Recent Rainfall Trends and Variability in Sudano- Sahelian Region of Nigeria (1986- 2015)

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Abstract

It was speculated that the droughts of the 1970s and 1980s that ravaged the Sahelian region of West Africa had ended following the occurrence of floods of different magnitudes in the last fifteen years or so which necessitated the need to re-examine the rainfall conditions in the region. Monthly rainfall data of five meteorological stations in the region were collected from the Nigerian Meteorological Agency (NiMet) over the period 1986-2015 and analyzed for trends and variability using linear regression model and coefficient of variation (C.V.%). A significant upward trend was found in annual regional rainfall composite of the region with similar patterns in annual rainfall series at all selected stations except Sokoto. The patterns of annual rainfall trend at individual stations did not reflect the patterns in their individual months. Further result showed that, annual rainfall was less variable in 1996-2005 decade at both Sokoto and Nguru stations while it was highly variable at Kano and Nguru in 1985-1995 decade. The observed rainfall patterns could be linked to dynamics of rain-producing systems in the region. The study has contributed to a deeper understanding of the recent changing rainfall patterns in the Sudano-Sahelian region of Nigeria. The implication of this study is that the climate change adaptation and mitigation policies designed based on apparent decline in rainfall from the late 1960s through 1980s need to be revisited and possibly replaced with new ones reflecting the current reality of increased rainfall in the region.

Keywords: trends, variability, rainfall anomalies, floods, ITD, Sahelian Region

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Introduction

Rainfall is the most critical element of weather and climate that directly affects rain-fed agriculture and water resources development especially in tropical Africa, therefore, it is not surprising that much has been said about its synoptic origin (Kamara, 1986; Adelekan, 1998); annual and seasonal variations (Anyadike, 1992, 1993; Olaniran and Sumner, 1990; Adejuwon, Balogun and Adejuwon,1990; Aondover and Woo, 1998; Ati, Stigter, Iguisi and Afolayan, 2009; Udjugo, 2005; Umar and Ismaila, 2017); onset and cessation (Bello, 1996, 1997; Olaniran and Sumner, 1989; Usman and Abdulkadir, 2013) and rainfall anomalies and their causal mechanisms (Adedoyin, 1989; Nicholson and Kim, 1997; Olaniran, 1991). The thrusts of these studies suggest that the Sahelian region of Africa in the late 1960s through 1970s and 1980s had experienced droughts of various magnitudes that ravaged the region resulting from protracted decline in rainfall. This has led to further examination of rainfall records of the region with most of the attention concentrated on annual rainfall trends and variability (Adefolalu, 1986; Hulme, 1992; Ayoade and Bamwo, 2007; Oguntunde, Babatunde and Leschied, 2011; Jury, 2013).

Nicholson (2005) examined the question of the "recovery" of rains in the West African Sahel using seasonal and August rainfall time series over the period 1998-2003 for eight zones within latitudes 12^0 N to 20^0 N. The study showed that, in the three zones to the south, seasonal totals exceeded the long-term means in all years and the conditions were comparable to or wetter than those during the wet decade of the 1950s. The wettest years were 1998, 1999 and 2003 respectively. Using rainfall variability index, Oguntunde *et al* (2011) examined the spatio-temporal patterns of rainfall in Nigeria over two climatic periods—1931-1960 and 1961-1990—and this showed that annual precipitation was reduced by 7% between the two periods. The study further demonstrated that while more than 90% of Nigerian landscape showed no significant rainfall change during the 1931-1960 period, about 57% of Nigeria showed a significant decrease during the 1961-1990 period.

Jury (2013) investigated a return to wet conditions over Africa from 1995-2010 using hydro-climatic and satellite-based data from various sources. The study concluded that major rivers such as Niger and Zambezi had reached their flow levels last seen in the 1950s (2,000 and 5,000 $m^3\ s^{-1}$, respectively) while rainfall across the Congo Basin increased steadily +0.16mm day $^{-1}$ year $^{-1}$. The study further showed that diurnal summer rainfall had increased three-fold over the 1995-2010 period in conjunction with a strengthened land-sea temperature contrast, onshore flow and afternoon uplift. Sanogo, Andreas, Omotosho, Abdramane and Robert (2015) examined the spatio-temporal characteristics of the recent rainfall recovery in West Africa using daily(monthly) rainfall data from 167(254) stations across West Africa over the period 1980-2010 and the gridded African Rainfall Climatology Version 2 (ARC2) for the period 1983-2010. The study revealed that majority of the stations in the Sahel between the West Coast and 15^0E showed a statistically significant positive rainfall trend for annual totals. The August-October period exhibited the largest rainfall recovery in the Sahel and the date of the retreat of the rainy season significantly moved later into the year by 2 days decade^{-1}. The study also argued that the recovery was reflected both in more rainy days associated with longer wet spells duration and more extreme rainfall events. From the foregoing, it is evidently clear that climatic anomalies of the 1970s and 1980s that were characterized by prolonged rainfall deficits that led to droughts had gradually changed to positive rainfall recovery especially in the West African Sahel.

Hence the need to re-examine trends and variability with a view to updating the state of knowledge on rainfall conditions especially given the frequency and intensity of seasonal floods that had been widely reported in different parts of the West African Sahel in the last fifteen years or so. The aim of this paper is to examine the recent rainfall trends and variability in Sudano-Sahelian region of Nigeria from 1986-2015.

Conceptual Model for the Study

The conceptual model adopted for this study is the Intertropical Discontinuity (ITD) model developed by Ilesanmi (1971) and slightly modified by Ojo (1977). The Sudano-Sahelian region of Nigeria, like other parts of the country, enjoys a tropical continental climate characterized by two distinct rainy seasons viz: the wet season and dry season. The country receives rainfall from the south westerlies emanating from the Gulf of Guinea coast. This moist air stream is overlain by the northeast trades which originate from above the Sahara and therefore are dry and dust laden. The zone of contact of the two air masses at the surface is a zone of moisture discontinuity and it is known as the Intertropical Discontinuity (ITD) which advances inland as far as 22-25^0 N in August at the margin of the Sahara. This is considerably beyond Nigeria's northern border (Ayoade, 2011). The ITD does not retreat equatorward beyond 4^{0}N latitude during the 'Harmattan' dry season (see Odekunle, Oniarah and Sholademi, 2008; Ayoade, 2011). The five weather zones that are associated with the ITD over Nigeria are illustrated in Figure 1, below.

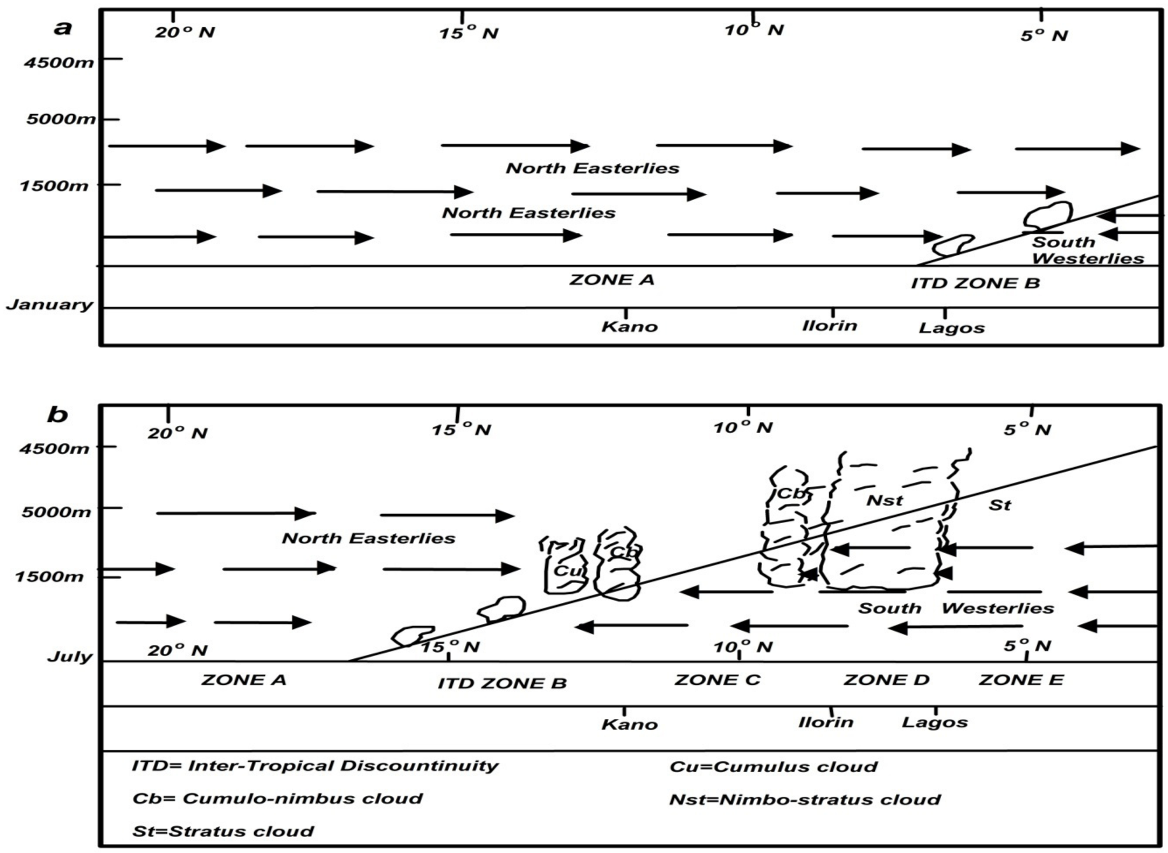

Figure 1: The ITD and the weather zones in an idealized atmospheric cross-section from South to North over Nigeria
Source: Ojo, 1977

Zone A lies to the north of the ITD and hence is rainless as well as zone B to the immediate south because both zones do not contain rain-producing clouds. Rainfall in the ITD occurs in zones C and D where conditions favour the development of clouds of great vertical extent. Thunderstorms and squall lines are associated with zone C and monsoon rains with zone D weathers. Consequently, rainfall is spatially discontinuous when zone C weather prevails. On the other hand, the monsoon system gives continuous rains which may last 12 hours or more (see Olaniran, 1991, 1995). Overall, rainfall occurs at a distance of about 500km south of the surface location of the ITD, 4-6 weeks later in its annual cycle. When the fifth weather type associated with the ITD i.e. zone E, prevails over an area, light rainfall usually occurs because Zone E weather is dominated by layered stratiform clouds. The amount, seasonal distribution, type of rainfall, and the length of the rainy season as well as the general weather conditions experienced in the course of the year, at any given location in the West African region, depend primarily on its location, relative to the position of the ITD and the associated weather zones (Ayoade, 1995).

Materials and Methods

Monthly rainfall data for Sokoto, Kano, Katsina, Maiduguri and Nguru meteorological stations located in the Sudano-Sahelian region of Nigeria (see Figure 2) were collected from the Nigerian Meteorological Agency (NiMet) Nigeria, for the period 1986-2015.

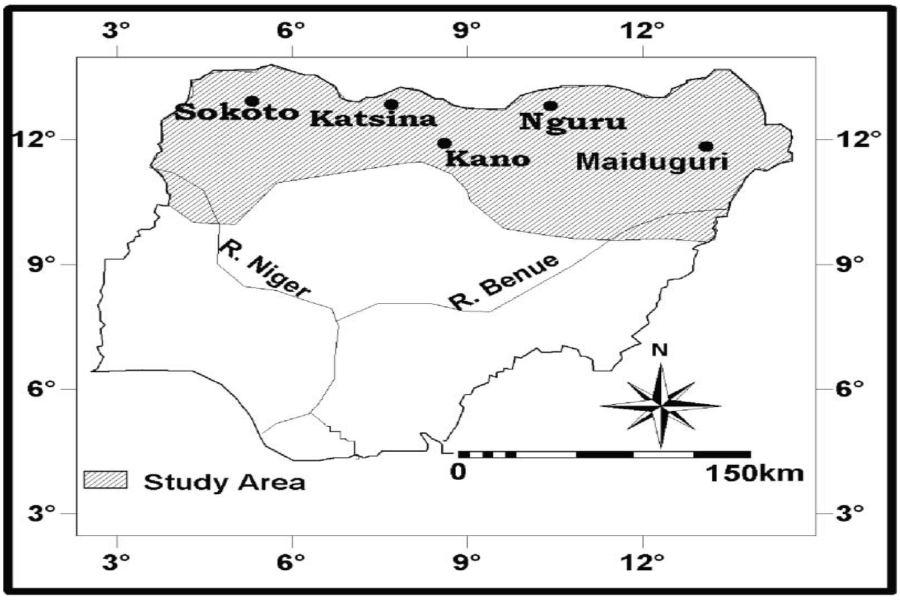

Figure 2. Generalized map showing the areal entent of the Sudano-Sahelian region of Nigeria
Source: Odekunle et al, 2008

The annual and monthly rainfall trends were analyzed using the simple linear regression model where the values in the time series (y) were regressed on time (x). The equation of the line of best fit was then computed using the least square criterion by which the sum of squares of the deviation of each observation from the trend line was minimized. The equation is as follows:

$Y = a + b\bar{x} Y = a + b\bar{x}$ +e ………………………(1)

Where $\boldsymbol{a}$ = intercept of the regression, $\boldsymbol{b}$ = regression coefficient and $\boldsymbol{e}$ = error term or residuals of the regression. For monthly rainfall trends, the months of April to October were selected for each year and for each station since this is the period when the rainy season lasts in the Sudano-Sahelian region of Nigeria. The annual rainfall trend for the entire Sahelian region of Nigeria was analyzed using yearly averages for the five selected stations over the period 1986-2015. Fluctuations in annual rainfall series at each station and for the region as a whole were generated and filtered using a 3-year running mean in order to smoothen out variations in annual rainfall on time scale of less than 3 years over the period of the study.

The inter-decadal variability in annual rainfall was analyzed using the *Coefficient of Variation* (C.V.%) – which is the standard deviation standardized by the mean. The adoption of the coefficient of variation in this study followed the argument put forward by Hulme (1992) that, since the standard deviation closely covaries with the mean rainfall, the difference between, or ratio of, two standard deviations is not necessarily the best measure to use when mean rainfall conditions are themselves changing, and instead, a measure of *relative* variability- a coefficient of variation (C.V.%) be used to represent changes in rainfall reliability. The coefficient of variation (C.V.%) is defined as follows:

$$\delta / \bar{x} \; X \; 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where δ is the standard deviation and $\bar{x}$ is the mean of the series

Results and Discussions

Mean Monthly Rainfall Distribution Patterns in the Sudano-Sahelian Region of Nigeria

Prior to examining the trends in monthly and annual rainfall series in Sudano-Sahelian region of Nigeria, the mean monthly rainfall distribution patterns for the selected stations and for the entire region was generated and presented in Figure 3.

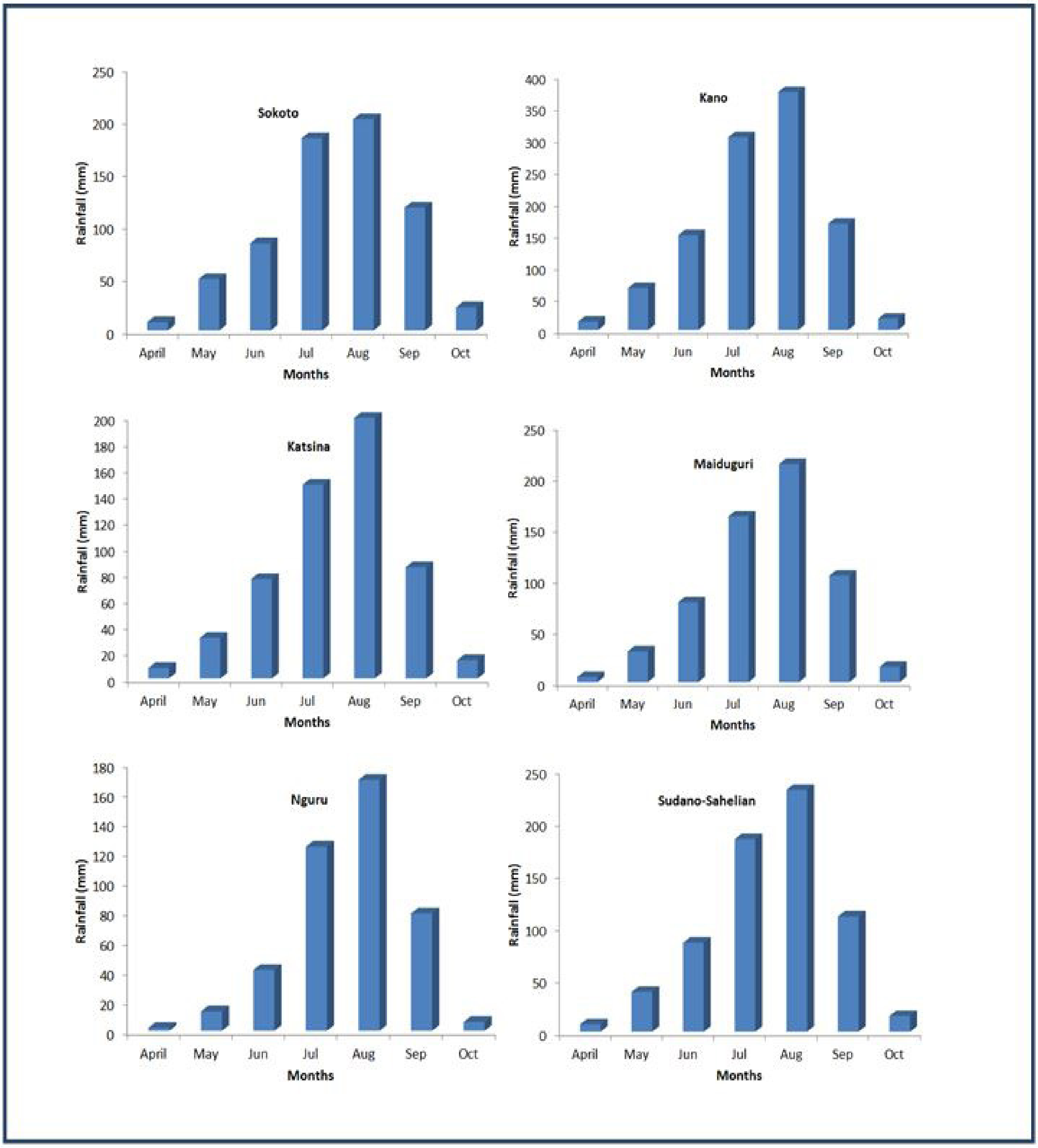

Figure 3: Mean monthly rainfall distribution patterns for selected stations and entire Sudano-Sahelian Region (*Source: Authors' Field work, 2018)*

The patterns of the mean monthly rainfall distribution presented in Figure 3 lend credence to earlier studies carried out individually by Balogun (1981) and Omotosho (1984) who studied the spatial and seasonal variations of thunderstorms and line squalls over Nigeria and West Africa respectively. These studies have shown that the major rain-producing systems, thus, the thunderstorms and line squalls, for Sahelian stations located between latitude 12^0 N – 14^0N had single maxima. The month of August which is the peak of their occurrences could explain the consistency in the occurrence of 'single rainfall maxima' in the rainiest month (i.e. August) at each of the stations and for the entire Sahelian region of Nigeria. Fontain, Janicot and

Moron (1995) also showed higher concentration of such synoptic disturbances in August after investigating the rainfall anomaly patterns and wind-field signals over West Africa in August over the period 1958-1989.

It is interesting to note that this is the period when the Intertropical Discontinuity (ITD) also attains its northernmost position around latitude 22^0 N and the whole country comes under the influence of rain-bearing south-westerly air mass as extensively discussed by Ayoade (1983). It should however be noted that, the period of relative rainfall minimum (April-May-June) and (September-October) observed at each station and for the entire region as shown in Figure 3, is due to the nature of occurrence of the onset and cessation of the rains in the region. This could be attributed to the gradual northward advance of the intertropical discontinuity (ITD) from January/February and its rapid southward retreat from August/September as extensively discussed in the literature (Ayoade, 1983, 2011; Sanogo *et al*, 2015). Olaniran and Sumner (1989) examined the climatic variability in Nigeria based on the onset, retreat and length of the rainy season over the period 1919-1987 and found among other things (such as, quasi-triennial and quasi-6-year oscillations in the series of retreat of rainfall, while that for rainy season length displayed quasi-biennial and quasi-triennial oscillations), that for the Sahelian region Lat. 12^0 N - 14^0 N, the mean dates of onset and cessation of the rain are June 15 (±3) and September 20 (±2) respectively.

Annual Rainfall Fluctuations in the Sudano-Sahelian Region of Nigeria

Fluctuations in annual rainfall series have previously been examined for different parts of West African sub-region by several climate scientists due to largely devastating droughts that afflicted the region from late 1960s through 1980s. Olaniran and Sumner (1990) examined the long-term variations of annual and growing season rainfall for the Coastal, Guinea Savanna, the Midland and Sahel zones of Nigeria using power-spectral, low pass filter techniques and Kendall tau statistic. They found among other things (i.e. quasi-periodic oscillations in the annual and growing season rainfall series are concentrated in four spectral bands: 2.0–2.4, 2.7–2.9, 3.2–3.6 and 5.6–6.3 years) that, areas north of latitude 9^0 N (Sokoto, Kano, Katsina, Nguru and Maiduguri inclusive) had experienced progressive decline in annual and growing season rainfall over the period 1939-1985. Adejuwon *et al* (1990) also analyzed monthly rainfall data for sixteen meteorological stations in Nigeria for evidence of trends and periodic fluctuations. It was revealed that, for all the series analyzed, there was a general tendency towards increasing aridity over the period 1922-1985.

The extent and nature of non-random changes such as fluctuations, trend and persistence in seasonal rainfall series have also been investigated for the Southern, Middle Belt and Northern zones of Nigeria from 1916-187. The results showed a tendency towards decreasing seasonal rainfall totals in all the regions, though only those for the northern region and the country as a whole were statistically significant (Anyadike, 1992). A careful examination of the various results of the aforementioned studies on rainfall fluctuations and several others not reported in this study showed that, the rainfall data used did not exceed the 1980s decade. Therefore, could not capture the recent rainfall conditions particularly after the droughts of the 1980s that ravaged the West African sub-region. The present study provides opportunity to update our understanding of the current rainfall conditions in Sudano-Sahelian region of Nigeria. Fluctuations in annual rainfall series for five selected stations and for the entire Sudano-Sahelian region of Nigeria were generated and presented in Figure 4.

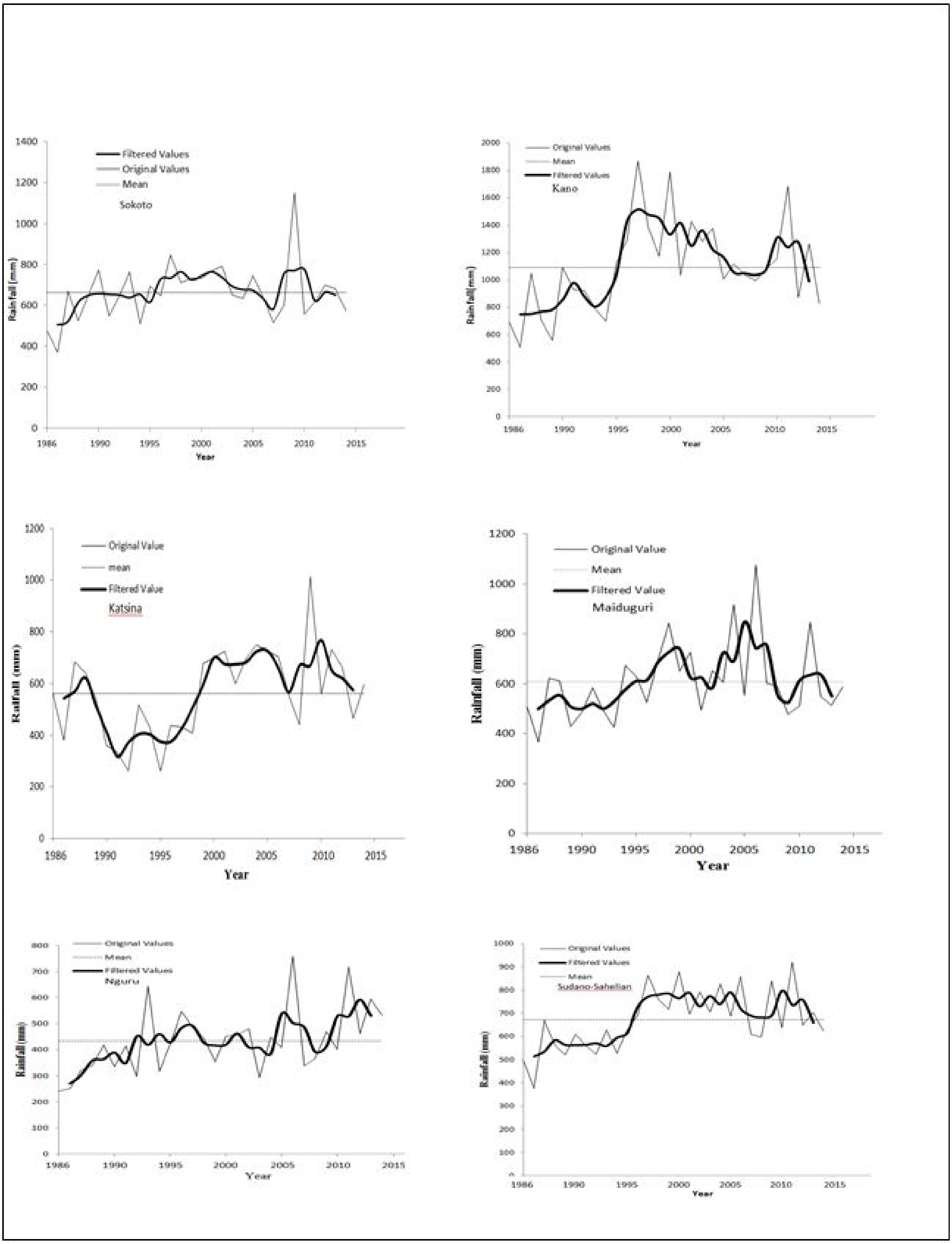

Figure 4. Annual Rainfall Fluctuations in Sudano-Sahelian Region of Nigeria

(*Source: Authors' Field work, 2018)*

It is interesting to note that, the well-publicized droughts of the 1980s that affected the Sudano-Sahelian region of West Africa did not end in the 1980s but entered well into 1990s as could be seen from Figure 4. The original and filtered values of annual rainfall for each of the selected stations and for the entire

Sudano-Sahelian region of Nigeria have also shown the period of progressive decline in rainfall from 1980s through the 1990s which captured droughts of the 1994-1997/98 though of lesser magnitude compared to those of the 1970s and 1980s in the region. Several factors have been suggested as the likely causes of droughts in the sub-Saharan Africa notable among these include land-surface feedback mechanisms (Charney, 1975), southward shift of sub-tropical high pressure belt and associated displacement of the ITD southward (Lamb, 1980, 1982; Nicholson, 1983) and large-scale sea surface temperature anomalies of the tropical oceans (Folland, Palmer and Parker, 1986; Nicholson and Kim, 1997; Camberlin, Janicot and Poccard, 2001; Barrios, Bertinelli and Strobi, 2010; Hastenrath, Polzin and Mutai, 2011; Biasutti, 2013; Diatta, 2014).

In the aftermath of 1972-73 drought that struck the Sahelian region of Africa, Lamb (1980) examined the tropical controls of Sahelian rainfall and found that, the low-level, moisture bearing south-west monsoon flow did not extend as far north along the West African coast during Sahelian droughts, consequent upon the upper tropospheric convergence, which overlay areas of subsidence further north. Consequently, a southward shift of subtropical high pressure belt and Tropical Easterly Jet (TEJ) made subsidence more prevalent over the Sahel. This rendered the environment less favourable for the propagation and development of the major rain-producing system in the Sahel, the Line Squalls as further demonstrated by Omotosho (1985).

The separate contributions of thunderstorms, line squalls and the ordinary monsoon to total annual rainfall has been investigated by Omotosho (1985) using daily registers of weather observations at five selected synoptic stations in Nigeria, for every month, over the period 1972-1976. The results showed that line squalls accounted for 69.9% to total annual rainfall for stations located north of latitude 12.5^0 N (Sokoto, Kano, Katsina, Maiduguri, Nguru inclusive), followed by thunderstorms and ordinary monsoon which accounted for 26.5% and 3.9% respectively. This has lent credence to Lamb's (1980) study on the likely cause of Sahelian droughts, and implied that during those drought years, the frequency of occurrence of line squalls and even thunderstorms had drastically reduced and consequently led to marked rainfall deficits (droughts) in the region. It should however be noted that from the year 2000 onwards, rainfall gradually began to appreciate in the Sudano-Sahelian region as revealed in Figure 4 at each of the selected stations and for the entire region. This became more pronounced from the year 2010 onwards leading to seasonal floods of different magnitudes in the region as recently reported by Umar, Bello, Dangulla and Nathaniel (2015) based on the analysis of extreme rainfall events over Nigeria from 1971-2010. Nka, Oudin, Karambiri, Paturel and Ribstein (2015) also reported similar results on increasing trends in flood occurrences based on the analysis of mean daily flow records of eleven catchments of West African sub-region over the period 1950-2010.

Rainfall Trends in Sudano-Sahelian Region of Nigeria

Monthly and annual rainfall trend equations for each of the selected stations are presented in Table 1, below.

Table 1. Monthly and Annual Rainfall Trend Equations for Sudano-Sahelian Stations in Nigeria

Months	Sokoto	Kano	Katsina	Maiduguri	Nguru
APRIL	Yt = 1.27 + 0.407*t	Yt = 15.55 - 0.149121*t	Yt = 0.46 + .506*t	Yt = 6.62 - 0.108699*t	Yt = 2.18 - 0.018532*t
MAY	Yt = 36.8 + 0.806*t	Yt = 111.2 + 243*t	Yt = 0.46 +0.506*t	Yt = 26.51 + 0.240*t	Yt = 8.95 + 0.230*t
JUNE	Yt = 183.0 - 0.032013*t	Yt = 234.7 + 4.43*t	Yt = 40.7 + 2.27*t	Yt = 55.8 + 1.43*t	Yt = 14.47 + 1.74*t
JULY	Yt = 177.6 + 1.52*t	Yt = 298.0 + 4.88*t	Yt = 133.1 +0.947*t	Yt = 160.8 + 0.0544*t	Yt = 121.6 + 0.149*t
AUGUST	Yt = 116.5 + 0.0240*t	Yt = 138.9 + 1.84*t	Yt = 137.1 + .01*t	Yt = 181.0 + 2.09*t	Yt = 128.1 + 2.66*t
SEPTEMBER	Yt = 1.4 + 1.30*t	Yt = 14.53 + 0.205*t	Yt = 91.3 –.384004*t	Yt = 88.8 + 0.997*t	Yt = 40.6 + 2.45*t
OCTOBER	Yt = 599.3 + 4.14*t	Yt = 867 + 14.5*t	Yt = 10.58 + .216*t	Yt = 11.36 + 0.261*t	Yt = 3.40 + 0.159*t
ANNUAL	Yt = 15.55 - 0.149121*T	Yt = 0.46 + 0.506*t	Yt = 432.8 + .35*t	Yt = 531.4 + 4.94*t	Yt = 319.3 + 7.38*t

*Significance at 0.05 percent (2-tailed test)

Source: Authors' Field work, 2018

It could be observed that the monthly rainfall patterns at Sokoto were characterized by significant upward trend in all selected months except June. The significant downward trend observed for June rainfall over the period 1986-2015 could be attributed to the occasional occurrences of dry spells after the onset of the rains which in most cases occured in June, as recently predicted by NiMet (2018). The upward trend observed in the months of April, May, July, August, September and October could however not be reflected in annual rainfall patterns as it was marked by a significant downward trend over the period of the study. At Kano, all the selected months, with exception of April, had positive rainfall trend while similar results were obtained for its annual rainfall series over the period 1986-2015. The downward trend observed in April rainfall series was not surprising since rain-producing systems for the Sahelian region had not been fully established during the period.

The September rainfall series for Katsina station over the period 1986-2015 was marked by a significant downward trend. This could be linked to the weakening intensity of meso-scale convective systems that produce rainfall during the period following gradual retreat of the Intertropical Discontinuity (ITD) southwards. It is interesting to note that despite the significant downward trend observed in September, monthly rainfall series for the remaining selected months as well as annual rainfall series showed a significant upward trend over the period of the study. Maiduguri and Nguru, both located in the extreme north-eastern part of Nigeria, showed similar rainfall patterns as both stations had significant downward trend in their April monthly rainfall series over the period of the study. Rainfall series for the months of May-October as well as the annual rainfall showed significant positive rainfall trends for both stations.

Illustrations of the results of regression for monthly, annual and regional rainfall trends for the selected Sudano-Sahelian stations and for the entire Sahelian region of Nigeria are presented in Figures 5 and 6.

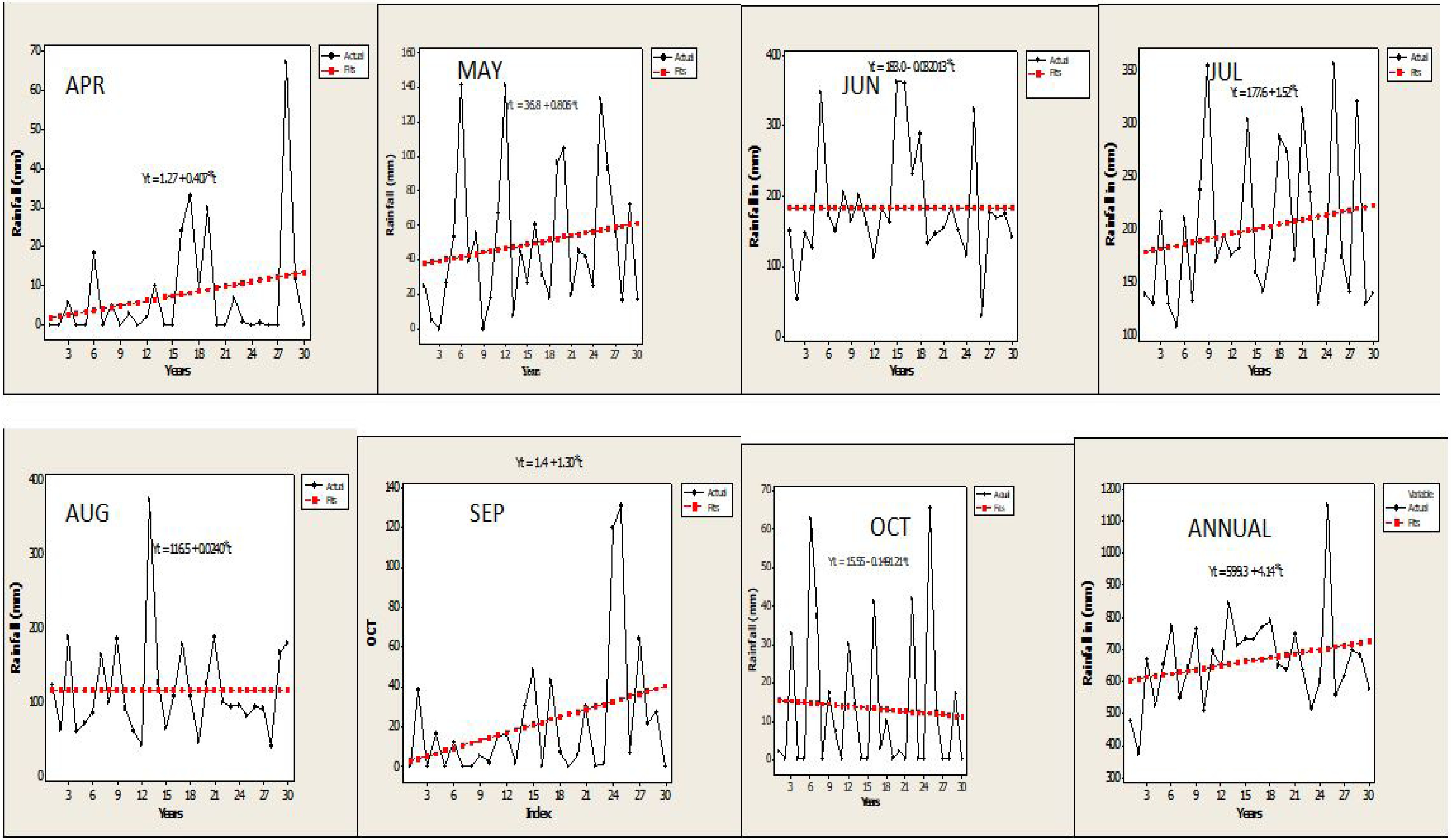

Figure 5a. Rainfall trends at Sokoto (1986-2015)

Source: Authors' Field work, 2018

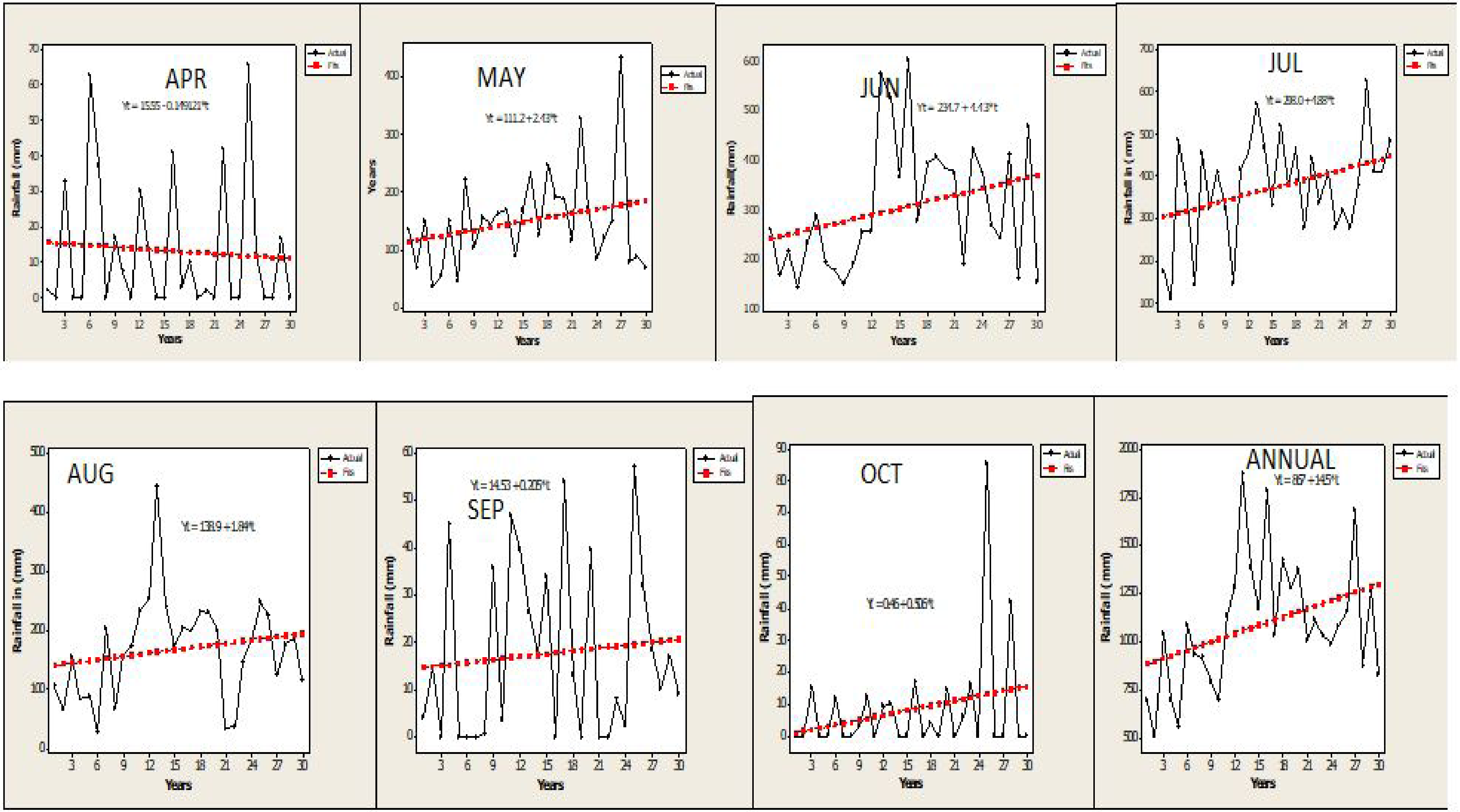

Figure 5b. Rainfall trends at Kano (1986-2015)

Source: Authors' Field work, 2018

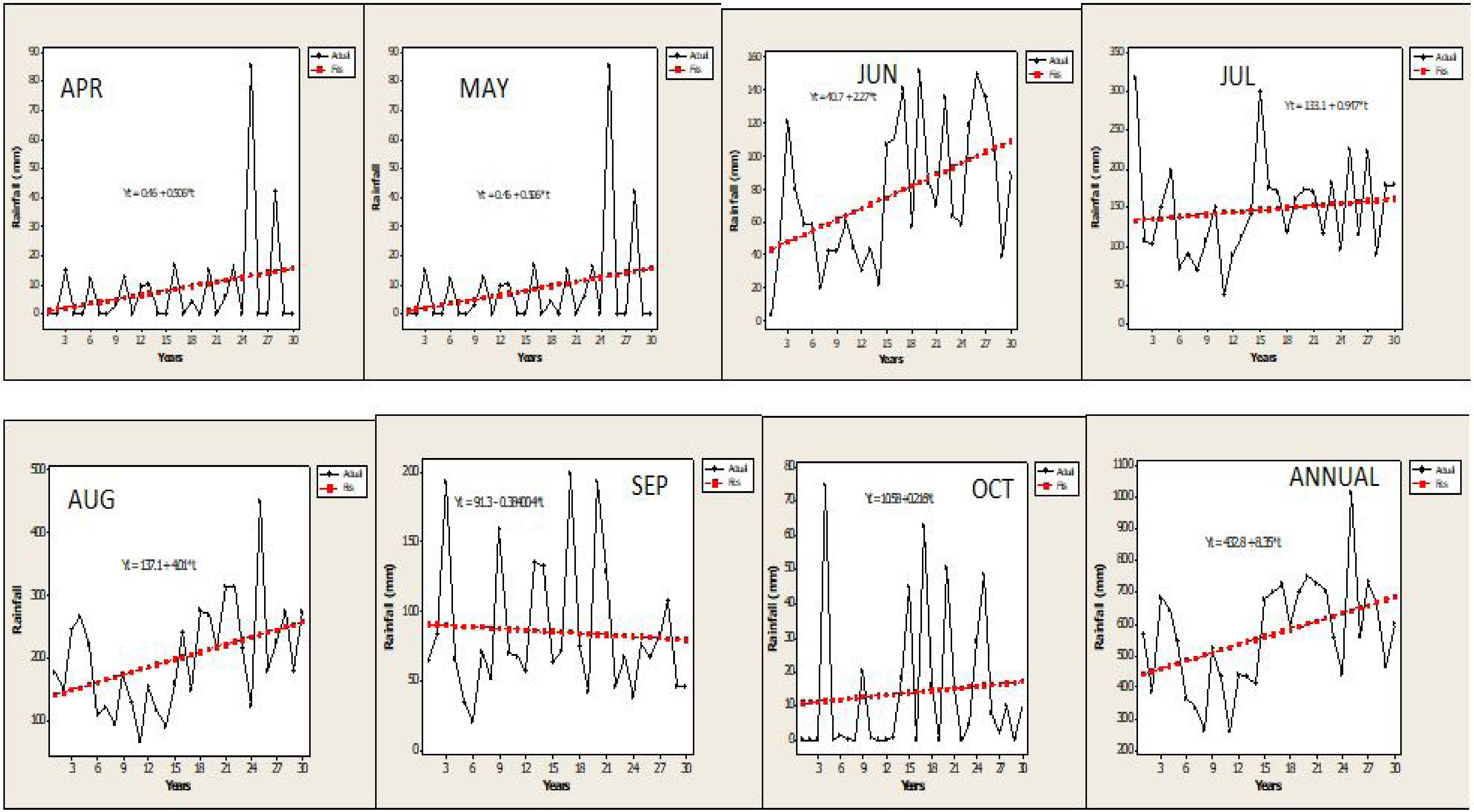

Figure 5c. Rainfall trends at Katsina (1986-2015)

Source: Authors' Field work, 2018

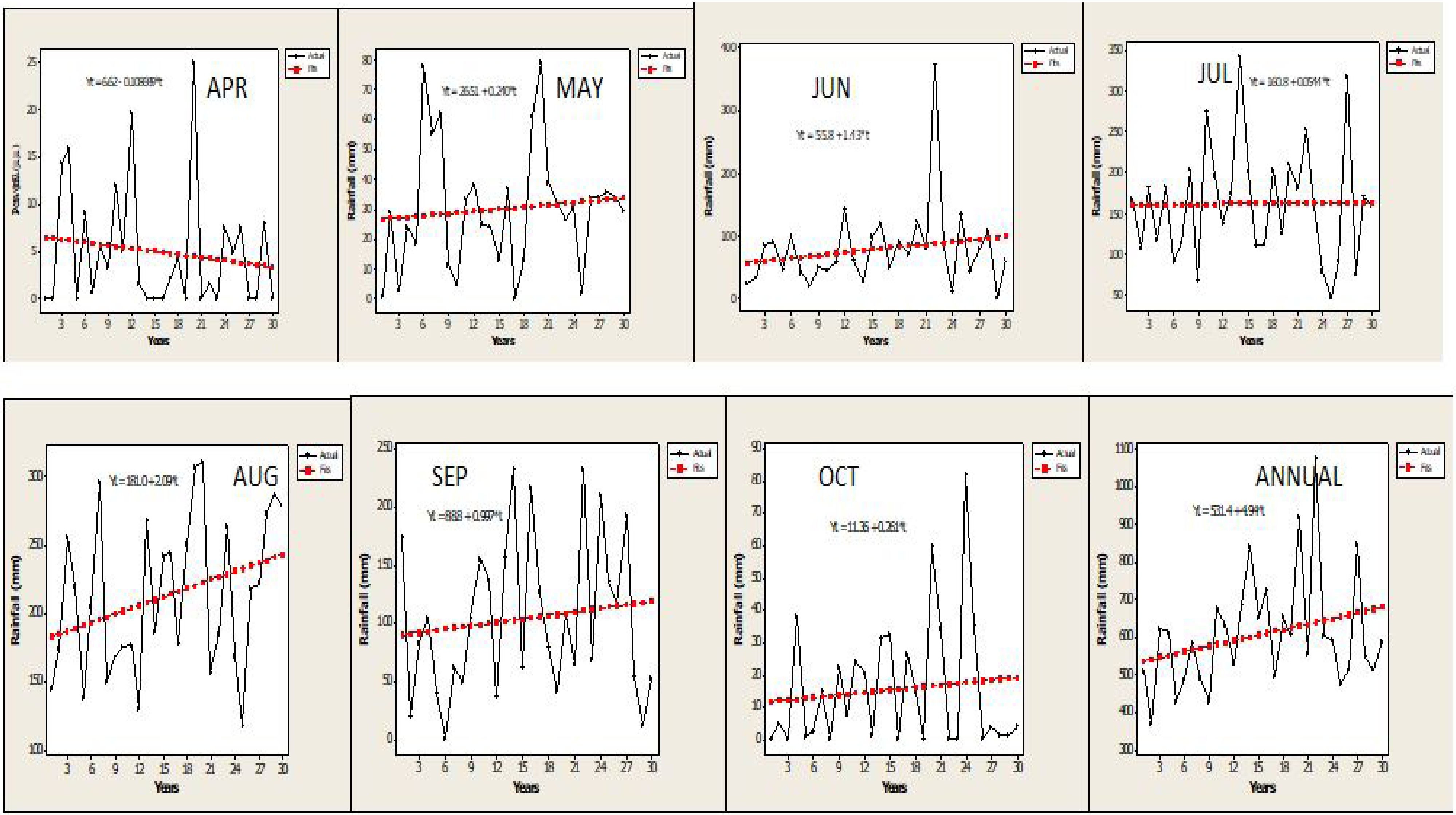

Figure 5d. Rainfall trends at Maiduguri (1986-2015)

Source: Authors' Field work, 2018

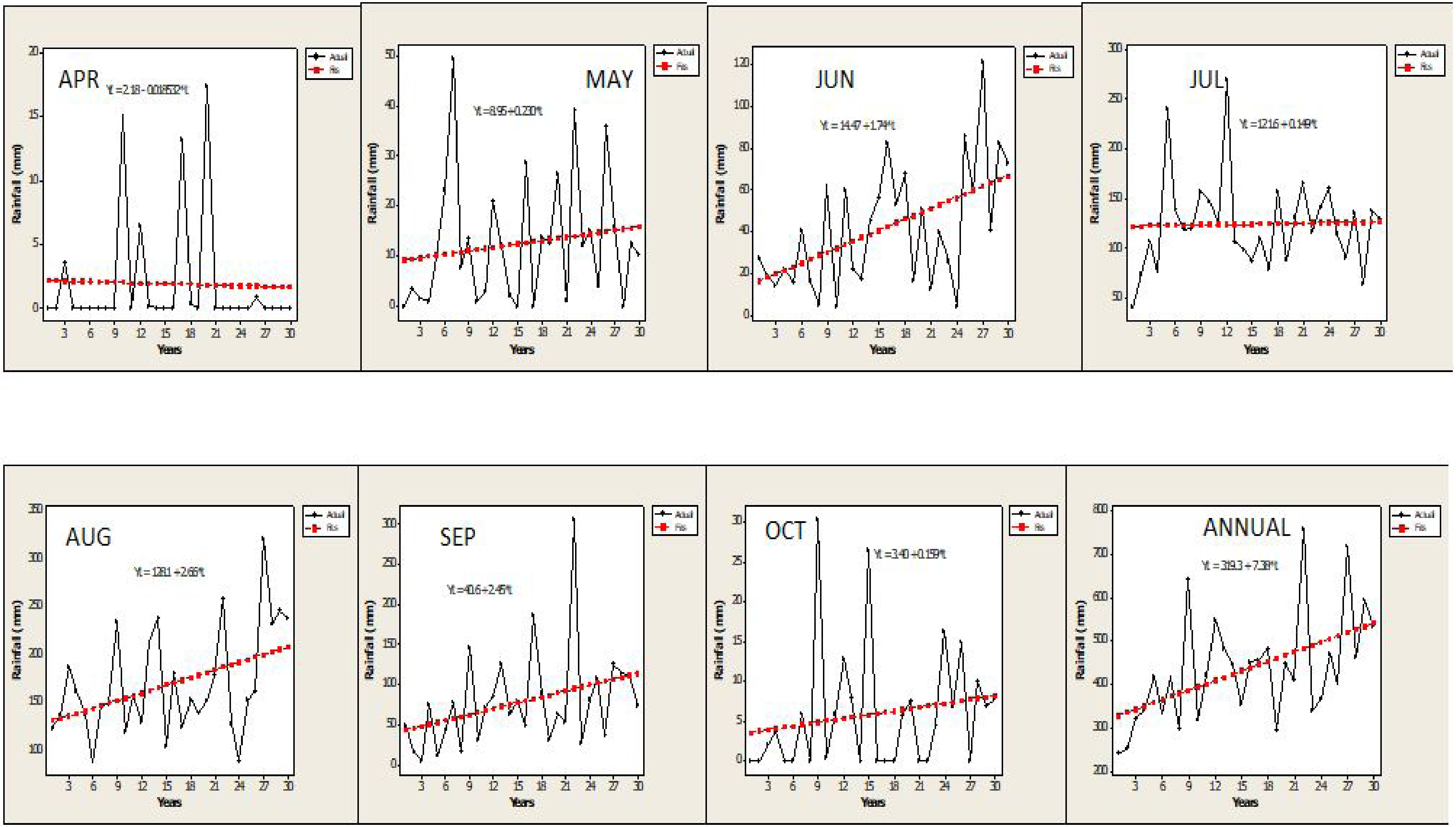

Figure 5e. Rainfall trends at Nguru (1986-2015)

Source: Authors' Field work, 2018

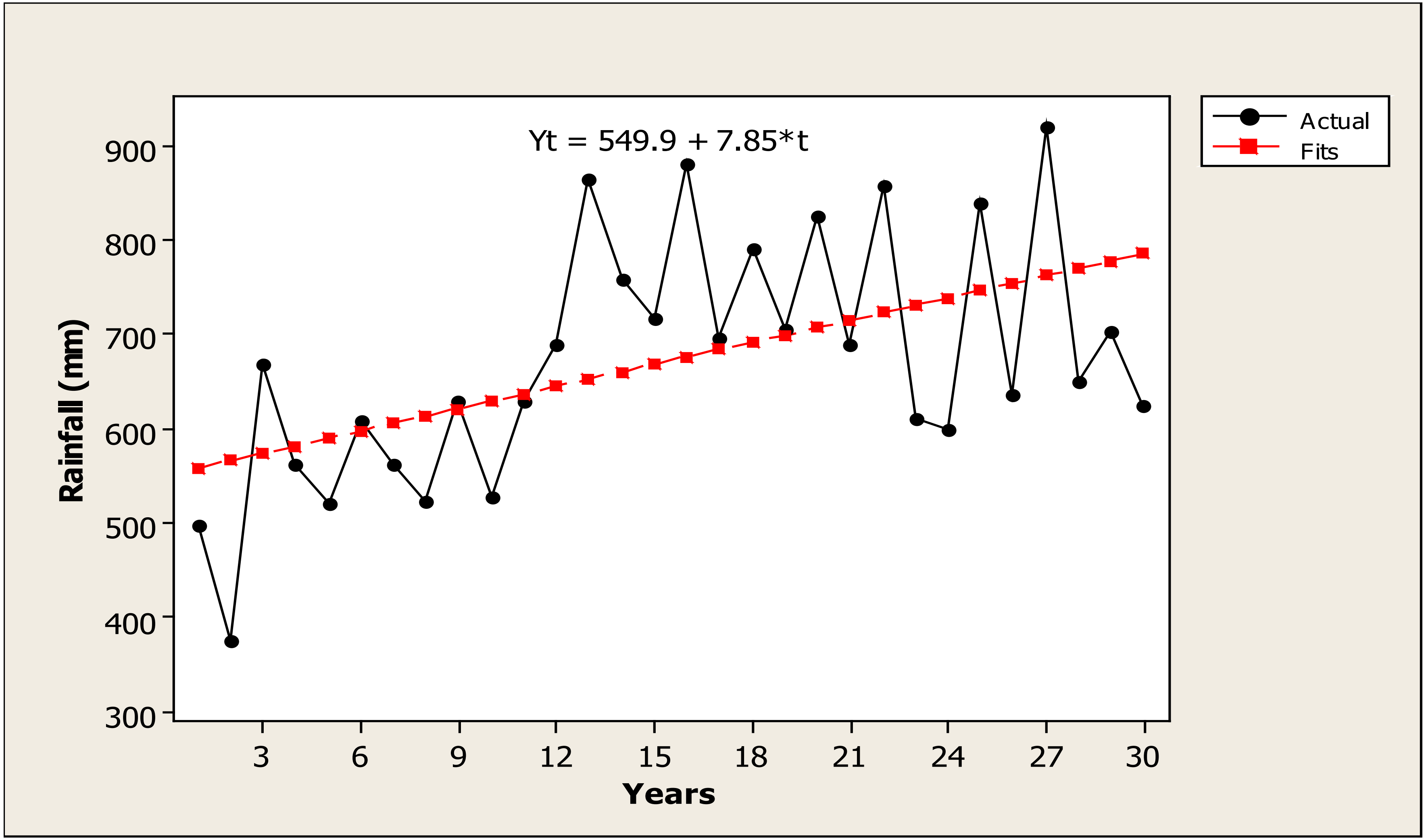

Figure 6. Annual Rainfall Trend for the Sudano-Sahelian Region of Nigeria

Source: Authors' Field work, 2018

One common feature associated with Figures 5a-5e and Figure 6 is the occurrence of periodic oscillations in monthly and annual rainfall series at individual stations and for the region as a whole. This is not surprising given the spatial and seasonal nature of the rainfall dynamics in the region. At Sokoto, the highest monthly rainfall record occurred in August 1998, and the highest annual rainfall record occurred in 2010. In the case of Kano, the highest monthly rainfall record occurred in July 2012, and the highest annual rainfall record occurred in 1998. At Katsina, the highest monthly rainfall record occurred in August 2010, and the highest annual rainfall record occurred in 2010. At Maiduguri, the highest monthly rainfall record occurred in July 1999, and the highest annual rainfall record occurred in 2007. At Nguru, the highest monthly rainfall record occurred in August 2012, and the highest annual rainfall record occurred in 2007. (see Figure 5a-5e)

For the Sudano-Sahelian region, the time series of the yearly averages for five selected stations was generated and regressed on time over the period 1986-2015 as presented in Figure 6. It is evidently clear that, following the apparent cessation of the Sahelian droughts in the late 1990s, a gradual recovery of rainfall was witnessed in the region from the year 1998 onwards. The five highest annual rainfall records in the region occurred in 1998, 2001, 2007, 2010 and 2012 respectively, as shown in Figure 6. This result further confirms Nicholson’s (2005) findings on the ‘question of rainfall recovery in the Sahel’ and several other researches on this issue (Umar, 2012; Jury, 2013; Sanogo *et al*, 2015).

Rainfall Variability in Sudano-Sahelian Region of Nigeria

In agricultural and water resources development projects, it is necessary to consider the reliability of rainfall over time before policies could be drawn for rainfall-dependent sectors of the economy. It is in consideration the importance of rainfall variability to the economy, of which this study also analyzed the inter-decadal variability of annual rainfall at each of the selected stations and for the Sahelian region of Nigeria as a whole as presented in Tables 2-7.

Table 2. Inter-decadal rainfall variability at Sokoto

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V. (%)	Difference from long- term mean (719.3mm)	Years with > +10% departure from long-term mean	Years with < -10% departure from long-term mean
1986-1995	5926	-	593	129	21.8	-70	1991,1994, 1998	1986,1987,1989,1992, 1995
1996-2005	7204	1278	720	68	9.4	+57	1998,2001,2002 2003	1997
2006-2015	6773	-431	677	180	26.6	+14	2006, 2010	2008,2011,2015

Table 3. Inter-decadal rainfall variability at Kano

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V (%)	Difference from long- term mean (1091mm)	Years with > +10% departure from long- term mean	Years with < -10% departure from long-term mean
1986-1995	7933	-	793	197	24.8	-298	-	1986,1987,1989 1990,1992,1993, 1994,1995
1996-2005	13757	5824	1376	269	19.5	+285	1997,1998,2001, 2001,2003,2014 2005	
2006-2015	11040	2717	1104	241	21.8	+13	2012,2014	2013,2015

Source: Authors' Field work, 2018

Table 4. Inter-decadal rainfall variability at Katsina

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V. (%)	Difference from long- term mean (mm)	Years with > +10% departure from long- term mean	Years with < -10% departure from long-term mean
1986-1995	4718	-	472	140	29.7	-90	1988,1989	1987, 1991,1992,1993,1995
1996-2005	5688	-970	569	170	29.9	+ 7	2000, 2001,2002 2004, 2005,2006	1996,1997,1987,1989
2006-2015	6458	-770	646	165	25.5	+84	2007,2010,2012, 2013	2009,2014

Source: Authors' Field work, 2018

Table 5. Inter-decadal rainfall variability at Maiduguri

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V. (%)	Difference from long -term mean (608mm)	Years with > +10% departure from long- term mean	Years with < -10% departure from long-term mean
1986-1995	5200	-	520	98	19.2	-88	1995	1986,1987,1990,1991, 1994,1993
1996-2005	6733	-1533	673	130	19.4	+65	1998,1999,2005	1997,2002
2006-2015	6304	+429	630	187	29.6	+22	2007,2012	2010,2014,2011,2014

Source: Authors' Field work, 2018

Table 6. Inter-decadal rainfall variability at Nguru

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V. (%)	Difference from long-term mean (433mm)	Years with > +10% departure from long- term mean	Years with < -10% departure from long-term mean
1986-1995	3575	_	358	116	32.4	-75	1994	1986,1987,1988,1989, 1991,1993,1995
1996-2005	4382	-707	438	71	16.1	+5	1997,1998	2000,2004
2006-2015	5052	-670	505	145	28.7	+72	2007,2012,2014, 2015	2008,2009

Source: Authors' Field work, 2018

Table 7. Inter-decadal rainfall variability in Sudano-Sahelian Region of Nigeria

Decade	Decadal Amount (mm)	Decadal change (mm)	Decadal Mean (mm)	S.D. (mm)	C.V. (%)	Difference from long-term mean (672.3mm)	Years with > +10% departure from long- term mean	Years with < -10% departure from long-term mean
1986-1995	5490	-	549	81.21	14.8	-123.3	-	1986-1987, 1989-1990, 1992-1993, 1995
1996-2005	7553	2063	755	82.71	11.0	+82.7	1998-2001, 2003, 2005	-
2006-2015	7126	-427	713	116.30	16.3	+40.7	2007, 2010, 2012	2009

Source: Authors' Field work, 2018

From Table 2, it could be observed that on a decadal basis, annual rainfall increased by 1.00mm at Sokoto over the period 1986-2015 with a mean annual rainfall of 719 mm. The least value of the co-efficient of variation of 9.4% for Sokoto implied that rainfall was less variable and, therefore, highly reliable in the 1996-2005 decade. This was reflected in the occurrence of only one year (1997), as a year of rainfall failure. All the years with annual rainfall of less than 10% departure from the long-term mean, were regarded as years of rainfall failure and the reverse was the case for the wettest years. In the case of Sokoto, the decades covering 1986-1995 and 2006-2015 respectively, had 6 and 3 years of rainfall failure while the 1996-2005 decade had the highest number of the wettest years among the three decades studied.

In the case of Kano (Table 3), no single year of rainfall failure in the 1996-2005 decade was observed. The years 1997-99, 2001, 2003-2005 respectively had been recorded as the wettest years during the 1996-2005 decade while the 1986-1995 decade had the highest number of rainfall failures, based on the variability analyses carried out in this study. There was however no noticeable increase or decrease in decadal rainfall within the three decades examined over the period 1986-2015. However, rainfall increased by 1.00 mm per decade at Katsina with the mean annual rainfall of 562 mm (Table 4). Similarly, rainfall was also less variable in 2006-2015 decade at Katsina. The 1986-1995 decade had the highest number of rainfall failures among the three decades investigated in the zone. It is interesting to note that both Maiduguri and Nguru stations (Tables 5 & 6) had 1998, 2007, and 2012 respectively as the wettest years over the period 1986-2015. The two stations also had 1986, 1987, 1991 and 1993 as years of rainfall failures over the period 1986-2015. While rainfall decreased by 1.00 mm per decade at Maiduguri, it however increased by 2.00 mm per decade at Nguru.

For the entire Sudano-Sahelian region (Table 7), it could be observed that the years 1986-1995 recorded the driest decade in the region over the period 1986-2015 with 1986-1987, 1989-1990, 1992-1993 and 1995 as years of rainfall failures with no single year qualifying as the wettest year, based on the variability analyses conducted in this study. In contrast, the 1996-2005 and 2006-2015 decades respectively had 1998-2001, 2003, 2005 and 2007, 2010, 2012 as the wettest years. However, rainfall was more reliable and therefore less variable in the 1996-2005 decade, having recorded the least value of the co-efficient of variability of 11.0%. This could be verified having no single year of rainfall failure as shown in the last column of Table 7. The results of the inter-decadal variability presented in Tables 2-7 further confirmed that the drought of 1980s that struck the West African Sahel region extended well into 1990s. It was, therefore, of wider coverage in terms of areal extent and magnitude as extensively discussed in the literature (Druyan, 1989). The results further validated the findings of Nicholson (2005) on the question of 'rainfall recovery in the Sahel'. The apparent cessation of the Sahelian droughts in the late 1990s and the subsequent recovery of rainfall in the region since 2003, had tempted several climate scientists to examine the nature, extent and severity of desertification; another endemic environmental hazard in sub-Saharan Africa. They subsequently came up with a number of evidences suggesting the end of desertification in drylands (Roy and Mortimore, 2016).

Conclusion and Recommendations

The paper has examined the recent rainfall trends and variability in Sudano-Sahelian region of Nigeria. The annual rainfall patterns in the region has changed from the downward trend experienced in the late 1970s and 1980s to a markedly upward trend, as observed from late the 1990s to the present, an indication that the region had started recovering from the huge rainfall deficits it experienced in the past. This study could not however conclude that the drought is over, given the cyclical nature of the climate in the region. The study has contributed to a deeper understanding of the recent changing rainfall conditions in the region. It is recommended that climate change adaptation and mitigation options designed based on acute rainfall deficits experienced in the past decades be revisited and possibly replaced with new ones reflecting the current reality of increased precipitation in the region.

References

Adefolalu, D. O. (1986). Rainfall trends in Nigeria. *Theoretical and Applied Climatology,* 37.4:205-219.

Adejuwon, J.O., Balogun, E. E. and Adejuwon, S. A. (1990). On the annual and seasonal patterns of rainfall fluctuations in Sub-Saharan West Africa. *International Journal of Climatology* 10: 839-848.

Adelekan, I.O. (1998). Spatio-temporal variations in thunderstorm rainfall over Nigeria, *International Journal of Climatology* 18: 1273-1284

Adedoyin, J.A. (1989). Global-scale sea surface temperature anomalies and rainfall characteristics in northern Nigeria. *International Journal of Climatology* 9:133-144.

Aondover, A. T. and Woo, M. (1998). Changes in rainfall characteristics in northern Nigeria. *Internaational Journal of Climatology* 18: 1261-1271.

Anyadike, R. N. C. (1992). Regional variations in fluctuations of seasonal rainfall over Nigeria. *Theoretical and Applied Climatology*, 45: 285-292.

Anyadike, R.N.C. (1993). Seasonal and annual rainfall variations over Nigeria. *International Journal of Climatology* 13: 567-580pp.

Ati, O. F., Stigter, C. J., Iguisi, O. E. and Afolayan, J. O. (2009). Profile of rainfall change and variability in northern Nigeria, 1953-2002. *Journal of Earth and Environmental Sciences*, 1(2): 58-63.

Ayoade, J. O. (1983). *Introduction to Climatology for the tropics*, Johnwiley-Chichester, UK.

Ayoade, J. O. and Bamwo, Y. (2007). Changes in annual rainfall characteristics in Nigeria between 1931-1960 and 1961-1990. *International Journal of Meteorology*, 32(318): 111-119.

Ayoade, J. O. (2011). *Introduction to Climatology for the tropics*, 2nd edition, Spectrum Books Limited, Ibadan.

Barrios, S., Bertinelli, L. and Strobi, E. (2010). Trends in rainfall and economic growth in Africa: a neglected cause of African growth tragedy. *Review of Economic Statistics*, 92(2): 350-366.

Balogun, E.E. (1981). Seasonal and spatial variations in thunderstorm activity over Nigeria. *Weather* 36: 192-196.

Bello, N. J. (1996). An investigation of the characteristics of the onset and cessation of the rains in Nigeria. *Theoretical and Applied Climatology*, 54(3-4): 161-173.

Bello, N. J. (1997). Investigating the spatial pattern of the characteristics of the onset and cessation of the rains in Nigeria. *Geojournal*, 43(2): 113-123.

Biasutti, M. (2013). Forced Sahel rainfall trends in the CMIPS5 archive. *Journal of Geophysical Research,* 118: 1613-1623.

Camberlin, P., Janicot, S. and Poccard, I. (2001). Seasonality and atmospheric dynamics of the teleconnections between African rainfall and tropical sea surface temperature: Atlantic vs. ENSO. *International Journal of Climatology*, 21: 973-1005.

Charney, J. G. (1975). Dynamics of desert and drought in the Sahel. *Quarterly Journal of Royal Meteorological Society*, 101: 193-202.

Diatta, S. and Fink, A. H. (2014). Statistical relationship between remote climate indices and West African monsoon variability. *International Journal of Climatology*, 34: 3348-3367.

Druyan, L. M. (1989). Advances in the study of Sub-Saharan drought. *International Journal of Climatology* 9, 77-90.

Folland, C.K., Palmer, T. N. and Parker, D. E. (1986). Sahel rainfall and world-wide sea surface temperatures. *Nature* 320, 602 -607.

Fontain, B., Janicot, S. and Moron, V. 1995. Rainfall anomaly patterns and wind-field signals over West Africa in August, 1958-89. *Journal of Climate,* 8,1503-1510.

Hastenrath, S., Polzin, D. and Mutai, C. (2011). Circulation mechanisms of Kenya rainfall anomalies. *Journal of Climate*, 24, 404-412.

Hulme, M. (1992). Rainfall changes in Africa: 1931-1960 to 1961-1990. *International Journal of Climatology* 12, 685-699.

Ilesanmi, O. O. (1971). An empirical formulation of an ITD rainfall model for the tropics. *Journal of Applied Meteorology*, 10.882.

Jury, M. R. (2013). A return to wet conditions over Africa: 1995-2010. *Theoretical and Applied Climatology*, 111, 471-481.

Kamara, S. I. (1986). The origin and types of rainfall in West Africa, *Weather*, *41* (2), 48-56.

Lamb, P. J. (1980). Persistence of sub-Saharan drought. *Nature*. *299*, 46-48.

Nicholson, S.E and Kim, J. (1997). The relationship of the El-nino/Southern Oscillation to African rainfall. *International Journal of Climatology, 17* (2), 117-135.

Nicholson, S. E. (2005). On the question of the "recovery" of the rains in the West African Sahel. *Journal of Arid Environment*, *63*, p. 615-641.

Nigerian Meteorological Agency (2017). Seasonal Rainfall Prediction (SRP) for 2017 Rainy Season.

Nka, B. N., Oudin, L., Karambiri, H., Paturel, J. E. and Ribstein, P. (2015). Trends in floods in West Africa: analysis based on 11 catchments in the region. *Journal of Hydrology and Earth System Sciences*, 19: 4707-4719.

Odekunle, T. O., Oniarah, A., Sholademi, O. A. (2008). Towards a wetter Sudano-Sahelian ecological zone in the twenty-first century. *Weather*. 63(3), 66-70.

Oguntunde, P. G., Babatunde, J. A. and Leschied, G. (2011). Rainfall trends in Nigeria, 1901-2000, *Journal of Hydrology*, 411.3: 207-218.

Ojo, O. (1977). *The Climate of West Africa*. Heineman, London.

Olaniran, J. O. 1991. Rainfall anomaly patterns in five wet and dry years over Nigeria. *International Journal of Climatology.* 8: 542-559

Olaniran, O. J. and Sumner, G.N. (1989). A case study of climatic variability in Nigeria based on the onset, retreat and length of the rainy season. *International Journal of Climatology* 9: 253-269.

Olaniran, O. J. and Sumner, G. N. (1990). Long term variation of annual and growing season rainfall in Nigeria. *Theoretical and Applied Climatology* 40: 2111-2123.

Olaniran, J. O. (2005). *Rainfall anomalies in Nigeria. The contemporary understanding*. An inaugural lecture delivered at the University of Ilorin, Nigeria., 55Pp.

Omotosho, J. B. (1984). Spatial and seasonal variation of line squalls over West Africa. *Archives for Meteorology, Geophysics and Bioclimatology, Series A* 33: 143-150.

Omotosho, J. B. (1985). The separate contributions of line squalls, thunderstorms and the monsoon to the total rainfall in Nigeria. *Journal of Climatology*, 5, 545-552.

Roy, H. B. and Mortimore, M. (2016). *The End of Desertification: Disputing Environmental Change in Drylands*. Springer Publishers, London.

Sanogo, S., Andreas, H. F, Omotosho, J. B., Abdramane, B and Robert, R. (2015). Spatio-temporal characteristics of the recent rainfall recovery in West Africa, *International Journal of Climatology,* 11:177-204.

Udjugo, P. O. A. (2005). An Analysis of rainfall pattern in Nigeria. *Global Journal of Environmental Sciences*, 4.2: p. 139-145.

Umar, A. T. (2012). Analysis of extreme rainfall events and risk of drought and flood occurrences in Nigeria", *Nigerian Geographical Journal*, Vol. 8. No. 1, Pp. 109-120.

Umar, A. T., Bello, N., Dangulla, M. and Nathaniel, E. B. (2015). The Changing Frequency of Extreme Daily Rainfall Events and its Implications for Flood occurrence in Northern Nigeria, In: Iliya, M. A. *et.al* (eds.), *Climate change, Environmental Challenges and Sustainable Development conference*, held at Usmanu Danfodiyo University, Sokoto, 23rd-26th November, 2015.

Umar, A. T. and Ismaila, A. (2017). Analysis of monthly rainfall variations: Further evidence of climate change in Sokoto State, Nigeria (1926-2017). *Ethiopian Journal of Environmental Studies and Management*, 10 (6): 728-745.

Usman, M.T. and Abdulkadir, A. (2013). On determining the 'real' onset date of seasonal rains in the semi-arid and sub-humid areas of West Africa. *Natural Hazards*, 66:749-758.