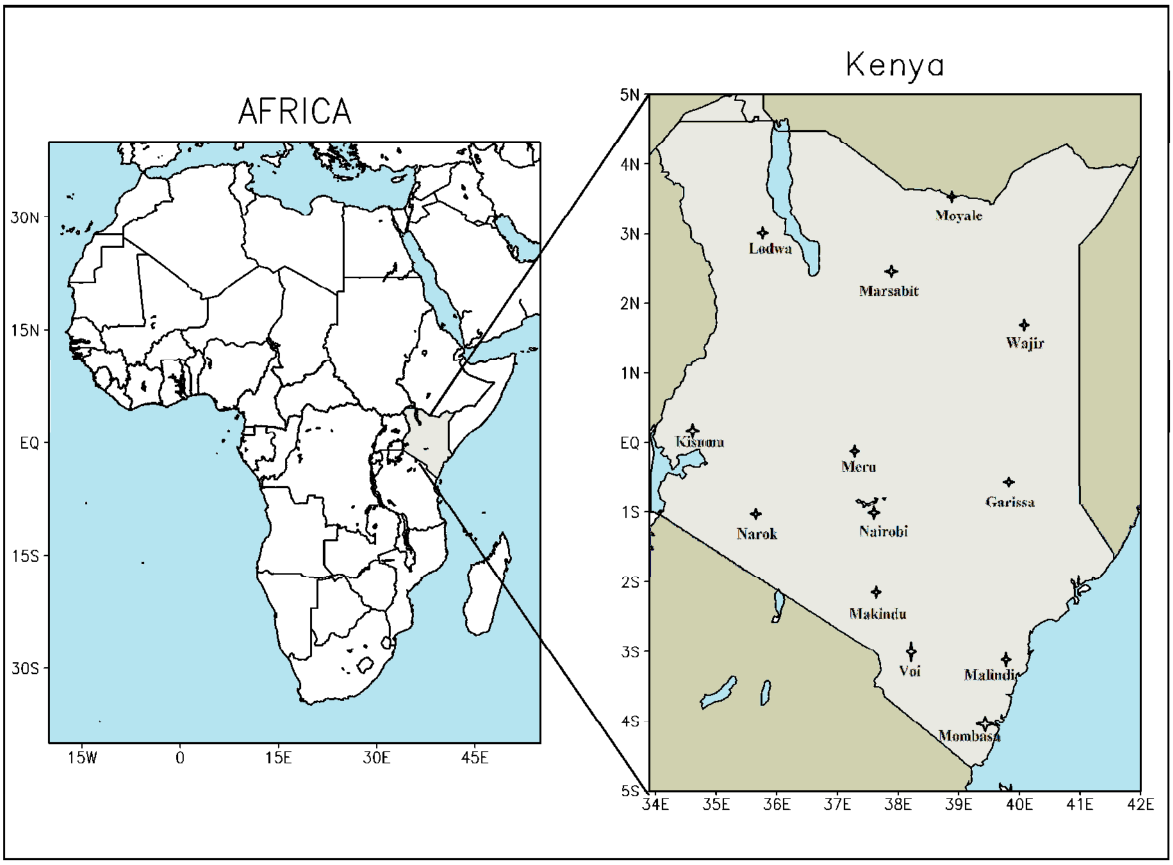


**Figure 1** Area of study showing the location of Kenya in Africa continent [The areas shaded blue are water bodies] and (right) is map of Kenya and distribution of synoptic stations

*2.2. Data sources*

Two types of historical monthly rainfall data were used in the study. These are synoptic data and gridded data. The synoptic data sets were sourced from the Kenya Meteorological Department (KMD) while gridded rainfall data sets were obtained from the Global Precipitation Climatology Center's (GPCC) and Climate Research Unit (CRU). These data sets which are in monthly basis were summed up to obtain seasonal and annual rainfall totals. In this study, the data covered the period of 40 years i.e. 1971-2010 for 26 synoptic stations (Table1).

The GPCC monthly data set has a resolution of 0.5°x0.5° latitude/longitude grid running from 1901 to 2013. GPCC precipitation data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA (http://www.esrl.noaa.gov/psd/). These data are purely observation-based and are derived from historical rainfall records. The GPCC apply thorough quality controls to these data to increase the reliability of their gridded monthly data.

Climate Research Unit (CRU) monthly rainfall time series (TS) version 3.22 data from the University of East Anglia (www.cru.uea.ac.uk/data) is derived from gauge observations, available from 1901 to date. The data is available 0.5° x 0.5° spatial resolution. According to Harris and Elliott, (2016), spatial interpolation of station data to obtain gridded data for the entire land surface is based on interpolation of monthly anomalies from the 1961–1990 climatology. Monthly CRU data were added together to obtain annual rainfall for 1971–2010. These two data sets were used by Ongoma and Chen, (2016) in their studies over East African to understand the temporal and spatial variability of temperature and precipitation.

*2.3 Methodology*

This study aimed to analyze spatial and temporal patterns of rainfall variations over Kenya from 1971-2010. The basic statistical analysis was conducted on the annual, seasonal and monthly rainfall data. Season identification for the period under study was based on calculating the sum of all corresponding monthly for averages of rainfall recorded during 1971-2010. Monthly rainfall series were converted to standardized monthly series ($R_{sy}$) by subtracting the long-term mean ($\overline{R}$) from the original monthly values ($R_i$) to obtain anomalies, and then dividing these anomalies by the standard deviation ($\sigma$) at each station. This process minimizes the problem of highly diverse means and variability and the randomness of station totals (Nicholson, 2014) The standard rainfall for a given station as expressed in Eqn. 1:

$$R_{sy} = \frac{R_i - \overline{R}}{\sigma} \qquad \text{(Eqn 1)}$$

The area-averaged (mean climatology) standardized monthly rainfall ( $R_{ry}$ ) was defined as presented in Eqn 2.

$R_{ry} = (1/N_j)\sum_{s=1}^{N_s} R_{sy}$ (Eqn.2) where ( $N_j$ ) is the number of country stations for the year j. The use of country average, in general provides series that is a better representation of large-scale and long-term climatic processes (Nsubugavet al, 2014; Partal and Kahya, 2006). Root Mean Square Error (RMSE) for the monthly and annual precipitation over Kenya by use of CRU and GPCC data sets against the station data was analyzed.

*Table 1: Synoptic Stations in Kenya*

| No | Station ID | Station Name | Longitude | Latitude | Period of Record |
|---|---|---|---|---|---|
| 1 | 636860 | Eldoret | 1;00-32N | 035-17E | 1972-2013 |
| 2 | 183028 | Nyahururu | 00°01-′43N | 36-20E | 1961-2013 |
| 3 | 637230 | Garrissa | 1;00-28S | 039-38E | 1959-2013 |
| 4 | 636870 | Kakamega | 1;00-17N | 034-47E | 1958-2013 |
| 5 | 184707 | Naivasha | 0°43-00S | 36°-26E | 1961-2013 |
| 6 | 637080 | Kisumu | 1;00-06S | 034-45E | 1959-2013 |
| 7 | 637090 | Kisii | 1;00-40S | 034-47E | 1963-2013 |
| 8 | 179330 | Thika | 01°01′59S | 37°-04E | 1957-2013 |
| 9 | 636120 | Lodwar | 1;03-07N | 035-37E | 1950-2013 |
| 10 | 637720 | Lamu | 1;02-16S | 040-50E | 1950-2013 |
| 11 | 636240 | Mandera | 1;03-56N | 041-52E | 1957-2013 |
| 12 | 636410 | Marsabit | 1;02-18N | 037-54E | 1950-2013 |
| 13 | 636950 | Meru | 1;00-05N | 037-39E | 1966-2013 |
| 14 | 637990 | Malindi | 1;03-14S | 040-06E | 1961-2013 |
| 15 | 638200 | Mombasa | 1;04-02S | 039-37E | 1957-2013 |
| 16 | 637660 | Makindu | 1;02-17S | 037-50E | 1950-2013 |
| 17 | 636190 | Moyale | 1;03-32N | 039-03E | 1950-2013 |
| 18 | 637410 | Nairobi / Dagoreti | 1;01-18S | 036-45E | 1955-2013 |
| 19 | 63740 | Nairobi JKIA | 1;01-19S | 036-56E | 1958-2013 |
| 20 | 637170 | Nyeri | 1;00-30S | 036-58E | 1968-2013 |
| 21 | 637140 | Nakuru | 1;00-16S | 036-06E | 1964-2013 |
| 22 | 637370 | Narok | 1;01-08S | 035-50E | 1950-2013 |
| 23 | 637420 | Nairobi / Wilson | 1;01-19S | 036-49E | 1957-2013 |
| 24 | 636943 | Nanyuki | 1;00-04S | 037-02E | 1957-2013 |
| 25 | 637930 | Voi | 1;03-24S | 038-34E | 1950-2013 |
| 26 | 636710 | Wajir | 1;01-45N | 040-04E | 1950-2013 |

Source: Kenya Metrological Department, Dagoretti, Nairobi

## 3. Results and Discussion

### *3.1 Data evaluation and comparison*

GPCC and CRU datasets were subjected to evaluation and comparison against the station data over Kenya. This process was mainly to evaluate which data sets among the two would perform better just as station data. This would therefore be used in place of station data since some stations have few discrepancies. This is because the African rain-gauge data observed during the post-independence era of 1970's through to recent years have many spatial and temporal discontinuities over large sections of East Africa (Ogwang et al., 2014; Schreck & Semazzi, 2004; Shilenje & Ongoma, 2014).

*Table 2: Evaluation and comparison of station data and gridded data sets of CRU and GPCC*

| Dataset | Correlation | RMSE |
|---|---|---|
| CRU | 0.979 | 0.791 |
| GPCC | 0.958 | 0.933 |

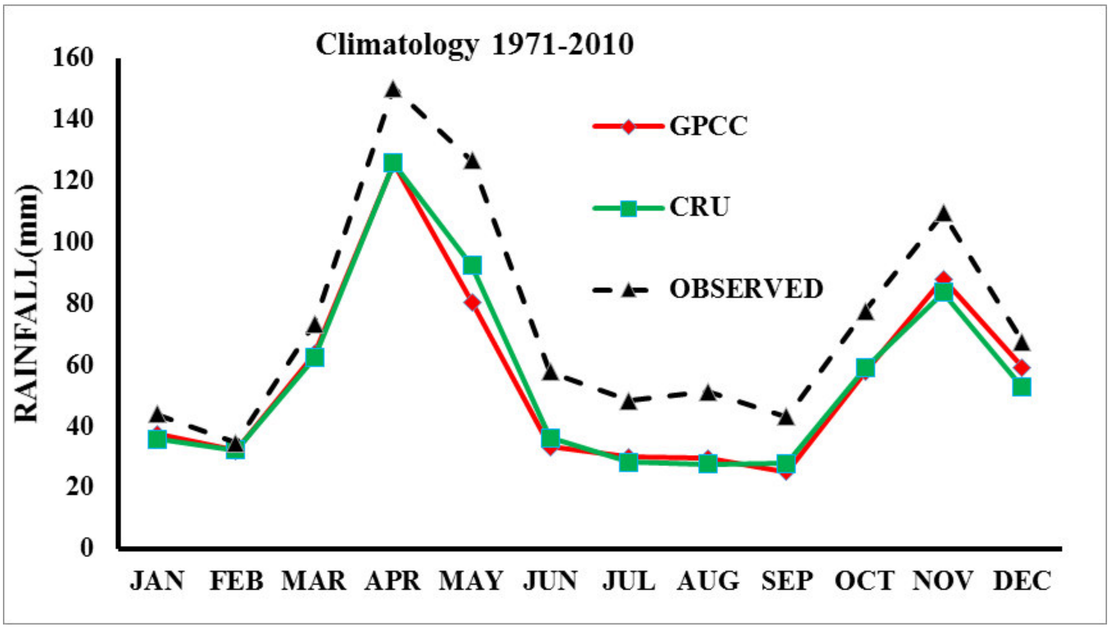


**Fig. 2** Mean monthly for rainfall (RF CLIM) based on CRU, STN and GPCC, Kenya (longitude 34º E - 42º E and latitude 5º S - 5º N), 1971 -2010.

Both data sets demonstrated clear patterns of rainfall seasons as the station data by capturing two rainfall periods in Kenya; the long rainy season with maximum in April and short rainfall in the months of October, November and December throughout the study period (Fig. 2). This similar rainfall trends and patterns have also been confirmed by several other studies using different data sets (Camberlin et al 2003; Semazzi et al 2004; Nicholson, 2014; Opiyo, Nyangito et al 2014; Sako et al., 2012; Shongwe, Greet et al 2010; Stefan et al, 2010; Wenchang et al 2015). From the (Table 2), the correlation coefficient between the CRU data and the observed data is higher compared to the correlation coefficient between GPCC and the observed data. The analysis of Root Mean Square Error (RMSE) in Figure 3 for generating the monthly and annual precipitation over Kenya by use of CRU and GPCC data sets against the station data is lower in CRU as compared to GPCC. This analysis therefore concludes that the CRU performs better than GPCC in generating station data. This supports the previous work done by Ongoma and Chen, (2016).

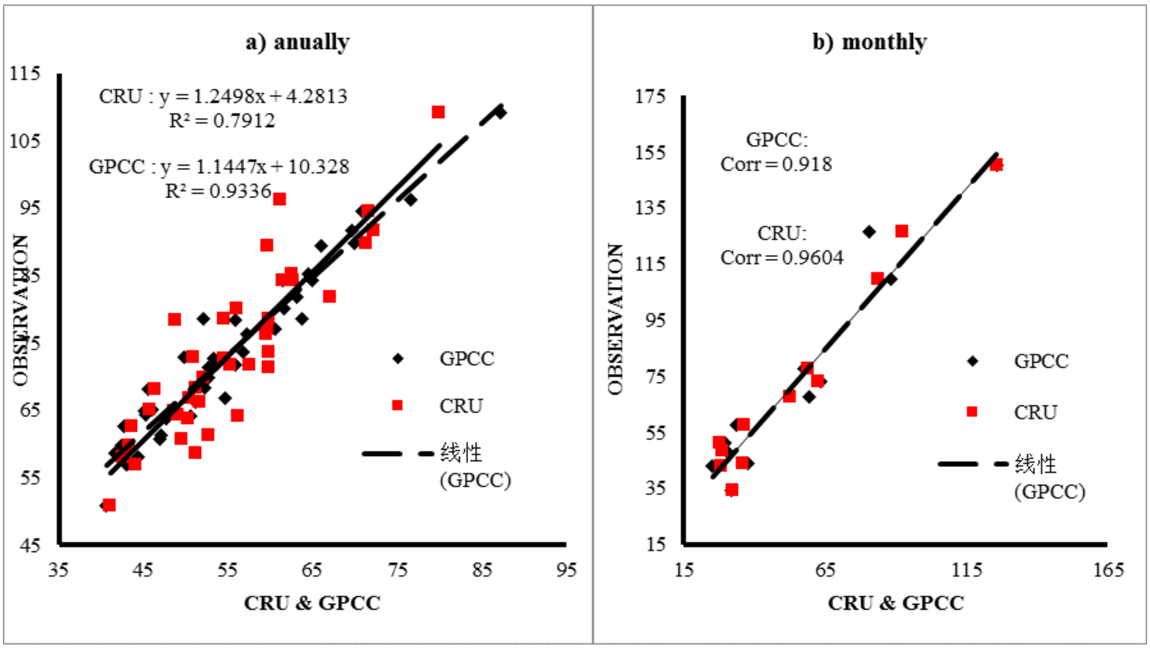


**Fig. 3** Data evaluation and comparison a (annual) and b (monthly) on the best performing gridded data in Kenya based on station data for CRU and GPCC. Test on the correlation coefficient and Root Mean Square Error.

*3.2 Spatiotemporal patterns of rainfall over Kenya*

Analysis for the mean monthly, seasonal and annual precipitation time series from 1971 to 2010 was done. Total rainfall distribution over Kenya for the period of study is demonstrated in Figure 4. Key statistics of data used in the study are shown in Table 4. Maximum mean annual rainfall (2087.0mm) was observed on Kisii station located in Western Kenya climatic zone, while the least mean annual rainfall (203mm) was reported at Lodwar station found Northern Kenya arid climate zone. The highest recorded rainfall within the analysis domain occurred at Kisii location (3673.6mm), while the least was recorded at Lodwar location (54.2mm). The findings also showed that the highest and lowest annual rainfall was recorded in 1997 (1309.1.2mm) and 2000 (609.4mm) respectively. In 1990s, particularly, majority of the stations above average rainfall was recorded. For example, the highest rainfall for 11 stations out of 26 stations was observed in 1997. The lowest recorded values were more concentrated in the 2000s (9 stations) and 1980s (5 stations). This is in agreement with Nicholson, (2014) findings that below average rainfall in equatorial latitudes in the 1970s and 1980s was experienced and reversed patterns in the 1990s as supported by study of (Xie et al. 2015). The rainfall changes per decade as observed demonstrate decreasing trends in Table 3. Drying trend was experienced in 1980s (864.9mm decadal mean rainfall) and 2000 with decadal mean rainfall of 888.0mm (Figure. 5). Positive change in which many stations had highest rainfall was in 1990s (1073.2mm). These findings are in agreement with the spatial distribution of rainfall in East Africa as observed by (Camberlin & Okoola, 2003; Indeje et al., 2000; Ongoma & Chen, 2016; Paul Berrisford, Dick, 2011). A study by Yang et al, (2014) explained that the dying trend of the Kenya's long rains in recent decades is caused by natural decadal variability and not anthropogenic related. The natural causes enlisted in his studies were: decal variability of sea surface temperature (SST) over the Pacific Ocean. The study demonstrated that the dry phases of the Kenya's long rain are associated with positive SST anomalies over the western tropical Pacific and opposite to the eastern parts of the ocean.

Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
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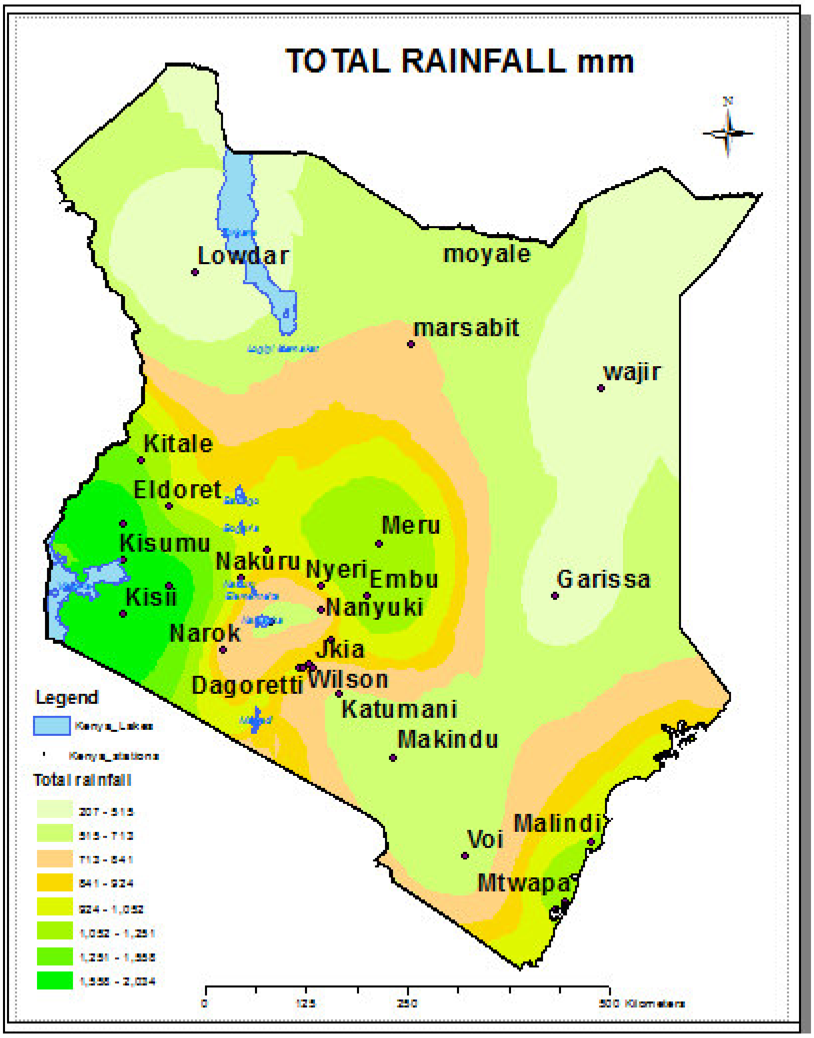


**Fig.4** Spatial distribution of total rainfall climatology based over Kenya (longitude 34º E - 42º E and latitude 5º S - 5º N) based on station data, 1971 -2010.

*Table 3: Decadal change of rainfall over Kenya (longitude 34°E 42°E) and latitude (-5°S 5°N) based on station data, 1971-2010.*

| **Decade** | 1970s | 1980s | 1990s | 2000s |
|---|---|---|---|---|
| **Mean (mm/Decade)** | 864.9 | 895.4 | 1073.2 | 888.0 |

Another studies by Liebmann et al., (2014) reported a decrease in rainfall in during the period of 1979-2005 over East Africa. Recent findings in a study by Williams et al., (2015) related the ongoing drying over East Africa and Kenya specifically to a number of causes which includes anthropogenic forced relatively enhanced warming of Indian Ocean SST, which extends the warm pool and Walker circulation westward, leading to a subsidence anomaly hence drying. The Indian Ocean anomalies causes anticyclonic moisture flow over the study area that disrupts main onshore moisture flows (Yang et al., 2014). A recent study by Tierney et al.,(2015) supported the findings of recent decrease in rainfall over the Greater Horn of Africa (GHA), especially during the long rains by concluding that the observed global warming being the cause and thus anthropogenic forcing.

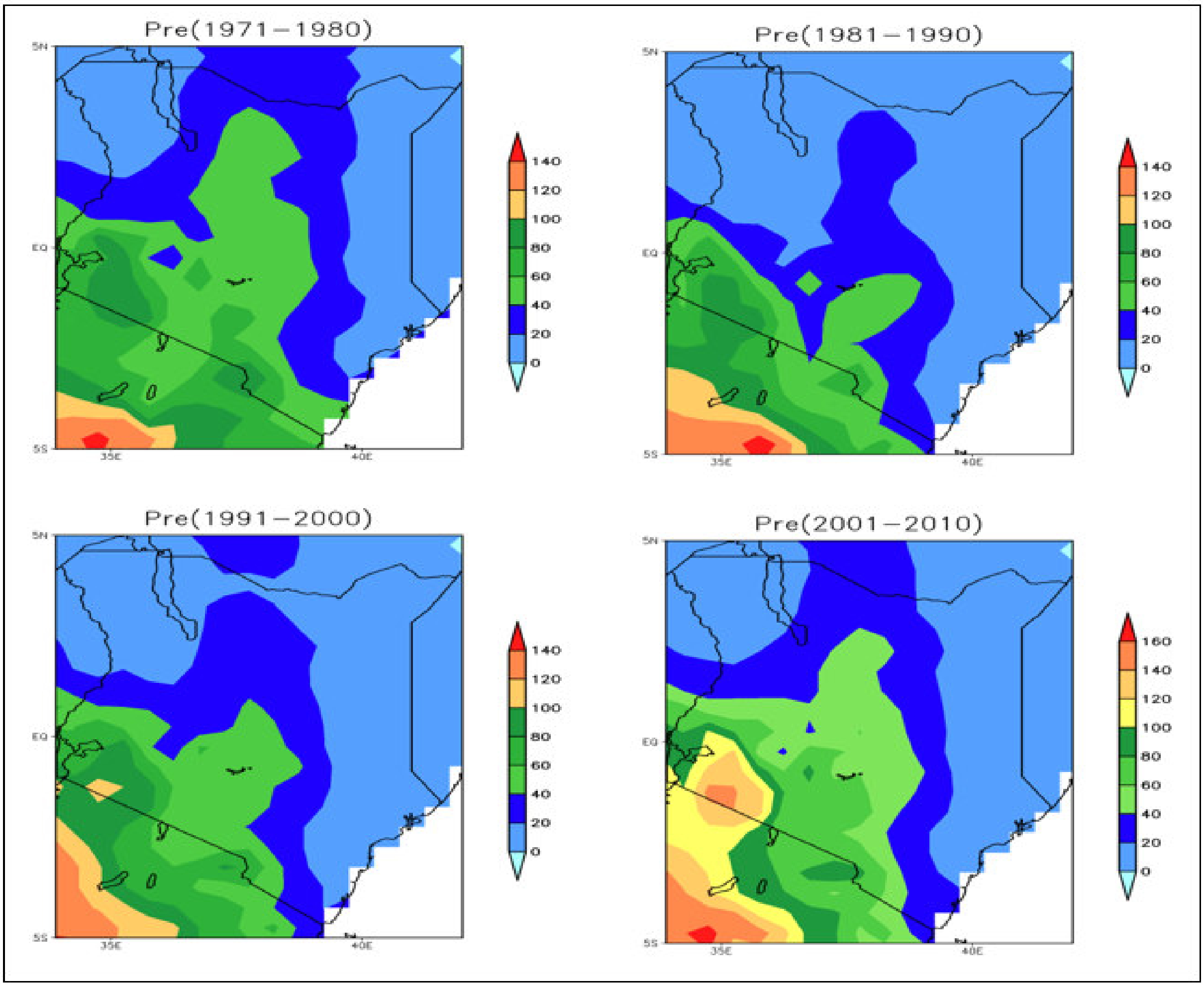


**Fig. 5** Inter-decadal rainfall anomalies over Kenya based on CRU data, 1971 -2010.

Analytical results indicate that the precipitation in the Kenya is not uniformly distributed through time and space. The study area experiences a particular precipitation regime within a year from March to May, with peak in April and September to October with peak in November. This is in agreement with previous studies (e.g. Camberlin & Okoola, 2003; Owiti & Zhu, 2012). A total of 73% of annual precipitation occurs during this period. There is very little rainfall from December to February. An examination of the spatial maps for mean monthly in Fig.ure 9 supports the argument suggested by other scholars that the country receives bimodal rainfall patterns. Moreover, Figure. 8 shows that during the bimodal regime, OND receives less rainfall compared to MAM season (Fig. 7) Temporal distribution of mean monthly precipitation amount in different seasons (Fig. 6) shows that, annually, most of the precipitation occurs in MAM (Fig. 7), with 63.99% of the total annual precipitation occurring in this season. Only about 3.28% of the total annual precipitation occurs in JF. In particular, the rainfall variation (351.0mm) is largest in MAM, and the mean precipitation (875.0mm) in this season is largest. In contrast, the JF season has lowest mean precipitation (78.4mm). The spatial maps for monthly rainfall in Figure 9 (a) and (b) and also the temporal maps (Figure. 6) shows that during January and February, the South and South Western parts of Kenya receives more rainfall than other parts. The rainfall during these months range from 180-200 mm, but during the March, April and May the rain belt has shifted to eastern parts and some parts of Western parts of the country, especially in March. This shift of rain belt is linked to the movement of ITCZ and the presence of water bodies over the regions. June, July, August, September it is slightly drier in most areas where rainfall is less than 50 mm in most of the country. During the October, November and December, some North, North Western part and East Coastal area of the country experience slightly higher rainfall compared to others.

The seasonal migration of the ITCZ mainly controls the seasonality of the rainfall observed in Kenya and East Africa region. Other factors that influence inter annual, seasonal and monthly variability of Kenya's rainfall include: Monsoon winds, subtropical high-pressure systems; (Mascarene High, St. Hellena, Azores, and Arabian Ridge), easterly/westerly waves, tropical cyclones, ENSO, Quasi Biennial Oscillation (QBO), and IOD (Ogwang et al., 2014). These factors are associated with either too much or failure of rainfall which usually results in flood or drought events over the area, respectively (Gamoyoet al 2015). According to Maidment et al.,

(2015) and Torrence, (1999) it is generally believed that the Indian Ocean has much more direct impact that influences the East African rainfall as compared to that of other oceans.

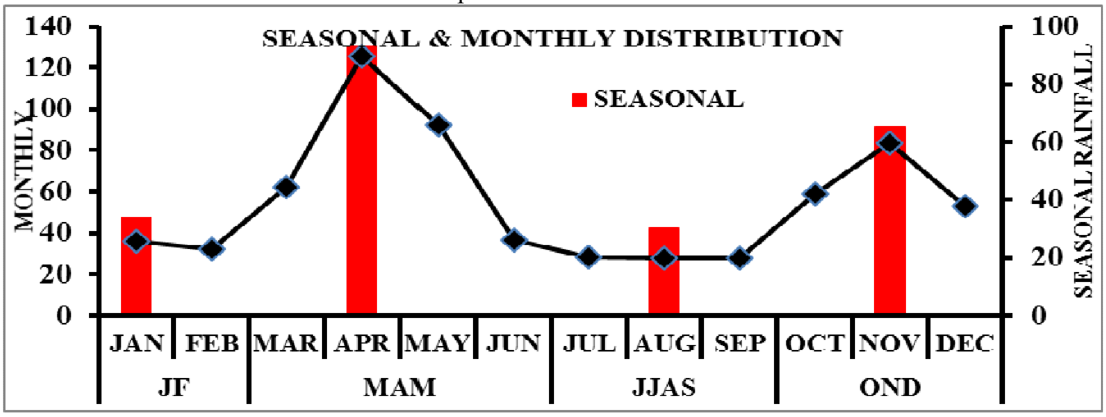


**Fig. 6** Temporal distribution of mean monthly and seasonal rainfall over Kenya (longitude 42º E - 34º E and latitude 5ºS - 5ºN) based on Station data, 1971 -2010

As demonstrated in Figure. 6 bimodal rainfall regimes are experienced in Kenya. The rainfall seasonality results however, reveal a decreasing rainfall trend for MAM season (seasonal mean 93.5) while the OND (Fig. 8) rains with seasonal mean of 65.2mm had a slight decrease for the period 1971-2010. This could be supported by recent studies by Sako et al., (2012) which established that OND rains are becoming more reliable compared to the MAM rainfall seasons in Kenya. This overall increase and decrease can be attributed to the ongoing global warming, coupled with other meso-scale factors, such as land use and land cover changes (Gichangi et al., 2015). The MAM season is the period in which many farmers in Kenya use for crop growing since the economy of the region is mainly dependent on rain fed agriculture hence of great concern (Omondi et al., 2014; Sako et al., 2012).

Inter annual distribution of rainfall amounts in space and time based on total rainfall (Fig. 4) shows those stations around the water bodies region (Lake. Victoria and Indian Ocean) receives above normal rainfall (Western and Coastal) areas compared to Eastern regions which are mainly Arid and Semi-arid lands. This variability of rainfall has a major impact in Kenya. Flooding can be caused by heavy rains in the rainy seasons. The failure of rains to arrive leads to periods of severe drought, especially in the arid and semi-arid regions of northern and eastern Kenya (Manatsa et al., 2014).

**Table 4**: Spatial distribution of mean annual, highest and lowest and rainfall over Kenya (longitude 42º E - 34º E and latitude 5ºS - 5ºN) based on station data, 1971 -2010

| No. | Stations | Mean Annual precipitation | Highest precipitation | Lowest precipitation |
|---|---|---|---|---|
| 1 | **Lodwar** | 203.8 | 714.7 | 54.2 |
| 2 | **Marsabit** | 702.9 | 1469.4 | 99.7 |
| 3 | **Moyale** | 660.4 | 1345.7 | 350.1 |
| 4 | **Garissa** | 356.3 | 724.5 | 117.5 |
| 5 | **Wajir** | 318.6 | 1109.2 | 80 |
| 6 | **Mandera** | 264.5 | 986.7 | 67.2 |
| 7 | **Kakamega** | 1938.9 | 2474.4 | 1394.3 |
| 8 | **Kisii** | 2087.0 | 3673.6 | 1558.2 |
| 9 | **Kisumu** | 1352.8 | 1765.7 | 1112.6 |
| 10 | **Nakuru** | 936.8 | 1372.0 | 602.8 |
| 11 | **Narok** | 739.4 | 1017.8 | 447.9 |
| 12 | **Nyeri** | 955.0 | 1544.8 | 589.8 |
| 13 | **Meru** | 1286.5 | 2219.4 | 597.8 |
| 14 | **Nanyuki** | 647.7 | 967.8 | 287.1 |
| 15 | **Dagoretti** | 1005.7 | 1549.3 | 482.7 |
| 16 | **Wilson** | 888.8 | 1475.5 | 511.8 |
| 17 | **JKIA** | 720.8 | 1226.4 | 325.1 |
| 18 | **Makindu** | 569.8 | 990.6 | 226 |
| 19 | **Voi** | 560.3 | 1118 | 210 |
| 20 | **Lamu** | 993.6 | 2262.8 | 466.8 |
| 21 | **Malindi** | 1051.8 | 1712.2 | 662.9 |
| 22 | **Mombasa** | 1059.9 | 2244.0 | 544.0 |
| 23 | **Thika** | 936.9 | 1598.8 | 356.8 |
| 24 | **Naivasha** | 656.8 | 917.2 | 336.0 |
| 25 | **Nyahururu** | 979.6 | 1414.1 | 426.9 |
| 26 | **Eldoret** | 1053.3 | 1615.3 | 619.2 |

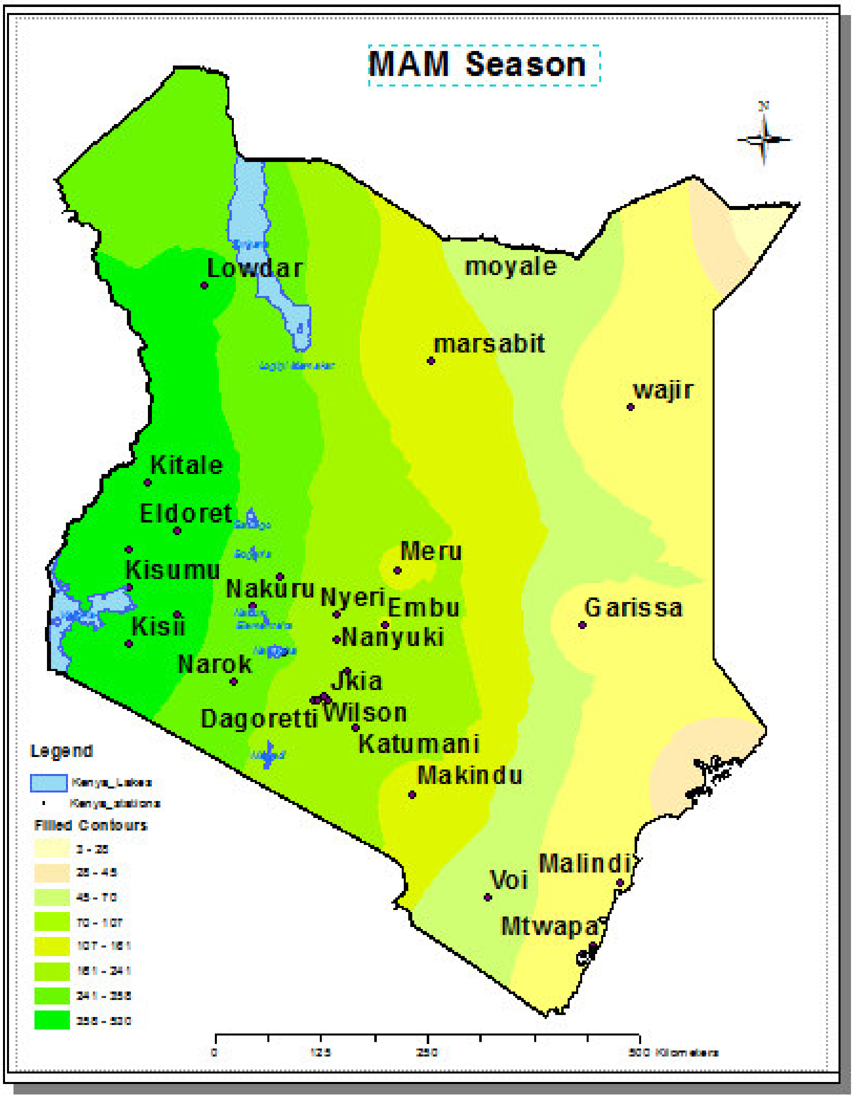


**Fig. 7** Spatial patterns of seasonal rainfall MAM over Kenya (longitude 42º E - 34º E and latitude 5ºS - 5ºN) based on Station data, 1971 -2010

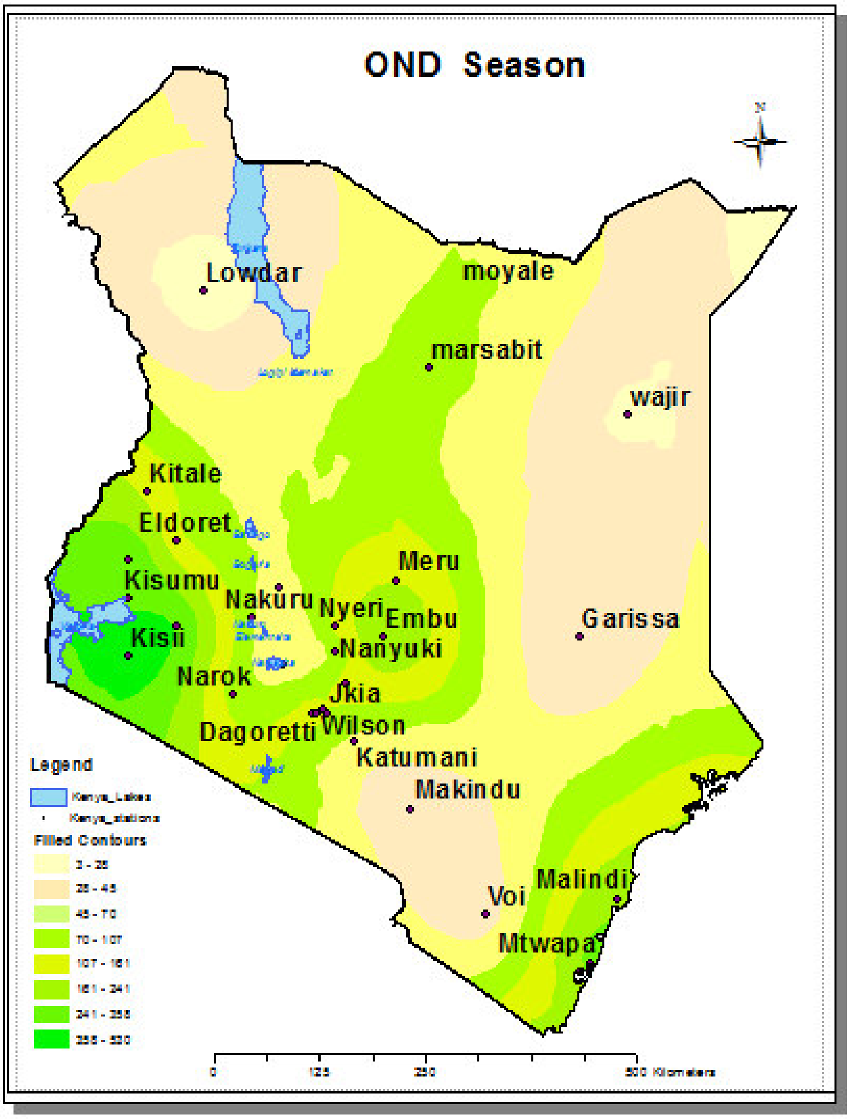


**Fig. 8** Spatial patterns of seasonal rainfall OND over Kenya (longitude 42º E - 34º E and latitude 5ºS - 5ºN) based on Station data, 1971 -2010

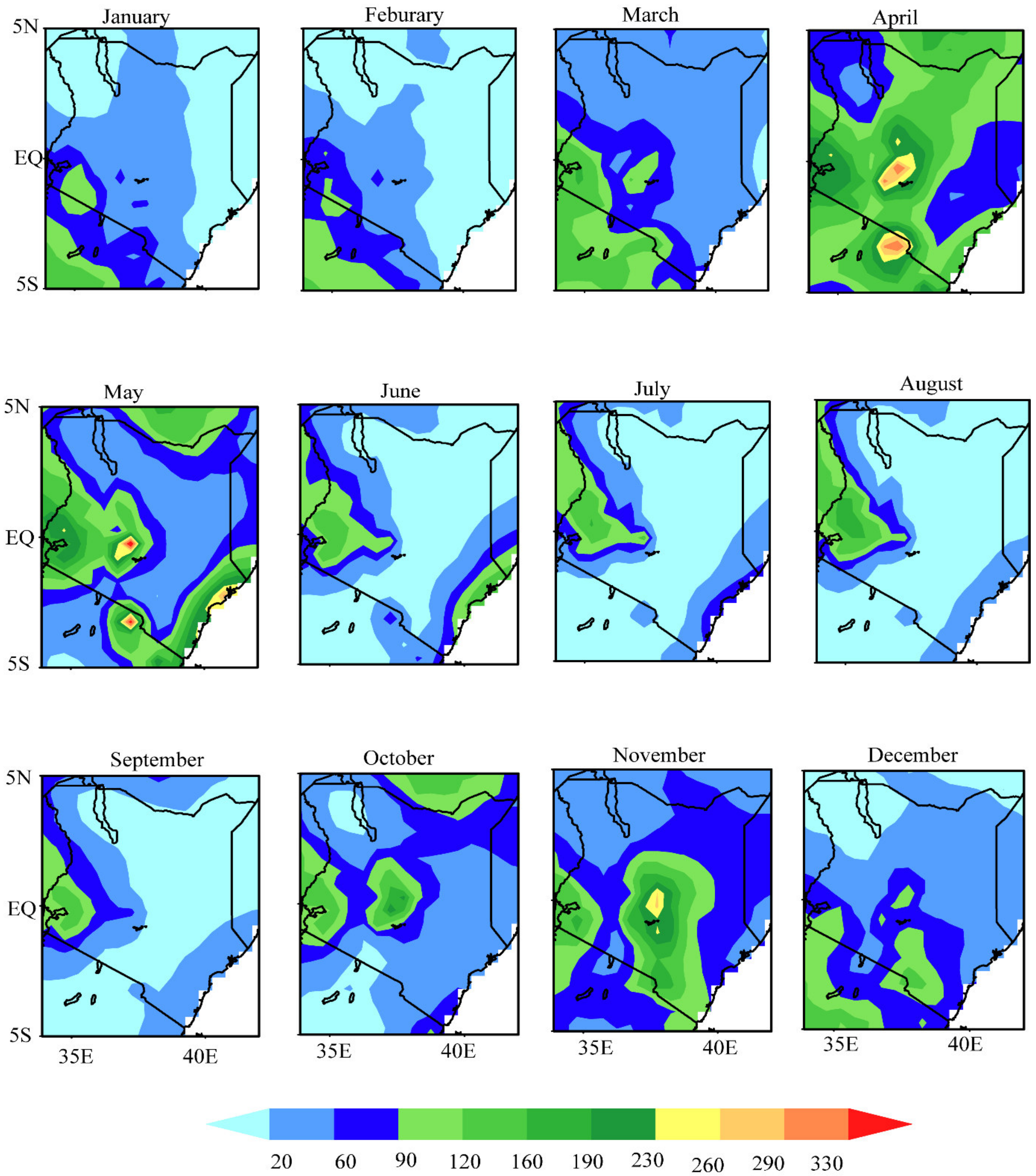


**Figure 9** Spatial patterns for mean monthly rainfall over Kenya (longitude 34º E - 42º E and latitude 5º S - 5º N) based on CRU data – 1971-2010.

## 4. Conclusion and Recommendation

The study evaluated both temporal and spatial distribution patterns of rainfall from 26 stations in Kenya for the period of 1971-2010. The analysis results provide further knowledge to improve our understanding on climate change in Kenya. It would be useful for future planning and management of water resources safely in Kenya, especially under the background of global warming. In the study, the following conclusions were arrived at:

The mean annual precipitation of Kenya has experienced four states: decrease (1971-1980), decrease (1981-1990), increase (1991-1999) and decrease in (2000-2010). The decade with most precipitation was in 1990s.

The annual precipitation increased from South West towards highlands and central parts of the country. Similarly, the seasonal precipitation values have the same phenomenon. With respect to mean annual precipitation, maximum mean annual rainfall (2087.0mm) was observed on Kisii station located in Western

Kenya climatic zone, while the least mean annual rainfall (203mm) was reported at Lodwar station found Northern Kenya arid climate zone. The highest recorded rainfall within the analysis domain occurred at Kisii location (3673.6mm), while the least was recorded at Lodwar location (54.2mm)

A noticeable decrease in March April and May (MAM: 95.5.0mm) and slight increase in October to December (OND: 65.3mm) was the trend in Kenya. The MAM season is the period in which many farmers in Kenya use for crop growing since the economy of the region is mainly dependent on rain fed agriculture hence of great concern.

**5. Acknowledgement**

This manuscript represents part of the Masters dissertation of the first author who acknowledges sources of data used as provided by the Kenya Meteorological Department, Climate Research Unit (CRU) and Global Precipitation Climate Centre (GPCC). The author expresses appreciation to the Chinese

Scholarship Council (CSC) for the financial support and also thank Nanjing University of Information Science and Technology (NUIST) for providing perfect environment that foster research.

**References**

Almazroui, M. et al., 2012. Recent climate change in the Arabian Peninsula: Seasonal rainfall and temperature climatology of Saudi Arabia for 1979-2009. *Atmospheric Research*, 111, pp.29–45. Available at: http://dx.doi.org/10.1016/j.atmosres.2012.02.013.

Arnell, N.W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14(1), pp.31–52.

Camberlin, P. & Okoola, R.E., 2003. The onset and cessation of the "' long rains '" in eastern Africa and their interannual variability. *Theoretical and Applied Climatology*, 54(1–2), pp.43–54.

Camberlin & Okoola, 2003. The onset and cessation of the "' long rains '" in eastern Africa and their interannual variability. *Theoretical and Applied Climatology*, 54(1–2), pp.43–54.

Christy, J.R., Norris, W.B. & McNider, R.T., 2009. Surface temperature variations in east Africa and possible causes. *Journal of Climate*, 22(12), pp.3342–3356.

Clark, C.O., Webster, P.J. & Cole, J.E., 2003. Interdecadal Variability of the Relationship between the Indian Ocean Zonal Mode and East African Coastal Rainfall Anomalies. *Journal of Climate*, 16, pp.548–554.

Cook, K.H. & Vizy, E.K., 2013. Projected Changes in East African Rainy Seasons. *Journal of Climate*, 26, pp.5931–5948.

Daron, JD (2014) "Regional Climate Message: East Africa". Scientific report from the CARIAA Adaptation at Scale in Semi-Arid Regions (ASSAR) Project, D. 2014, 2014. *Daron, JD (2014) "Regional Climate Message: East Africa". Scientific report from the CARIAA Adaptation at Scale in Semi-Arid Regions (ASSAR) Project, December 2014*,

F.N.W Nsubuga, J. M. Olwoch, C.J. deW. R.O.. B., 2014. Analysis of mid-twentieth century rainfall trends and variability over southwestern Uganda. *Theoretical and Applied Climatology*, 115, pp.53–71.

Gallego, M.C. et al., 2011. Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century. *Journal of Geophysical Research*, 116, pp.1–18.

Gamoyo, M., Reason, C. & Obura, D., 2015a. Rainfall variability over the East African coast. *Theoretical and Applied Climatology*, 120, pp.311–322.

Gamoyo, M., Reason, C. & Obura, D., 2015b. Rainfall variability over the East African coast. *Theoretical and Applied Climatology*, 120(1–2), pp.311–322.

Gichangi, E.M. et al., 2015. Assessment of climate variability and change in semi-arid eastern Kenya. *Climatic Change*, pp.287–297.

González-Hidalgo, J.C., Brunetti, M. & de Luis, M., 2011. A new tool for monthly precipitation analysis in Spain: MOPREDAS database (monthly precipitation trends December 1945-November 2005). *International Journal of Climatology*, 31(5), pp.715–731.

Guirong, T., Ogwang, B.A. & Ngarukiyimana, J.P., 2015. Diagnosis of Seasonal Rainfall Variability over East Africa : A Case Study of 2010-2011 Drought over Kenya. *Pakistan Journal of Meteorology*, 11(22), pp.13–21.

Harris, L. & Elliott, T.L., 2016. Harris et al. 2014. *ECOSPHERE*, 5(9).

Held, I.M. & Soden, B.J., 1995. Robust responses of the hydrologic cycle to global warming. *J. Clim.*, 19, pp.5686–5699. Available at: http://dx.doi.org/10.1175/JCLI3990.1.

Hulme, M. et al., 2001. African climate change: 1900-2100. *Climate Research*, 17(2 SPECIAL 8), pp.145–168.

Iii, C.J.S. & Semazzi, F.H.M., 2004. Variability of the recent climate of eastern africa. *International Journal of Atmospheric Sciences*, 24, pp.681–701.

Indeje, M., Semazzi, F.H.M. & Ogallo, L.J., 2000. ENSO signals in East African rainfall seasons. *International Journal of Climatology*, 20(1), pp.19–46.

IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assesment Report of the Intergovernmental Panel on Climate Change [Core Wrting Team, Pachauri, R.K and Reisinger, A.(eds)]. IPCC, Geneva, Switzer, P., 2007. *IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assesment Report of the Intergovernmental Panel on Climate Change [Core Wrting Team, Pachauri, R.K and Reisinger, A.(eds)]. IPCC, Geneva, Switzer*,

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assesment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer(eds).] IPCC, Geneva, Switzerlan, 151 pp, 2014. *IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assesment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer(eds).] IPCC, Geneva, Switzerlan*,

IPCC, 2014: Summary for policymakers. In:Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Fi, pp. 1-32, 2014. *IPCC, 2014: Summary for policymakers. In:Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Fi*,

Liebmann, B. et al., 2014. Understanding recent eastern Horn of Africa rainfall variability and change. *Journal of Climate*, 27(23), pp.8630–8645.

Liu, B., Xiao, C. & Liang, X., 2015. Evaluation of spatial and temporal characteristics of precipitation variations in Jilin Province , Northeast China. *Theoretical and Applied Climatology*, 122, pp.129–142.

Maidment, R.I. et al., 2015. Recent Observed and Simulated Chnages in precipitation over Africa. *Geophysical Research Letters*, pp.1–10.

Manatsa, D. et al., 2014. Impact of Mascarene High variability on the East African “short rains.” *Climate Dynamics*, 42(5–6), pp.1259–1274.

Mcsweeney, C., New, M. & Lizcano, G., General Climate. *Tyndall centre for Climate Change Research*, pp.1–26.

Mooley, D.A. & Parthasarathy, B., 1984. Fluctuations in All-India summer monsoon rainfall during 1871-1978. *Climatic Change*, 6(3), pp.287–301.

Nicholson, S.E., 2014. A detailed look at the recent drought situation in the Greater Horn of Africa. *Journal of Arid Environments*, 103, pp.71–79. Available at: http://dx.doi.org/10.1016/j.jaridenv.2013.12.003.

Ogwang, B.A. et al., 2014. The influence of Topography on East African October to December climate : Sensitivity experiments with RegCM4 Key Laboratory of Meteorological Disaster , Ministry of Education , Nanjing University of E-mail Addresses : bob_ogwang@yahoo.co.uk ( Bob Alex Og. *Advanced Meteorology*, 2014, pp.1–27.

Omondi, P.A. et al., 2014. Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010. *International Journal of Climatology*, 34(4), pp.1262–1277. Available at: http://doi.wiley.com/10.1002/joc.3763.

Ongoma, V. & Chen, H., 2016. Temporal and spatial variability of temperature and precipitation over East Africa from 1951 to 2010. *Meteorology and Atmospheric Physics*. Available at: "http://dx.doi.org/10.1007/s00703-016-0462-0.

Opiyo, F. et al., 2014. Trend Analysis of Rainfall and Temperature Variability in Arid Environment of Turkana, Kenya. *Environmental Research Journal*, 8(2), pp.30–43.

Owiti, Z. & Zhu, W., 2012. Spatial distribution of rainfall seasonality over East Africa. *Journal of Geography and Regional Planning*, 5(15), pp.409–421.

Parry, J.-E. et al., 2012. Climate Risks, Vulnerability and Governance in Kenya: A review. , p.83. Available at: http://www.preventionweb.net/files/globalplatform/entry_bg_paper~keynaclimaterisksvulnerabilityandgovernanceinkenyaareviewiisdundpjan13.pdf.

Partal, T. & Kahya, E., 2006. Trend analysis in Turkish precipitation data. *Hydrological Processes*, 20(9), pp.2011–2026.

Paul Berrisford, Dick Dee, P.P. and A.S., 2011. *A full list of ECMWF Publications can be found on our web site under : Contact : library@ecmwf.int Date August 2009 October 2011 Version Comments Original version • Addition of vertical integrals • Enhanced web-based data services • Extension of ERA-Inter*,

Sako, C.. et al., 2012. Determination of seasonal rainfall variability , onset and cessation in semi-arid Tharaka district , Kenya. *Theoretical and Applied Climatology*, 108, pp.479–494.

Schreck, C.J. & Semazzi, F.H.M., 2004. Variability of the recent climate of eastern Africa. *International Journal of Climatology*, 24(6), pp.681–701.

Shilenje, Z.W. & Ongoma, V., 2014. Observed surface ozone trend in the year 2012 over Nairobi, Kenya.

*Atmosfera*, 27(4), pp.377–384. Available at: http://dx.doi.org/10.1016/S0187-6236(14)70036-0.

Shongwe, M.E., Greet Jan Van OldernBorgh & Hurk, B. Van Den, 2010. Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming . Part II : East Africa. *Journal of Climate*, 24, pp.3718–3733.

Stefan, H., Polzin, D. & Mutail, C., 2010. Circulation Mechanisms of Kenya Rainfall Anomalies. *Journal of Climate*, 24, pp.404–412.

Tierney, J.E., Ummenhofer, C.C. & Peter, B., 2015. Past and future rainfall in the Horn of Africa. *Research Article Climatology*, (October), pp.1–9.

Torrence, C. and P.J.W., 1999. Interdecadal Changes in the ENSO – Monsoon System. *Journal of Climate*, 12, pp.2679–2690.

Wenchang, Y., Richard, S. & Cane, M.A., 2015. The Annual Cycle of East African Precipitation. *Journal of Climate*, 28, pp.2385–2404.

Williams, K. et al., 2015. Regional climate model performance in the Lake Victoria basin. *Climate Dynamics*, 44(5–6), pp.1699–1713.

Xie, S.-P. et al., 2015. Towards predictive understanding of regional climate change. *Nature Clim. Change*, 5(10), pp.921–930. Available at: http://dx.doi.org/10.1038/nclimate2689.

Yang, W. et al., 2014. The East African long rains in observations and models. *Journal of Climate*, 27(19), pp.7185–7202.

Yuan, Z. et al., 2014. Temporal and spatial variability of drought in Huang-Huai-Hai River Basin, China. *Theoretical and Applied Climatology*, (January 2011), pp.755–769.