Research Journal of Applied Sciences 8 (1): 27-32, 2013
ISSN: 1815-932X

Rainfall Distribution and Change Detection in Northern Nigeria

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Abstract: This study approached climate and climate change study using the rainfall distribution over each climatological zone of Northern Nigeria. Nigeria today boasts of not <44 weather observation stations which provide measurement of rainfall amount for different locations across the country. Data were collected for 90 years (1910 to 1999) for all the weather observation stations that falls in the Sahel and Sudan Savannah zones of Nigeria while a subdivision was made to three non-overlapping climatic regimes of 30 years viz 1910 to 1939, 1940 to 1969 and 1970 to 1999. Statistical methods were utilized to justify any such change in the averaged weather. The trend and variability of averaged zonal rainfall was investigated using the probability density function, Wilcoxon Signed-Rank test, Paired Sample test and Mann Whitney test which all form the non-parametric components of the test in order to investigate variations and detect the change points. Results show common change points and transitions from wet to dry (downward shift) and vice versa in both zones. Statistical tests performed on the data show that rainfall variation over the Sahel is significant ($p<0.05$) between pairs of regimes (1st and 3rd, 2nd and 3rd) while it is not significant ($p<0.05$) between 1st and 2nd. Over the Sudan, rainfall variability between climate regimes were not statistically different at 95% confidence interval. Suggestions were therefore made at the end of the study on the use of the contained information for socio-economic improvement and agricultural development of the zones.

Key words: Climate change, climate regime, rainfall variability, zone, regimes

INTRODUCTION

Nigeria faces many significant challenges associated with climate change despite having a strong and diverse economy relative to other countries in Sub-Saharan Africa, significant portions of her population and economy are tied to activities that are climate sensitive such as rain-fed agriculture, livestock rearing, fisheries and forest products extraction. IPCCC (2007) defines climate change as a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period typically decades or longer. Ironically, developing countries like Nigeria who contribute least in anthropogenic actions are most vulnerable to its impact climate change. Climates varied in the past on different time scales and intra-annual rainfall variability refers to the distribution of rainfall within a year and in recent times, a prolonged variability in rainfall distribution as a component of climate change is suspected and the magnitude of such change is continuously being studied by meteorologists and climatologists. Various adaptive measures have been suggested and employed for climate users and such include changing to early maturing crop varieties, streamlining farming calendars with the changing rainfall regime or irrigated agriculture, etc. but all these have not solved the impending danger of food insecurity of the nation and sustainable growth and development in Africa. The progressive decline in rainfall activities may be captured thus the decline begins with the inhibition of rainfall activity south of the ITD in July/August over the Sahelian zone and as the ITD retreats, inhibition in rainfall activity is extended to the Sudan Savanna belt, Sahel's immediate neighbor to the south, in September and finally to the rest of the country by October (Olaniran and Summer, 1989). Mono-modal rainfall regime characterizes the Northern Nigeria with monthly maximum rainfall receipt around August when the ITD is expected to have moved farthest North. Recent studies have investigated decadal rainfall variability but few examine the variability within climatic regimes. Eludoyin *et al*. (2009) studied monthly rainfall distribution between (1985 to 1994) and (1995 to 2004) and noticed some fluctuations in most months within the decades. Ayansina and Odeyemi (2009) also research on the Seasonal Rainfall Variability in

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Guinea Savanna part of Nigeria and concluded that rainfall variability continues to be on the increase as an element of climate change. However, this study investigates rainfall distribution on spatial and temporal scales over the Northern Nigeria change point analysis was performed on the average zonal rainfall to show transitions in wet to dry and dry to wet within three different non-overlapping climatic normals of 30 years (1910 to 1939), (1940 to 1969) and (1970 to 1999). This enables observation of increase or decrease in rainfall receipt in each of the climatic zones of Northern Nigeria to be established.

MATERIALS AND METHODS

Study area: The study area comprises the Sahel and Sudan Savannah zones of Nigeria and subdivisions to climatic zones were shown in Table 1 which was show as Fig. 1. IPCCC (2007) proposed a statistical approach to Climate and Climate change studies and this forms the focal point of this study as an attempt was made to study rainfall distribution in Northern Nigeria.

A 90 years monthly rainfall values for all the available meteorological stations in the Sahel and Sudan Savannah region of Nigeria were collected from the archive of the Nigerian Meteorological Agency (NIMET) and the annual values over each stations were calculate using relation (1).

Further subdivisions were however done to three different non-overlapping climate regimes of 30 years.

$$A = \sum_{i=1}^{12} R_i \qquad (1)$$

Where:

R = The monthly rainfall amount at each station
i = The months of the year
A = The annual rainfall amount at that station

Variation exists in rainfall receipt even between stations that fall in the same climatic zone hence for

Table 1: Meteorological stations within each climatic zone in Nigeria

Climatic zones	Meteorological stations
Sudan Savannah	Yola, Kano, Yelwa and Birni Kebbi
Sahel	Sokoto, Gusau, Nguru, Katsina, Potiskum and Maiduguri

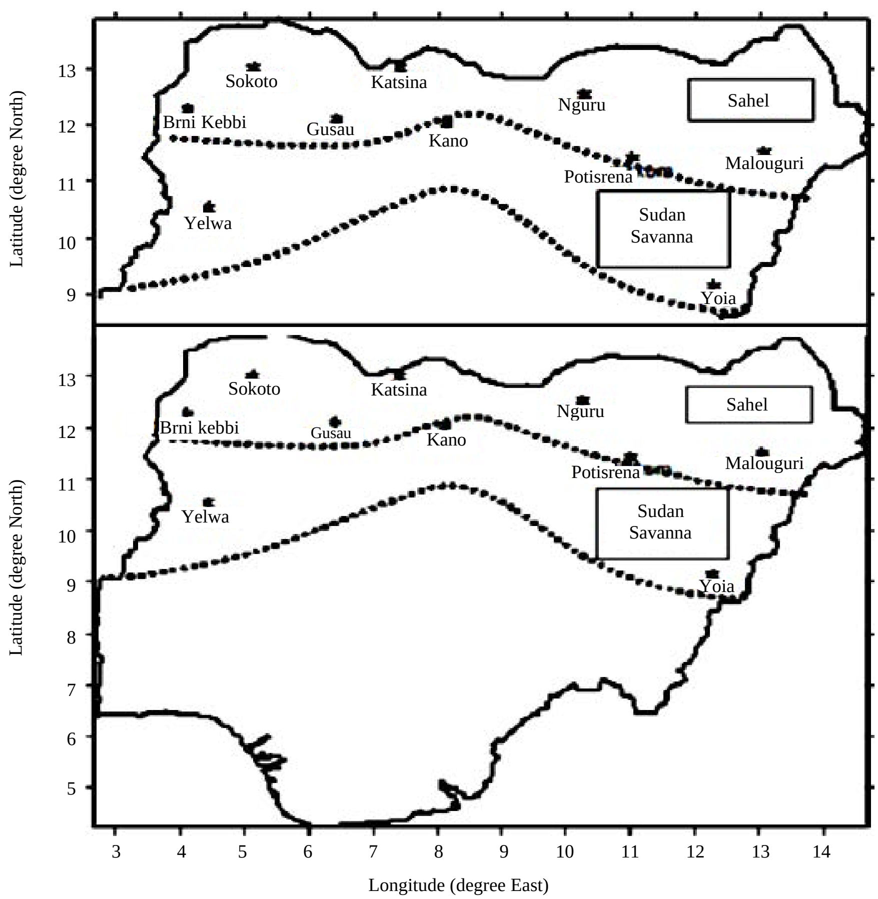

Fig. 1: The study area

stations that falls in the same zone, zonal averages of rainfall were obtained for stations (1-j) using the relation (2).

$$\overline{R_z} = \frac{\sum_{j=1}^{n} A_j}{n} \quad (2)$$

$\overline{R_z}$ = The averaged annual rainfall for the zone at any given year
n = The number of meteorological stations in that zone

The Probability Density Function (PDF) describes the relative likelihood for any random variable to occur at a given point. The probability for the random variable to fall within a particular region is given by the integral of this variable's density over the region. The probability density function is non-negative everywhere and its integral over the entire space is equal to one. A random variable X has density f where f is a non-negative Lebesgue-integrable function if:

$$P[a \le x \le b] = \int_a^b f(x)\,dx \quad (3)$$

The uniform distribution on the interval [0, 1] has probability density f (x) = 1 for $0 \le x \le 1$ and f (x) = 0 elsewhere. The standard normal distribution has probability density:

$$f(x) = \frac{1}{\sqrt{2\pi}} x^{-x^2/2} \quad (4)$$

If a random variable X is given and its distribution admits a probability density function f then the expected value of X (if it exists) can be calculated as:

$$E[X] = \int_{-\infty}^{\infty} x f(x)\,dx \quad (5)$$

The non-parametric Pettitt change point test is used to test for the occurrence of such change point in average zonal rainfall recieipt. The Pettitt criterion hypothesized that the change point K is detected in:

$$K = \max_{1 \le k \le N} |U_k| \quad (6)$$

U_k describes is gotten from the relation:

$$U_k = 2\sum_{i=1}^{k} M_1 \text{-} k(N+1) \quad (7)$$

The modulus of U_k shows a downward or upward shifts in trend and this indicates areas of abrupt change over the zones. Significance of such change point is tested by the relation:

$$K_\alpha = \sqrt{\left\{-\text{In}\alpha \frac{(N^3+N^2)}{6}\right\}} \quad (8)$$

And change points exist where U_k shows maxima.

RESULTS AND DISCUSSION

Rainfall distribution over the northern Nigeria takes its traditional mono-modal distribution with peaks around August and agriculturally sufficient rainfall would not start over such domain until April. Hence, the inter-annual variation in rainfall amount when extended over different climatic regimes 1, 2 and 3 as contained in Table 2 shown a comparative assessment of monthly averages of rainfall received in different climatic normals of thirty years. April over the Sahelian zone gave a negative (-ve) all through which implies that the first regime (1910 to 1939) enjoyed the highest rainfall in April throughout the 90 years considered and in clear terms, April was wettest in the first regime, wetter in the second regime and the driest in the third regime. This inference goes for other months like May, June, July and September which describes the first regime over the Sahelian zone as the wettest regime followed by the second regime and later by the third regime.

August was however wetter during the second regime over the Sahelian region while the third regime rainfall receipt in August was the least over the entire

Table 2: A comparative assessment of rainfall variability in Northern Nigeria

	Zones in the Northern Nigeria					
	Sahel zone			Sudan savannah zone		
Months	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd	1st vs. 2nd	2nd vs. 3rd	1st vs. 3rd
January	*	*	*	*	*	*
February	*	*	*	*	*	*
March	*	*	*	*	*	*
April	-	-	-	-	+	*
May	-	-	-	-	-	-
June	-	-	-	+	-	-
July	-	-	-	+	+	+
August	+	-	-	-	+	-
September	-	-	-	-	-	-
October	*	*	*	-	*	-
November	*	*	*	*	*	*
December	*	*	*	*	*	*

1st (first climate regime): 1910 to 1939; *No rainfall or no significant change; 2nd (second climate regime): 1940 to 969; +: Increase in rainfall amount, 3rd (third climate regime): 1940 to 999; - :Decrease in rainfall amount

90 years considered. Comparative assessment of monthly distribution of rainfall over the Sahel region shows that the highest rainfall researchers have ever received were more to the first regime which concludes that monthly rainfall receipt over the Sahelian region is on the decrease in recent times. There was a steady decrease in monthly rainfall receipt from the first to the third regimes in the months of May and September over the Sudan Savannah, second regime was wetter in June and generally, there is an increasing monthly rainfall trend between the regimes also in July over the Sudan Savannah. April and August show fluctuations while others months give signals of no significant change.

Rainfall distribution over Northern Nigeria was analyzed for each of the climatic zones (Sahel and Sudan savannah) as shown in Fig. 2, the Gaussian Normal Distribution shows that the Sahelian rainfall ranges from 410-900 mm with 34% at about 650 mm while the Sudan Savannah peaks at 1300 mm and recorded the least annual of 600 mm for the total 90 years period considered which agrees with earlier studies that the Sudan Savannah receive more rainfall than the Sahel, meanwhile, <1% of the total rainfall for the 90 years fall between 1200 and 1400 mm over the Sudan Savannah zone which describes that larger percentage of rainfall receipt over the Sudan is between 700 and 1100 mm, annually.

For better understanding of rainfall variability across the three climatic regimes, Fig. 3 shows the probability density curve for the Sahel and Sudan Savannah over each of the climatic normals of 30 years. Interestingly, the Sudan zone shows jumps in-between climatic regimes (Fig. 3b) with steady decrease in midpoint rainfall receipt of 900 mm, the skewness to the right on the third regime's curve shows that the maximum annual rainfall receipt over the zone during the 90 years considered was during the third regime, this however indicates that increasing rainfall characterized the third regime over the Sudan Savannah zone of Nigeria while minima annual rainfall receipt were during the first and second regimes.

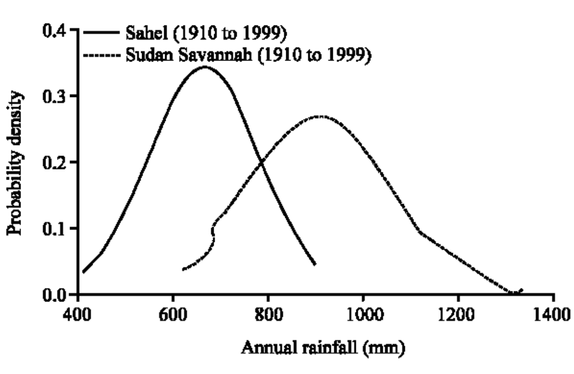

Fig. 2: Rainfall distribution over the zones

During the first regime (1910 to 1939) rainfall ranges between 500-900 mm with about 40% of the total annual rainfall receipt at 700 mm which is similarly to the second regime where annual rainfall receipt ranges between 400 and 900 mm with about 30% at 700 m skewing to the left (Fig. 3). During the third regime, rainfall distribution reduced drastically and the minimum to maximum rainfall receipt falls between 400 and 780 mm with 42% of the total distribution at 600 mm (Table 3).

Results of non-parametric test (Paired-Samples test and Wilcoxon Signed-Rank test) show there was significant difference between rainfall during the second and third, first and third at 95% confidence interval as shown in Table 4 over the Sahel. Mann-Whitney test for change detection as shown in Fig. 4 and 5 shows averaged annual rainfall series for Sudan and Sahel,

Table 3: Result of paired sample test for different pairs of climate regimes

	Paired samples test	
Zone	Paired regimes	Sig. (2-tailed)
Sahel	1-2	0.153
	2-3	0.047*
	1-3	0.026*
Sudan	1-2	0.072
	2-3	0.472
	1-3	0.128

*Significant at 0.05

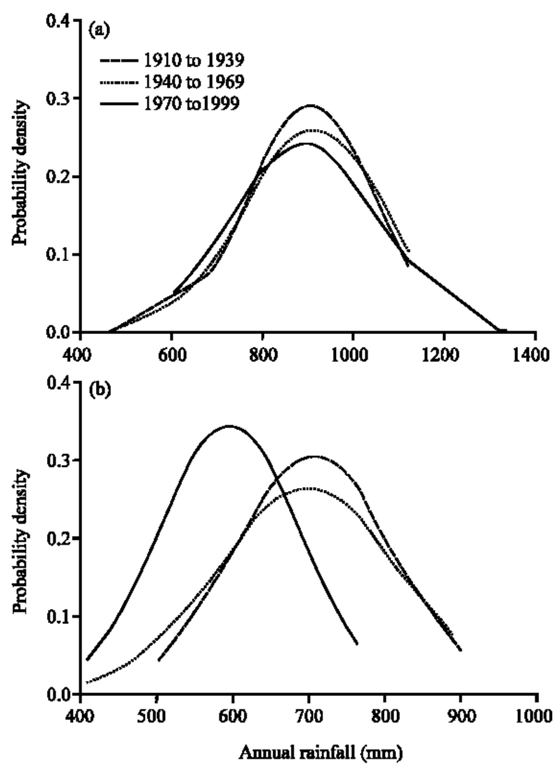

Fig. 3: Zonal rainfall distribution over the climatic regimes. a) Sudan Savannah and b) Sahel

respectively over-laid on the change point series of Pettitt, both figures show common change points and transitions were observed from wet to dry (downward shift) in 1946 during the first regime and in 1969 during the second regime while a upward shift which describes a transition from dry to wet were observed in 1922 during the first regime in 1955 during the second regime and in 1995 during the third climate regime. This indicate the there were both upward and downward shifts across the three regimes except for the third regime with no downward shift in consistence with Olaniran and Summer (1989) who concluded that the Sahelian zone manifested evidence of climate change in rainfall regime. The change points were clearly significant over the Sahel at 99% confidence level which agrees with Oluleye (2009). Some major works have identified the role of different climatological and dynamical features of West Africa to be responsible for such change in rainfall distribution and the dynamics of major factors responsible for dry period over Sahel have been established in several studies

Table 4: Result of Wilcoxon Signed-rank test for different pairs of climate regimes

Climate regims	---Sudan Savannah---			------------Sahel------------		
Regime pair	1-2	2-3	1-3	1-2	2-3	1-3
p-value (2-tailed)	0.152	0.481	0.158	0.134	0.003*	0.043*

*Significant at 0.05

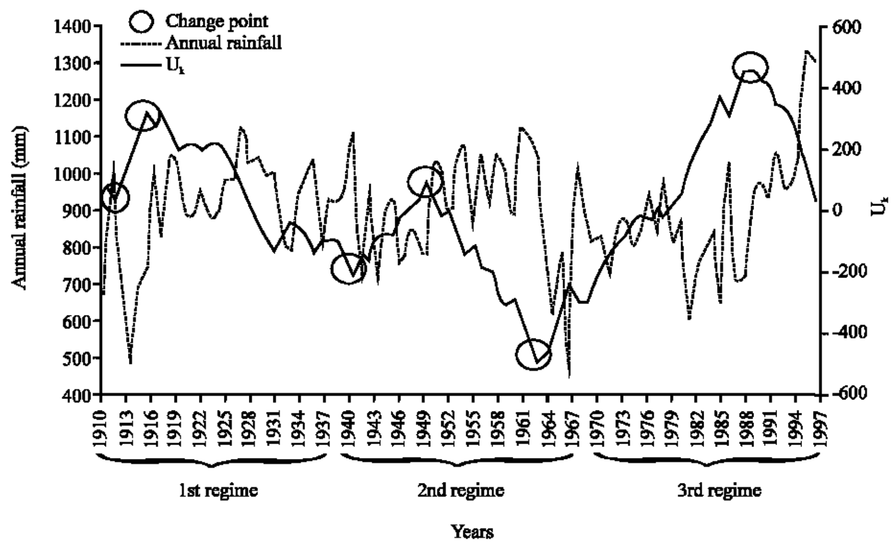

Fig. 4: Pettitt test analysis and rainfall time series for Sudan Savannah

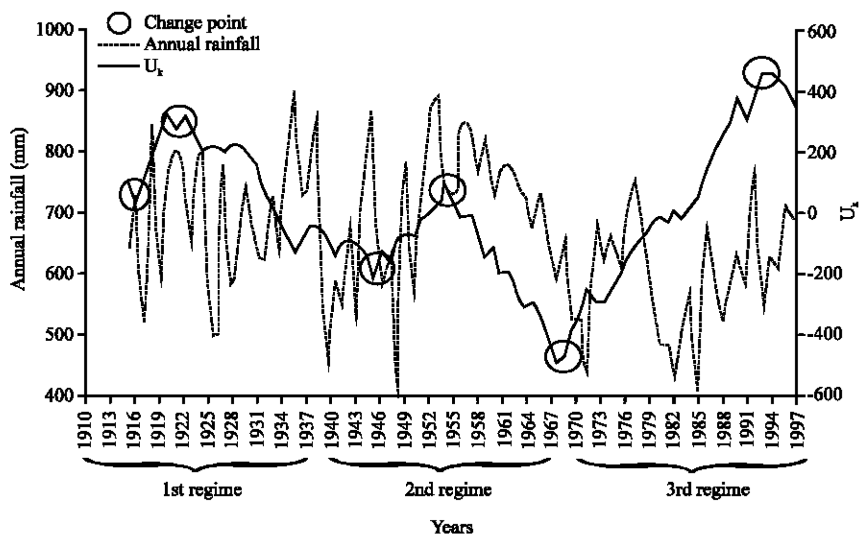

Fig. 5: Pettitt test analysis and rainfall time series for Sahel

(Nicholson, 1986; Omotosho, 2008; Oluleye, 2009). Also, the role of latitudinal location of African Easterly Jets in Sahelian rainfall production mechanism were pointed out in few studies (Grist and Nicholson, 2001; Omotosho, 2008).

Over the Sudan, the distribution of rainfall of the three regimes is not distinctively different as they show almost the same distribution generally ranging from 500-1300 mm. The only observed difference is in the skewness where the first and second regimes were shifted to the left, the third regime skewed to the right. This indicate higher maximum rainfall during the third regime and lower minimum rainfall during the first and second regimes, the non-parametric test carried out over Sudan rainfall shows no significant difference at 95% confidence interval between any pair of the three regimes. However, change points were detected over the entire zone with an observed downward shifts in 1941 and 1964 while an upward shifts were noticed in 1915, 1950 and 1990 with a statistical significant at 95% confidence interval in change points analysis.

CONCLUSION

Analysis of graphs and statistical tests have showed prolonged variability in averaged annual rainfall receipt over the Sahel across the three partitions of climatic regimes, but such change was not statistically established over the Sudan Savanna during the regimes.m The changing point analysis shows transitions between the wet dry and dry wet over the Sahel and Sudan Savannah regions of Northern Nigeria in 1915, 1922, 1955, 1946, 1969 and 1995. There were observed jumps and skewness in averaged zonal rainfall distribution across the climatic regimes which establish variability and change in zonal rainfall receipt over the Northern Nigeria. However, the supposed redistribution of rainfall due to global warming imposes a change in zonal rainfall receipt and this follows with erratic rainfall pattern which alters agricultural practices over the region such prolonged variability also extend its socioeconomic importance to the groundwater resources and hydrological pattern in Nigeria.

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