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Rainfall distribution and change detection across climatic zones in Nigeria

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ABSTRACT

Nigerian agriculture is mainly rain-fed and basically dependent on the vagaries of weather especially rainfall. Nigeria today has about forty-four (44) weather observation stations which provide measurement of rainfall amount for different locations across the country. Hence, this study investigates change detection in rainfall pattern over each climatic zone of Nigeria. Data were collected for 90 years (1910–1999) period for all the weather observation stations in Nigeria, while a subdivision was made to three (3) non-overlapping climate period of 30 years i.e. 1910–1939, 1940–1969 and 1970–1999. Statistical methods were utilized to justify any change in the average monthly and annual rainfall trend using probability density function and non-parametric tests such as the Pettitt test, Wilcoxon signed-rank test and paired sample test. Results show common change points and transitions from dry to wet (upward shift) in all climatic zones. Statistical tests performed on the data show that rainfall variation over each climatic zone is significant ($p < 0.05$) between pairs of climate periods. 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.

1. Introduction

Nigeria's population and economy are linked to climate sensitive activities including rain-fed agriculture. An understanding of current and historical rainfall trends and variation is inevitable to her future development especially in agriculture and hydrological sectors. Previous studies have analyzed rainfall trends over entire or part of Nigeria. For example, Adefolalu (1986) examines trends in rainfall pattern using 70-year period (1911–1980) rainfall data from 28 meteorological stations. Bello (1998) extended the work and compared the seasonality of rainfall distribution in Nigeria for two climate periods, 1930–1961 and 1962–1993. Ati et al. (2009) reported significant increase in rainfall over nine stations in northern Nigeria between 1953 and 2002. The results showed a general decline of dry season's contribution to annual rainfall i.e. dry period is getting drier. More recently, Oguntunde et al. (2011) analyzed rainfall trends over Nigeria using 1901–2002 rainfall data from Global Gridded Climatology of Climate Research Unit Time series (CRU TS.2.1). They concluded that annual rainfall has been reduced significantly over 20% of the landscape and the amount of annual rainfall reduced by 50–350 mm in 64% portion of Nigeria. It is important to state that rainfall of Nigeria and West Africa in generally is influenced by the dynamics of continental air mass and maritime air mass which meet along a slanting surface called Inter-Tropical Discontinuity (ITD) (Odekunle, 2004). Varying degrees of convective activity and precipitation takes place at the south of ITD while little or no cloud development or precipitation occur in the northern part of ITD (Ilesanmi, 1972).

This present study differs from the previous ones in the following perspective; firstly, ground observation data used by Adefolalu (1986) and Bello (1998) was extended to year 1999. Secondly, the statistical approach employed is different and more recent. The present study aims to detect change (transition) point in rainfall pattern over Nigeria on a climatic zone basis using non-parametric statistical analysis. This was performed on the average zonal rainfall to show transitions in wet to dry and dry to wet among three (3) different non-overlapping climate periods of 30 years each ie., 1910–1939, 1940–1969 and 1970–1999. This enables the observation of increase or decrease in rainfall received in each of the climatic zones of Nigeria to be established.

2. Study area

The study area, Nigeria was subdivided latitudinally into three zones: Guinea (coast-8°N), Savanna (8–11°N) and Sahel (11–16°N)

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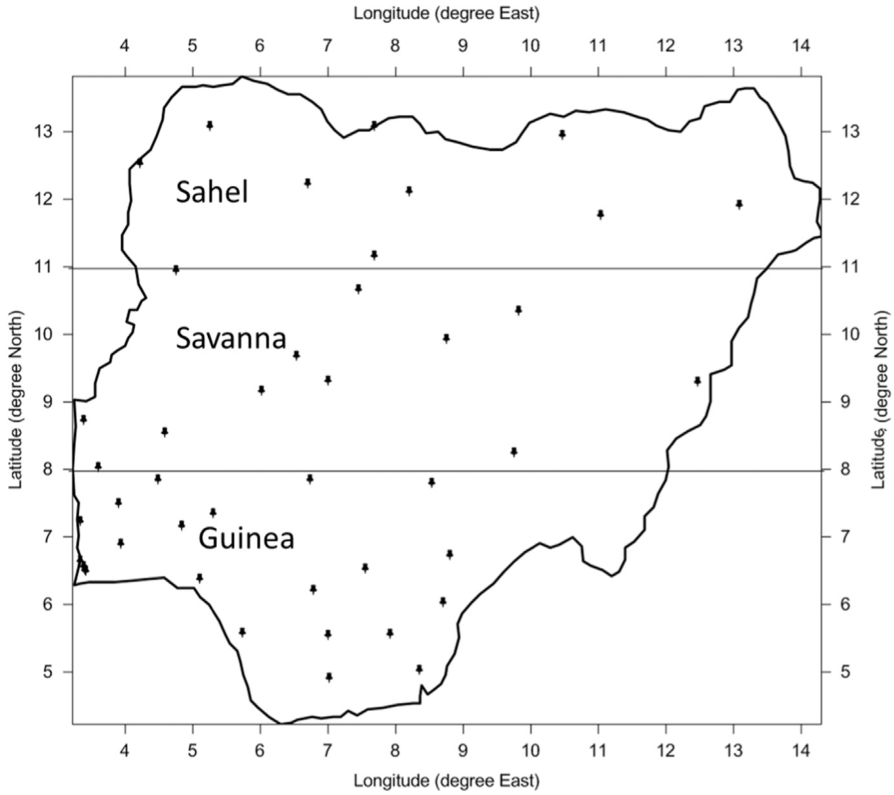

Fig. 1. Meteorological stations and climatic zone division after Omotosho and Abiodun (2007).

Table 1
Utilized Meteorological Stations, and classification to climatic zones after (Omotosho and Abiodun, 2007).

Guinea	Savanna	Sahel
Ikeja, Oshodi (Agromet), Lagos (Roof), Lagos (Marine), Ibadan, Ijebu-Ode, Abeokuta, Oshogbo, Ondo, Benin, Akure, Warri, Onitsha, Port-Harcourt, Owerri, Enugu, Uyo, Calabar, Ikom, Ogoja	Yelwa, Kaduna, Bauchi, Ilorin, Shaki, Bida, Minna, Abuja, Jos, Ibi, Yola, Iseyin, Makurdi, Lokoja	Birni Kebbi, Sokoto, Katsina, Gusau, Zaria, Kano, Nguru, Potiskum, Maiduguri

following Omotosho and Abiodun (2007) as shown in Fig. 1. The names of Nigeria Meteorological Agency (NIMET) stations that falls within each zone are given in Table 1.

3. Methodology

IPCC (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 over Nigeria.

Ninty-year monthly rainfall values for all the available meteorological stations in each climatic zone of Nigeria were collected from the archive of the Nigerian Meteorological Agency (NIMET) and the annual values over each station were calculated as per equation (1):

$$A = \sum_{i=1}^{12} R_i \tag{1}$$

Where R is the monthly rainfall amount at each station, i is the months of the year, and A is the annual rainfall amount at that station.

Further subdivision was done and the study period was classified into three different non-overlapping climate periods of 30 years each.

Variation exists in rainfall received even between stations that fall in the same climatic zone, hence, for stations that fall in the same zone, zonal averages of rainfall were obtained for stations (1 to j) using relation (2).

$$\overline{R_z} = \frac{\sum_{j=1}^{n} A_j}{n} \tag{2}$$

where $\overline{R_z}$ represents the average annual rainfall for the zone at any given year, and n is 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

$$P[a \le X \le b] = \int_a^b f(x)dx \tag{3}$$

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

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

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

$$E[X] = \int_{-\infty}^{\infty} xf(x)dx \tag{5}$$

Note: Variable in the context of this study is rainfall amount.

To determine if two sets of data are significantly different from each other Wilcoxon signed-rank test which is non-parametric was used to comparing data from paired samples (zonal average rainfall amount of climate periods). The computation was carried out using the SPSS17.0 software. Details of this test can be found in SPSS manual or other statistics text.

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

$$K = \max_{1 \le k \le N} |U_k| \tag{6}$$

where the description of U_k is given by the relation

$$U_k = 2 \sum_{i=1}^{k} M_i - k(N+1) \tag{7}$$

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

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

And change points exist where U_k shows maxima.

4. Results and discusions

4.1. Variation of mean monthly rainfall per climatic period

Monthly rainfall pattern over Nigeria takes its conventional mono-modal (Savanna and Sahel) and bi-modal (Guinea) distribution as shown in Fig. 2 and agriculturally sufficient rainfall would not start over the study domain until April. Over Sahel and Savanna, it peaks between August and September. Over Guinea, the first peak is in July followed by a short dry break in August known as the 'August break', then follows the second peak in September. Comparison between monthly rainfalls received in each climatic period over Sahel shows reduction in all months except in August when there was a slight increase in second climate period. The pattern over Guinea and Savanna has some similarities; firstly, there was reduction in early months (March–May) of rainy season during the third climatic period. Secondly, there was an increase and decrease in August and September respectively during the third climatic period.

4.2. Annual rainfall distribution over each climatic zone and period

Gaussian normal distribution (see Fig. 3) shows that annual rainfall ranges from 1400 to 2700 mm (Guinean zone), 950 to 1400 mm (Savanna zone) and 450 to 1050 mm (Sahelian zone) over the entire 90 years of study. Over Guinea, the first period (1910–1939) rainfall ranges between 1740 and 2700 mm with about 10% of the total annual rainfall received at 2200 mm. Second period's annual rainfall received was reduced and ranged between 1600 mm and 2400 mm with about 11% at 2000 mm. Further reduction was observed during the third climate period where the minimum to maximum rainfall received falls between 1400 mm and 2300 mm with 18% of the total distribution at about 1800 mm.

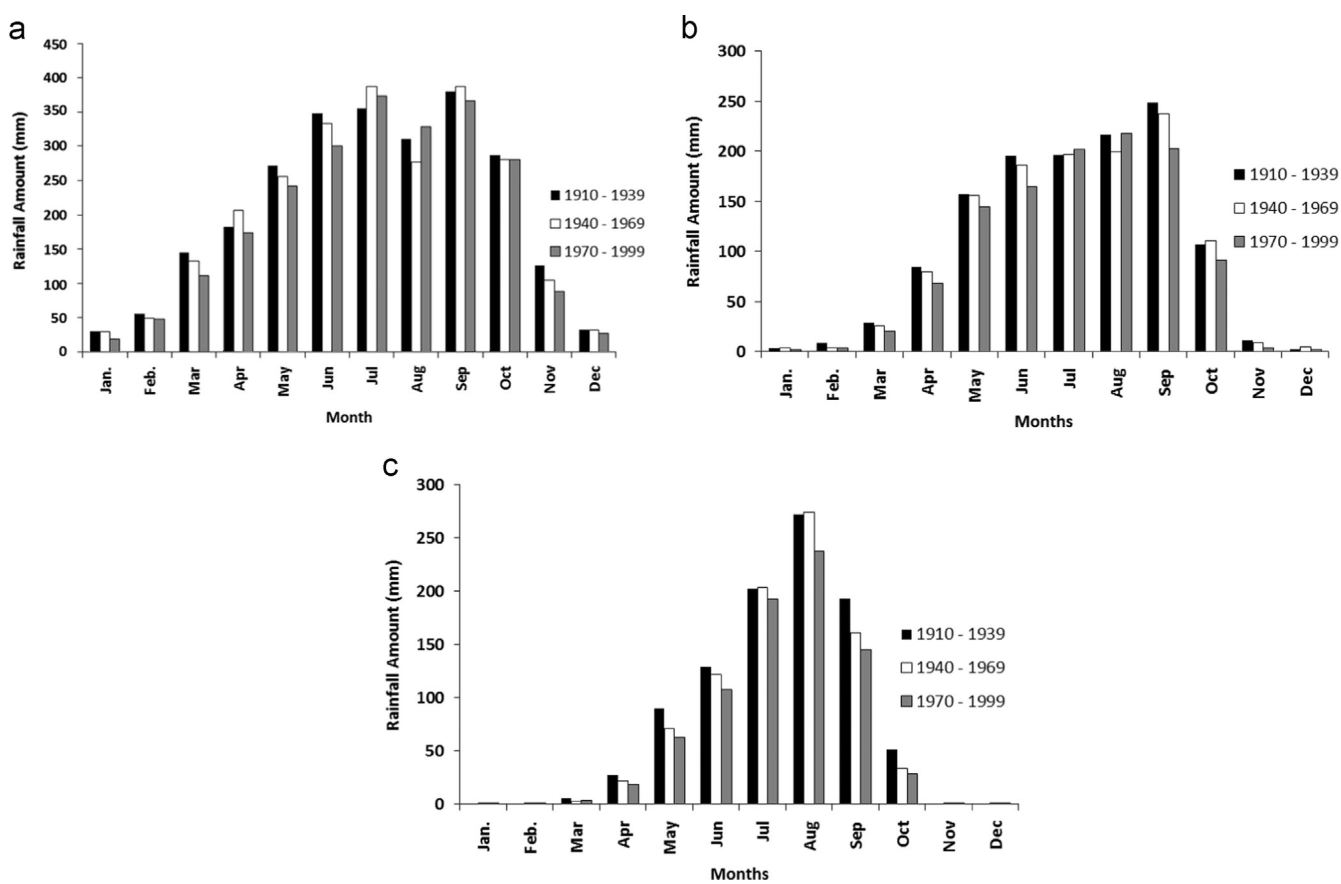

Fig. 2. Comparison of mean monthly rainfalls over Guinea (a), Savanna (b) and Sahel (c).

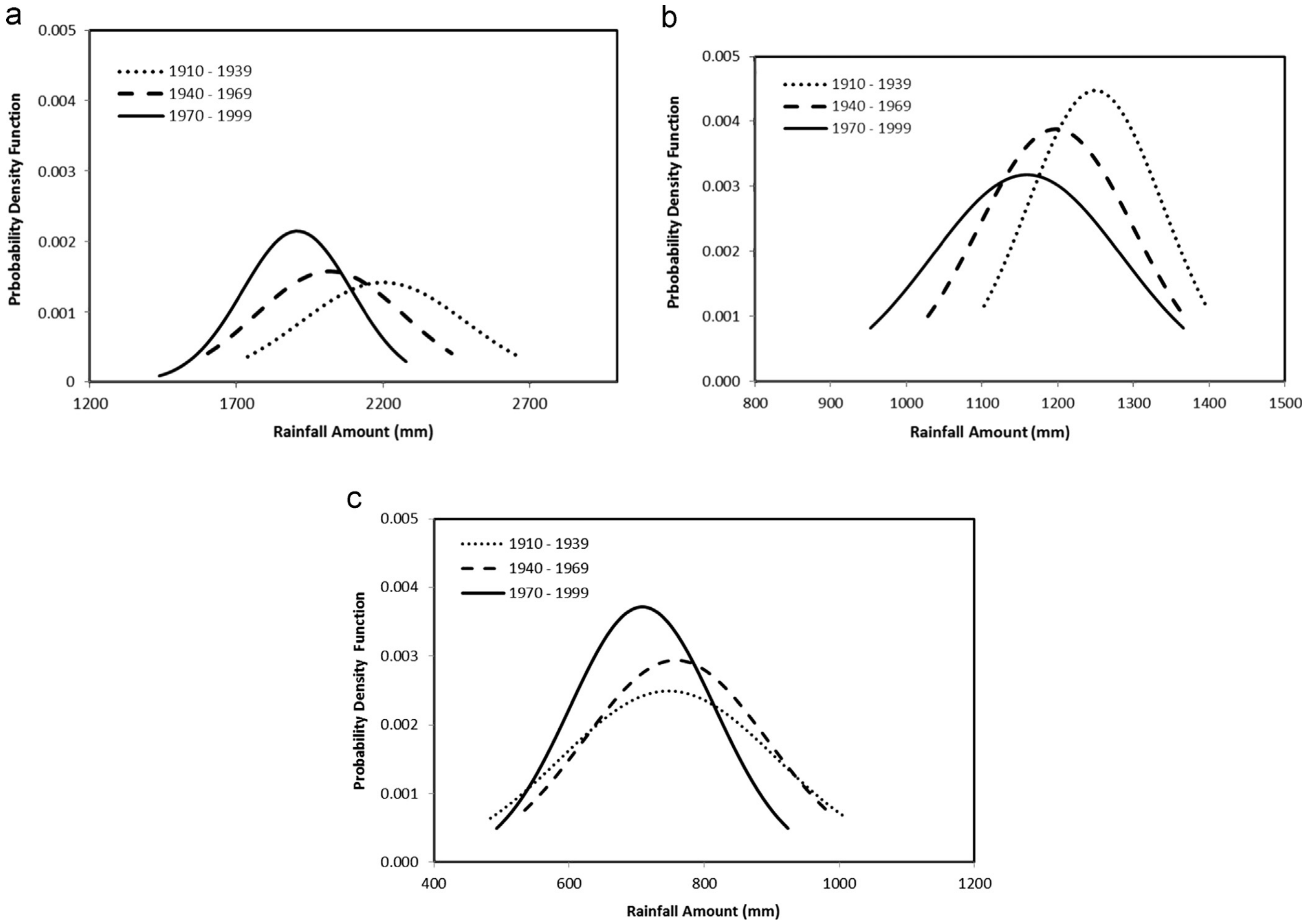

Fig. 3. Mean annual rainfall distribution over Guinea (a), Savanna (b) and Sahel (c).

Table 2
Result of Wilcoxon signed-rank test for different pairs of climate period.

	Guinea			Savanna			Sahel		
Climatic period pair	1 and 2	2 and 3	1 and 3	1 and 2	2 and 3	1 and 3	1 and 2	2 and 3	1 and 3
***P*-value (2-tailed)**	0.015[a]	0.002[a]	0.001[a]	0.003[a]	0.003[a]	0.001[a]	0.026[a]	0.004[a]	0.002[a]

[a] Significant at 0.05.

Over Savanna, first period (1910–1939) rainfall ranges between 1100 and 1400 mm with about 42% of the total annual rainfall received at 1250 mm. Second period's annual rainfall received reduced and ranged between 1000 mm and 1400 mm with about 38% at 2000 mm. Further reduction was observed during the third climate period where the minimum to maximum rainfall received falls between 950 mm and 1360 mm with 30% of the total distribution at about 1150 mm. Over Sahel, first period (1910–1939) rainfall ranges between 480 and 1000 mm with about 23% of the total annual rainfall received at 740 mm. Second period's annual rainfall received reduced and ranged between 580 mm and 1000 mm with about 28% at 760 mm. Further reduction was observed during the third climate period where the minimum to maximum rainfall received falls between 500 mm and 920 mm with 35% of the total distribution at about 700 mm.

This indicates a northward reduction in annual rainfall as supported by previous studies (Adefolalu, 1986; Bello, 1998; Oguntunde et al., 2011). Observation also shows that annual rainfall amount is normally distributed over each zone as there was no obvious skewness in the distribution curve. This does not imply that there were no extreme events during the period of study, such extreme cases are being captured within each climate period curve. A good illustration is the earlier Sahelian drought events of 1968–1973 captured in the third climate period which might be responsible for the significant shift leftward from periods 1 to 3. Quantitatively, a steady leftward jump in between climate periods characterized rainfall distribution over the Guinea coast and Savanna while the shift over the Sahelian zone was only obvious between previous climatic periods and the third. However, Wilcoxon signed rank test result (see Table 2) shows significant difference between each climatic period pair over each zone at 95% confidence interval.

4.3. Annual rainfall trend and change point detection over each climatic zone and period

Pettit test for change detection as shown in Fig. 4 shows averaged annual rainfall series for Guinean, Savanna and Sahelian

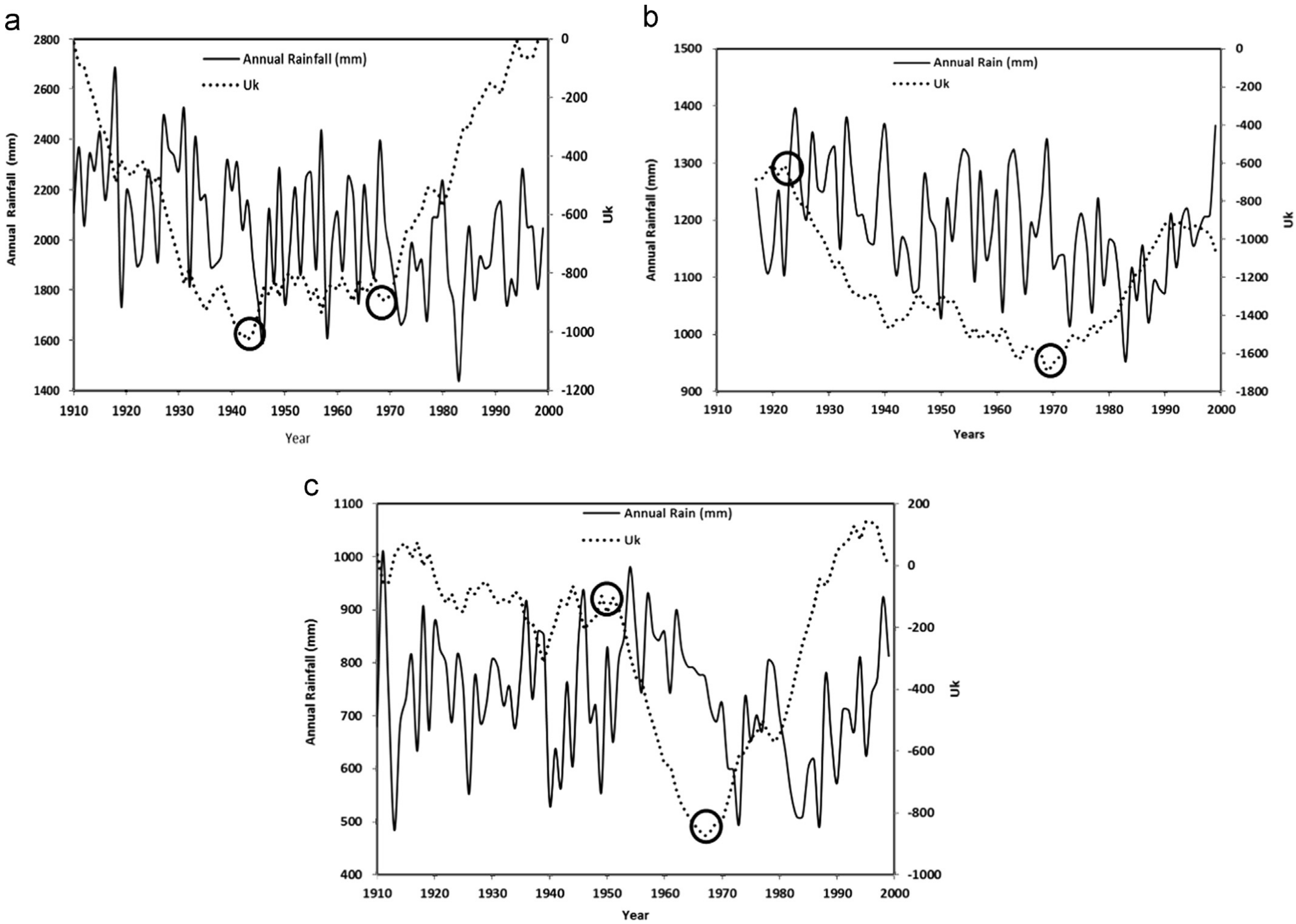

Fig. 4. Mean annual rainfall variation and overlaid change detection parameter over Guinea (a), Savanna (b) and Sahel (c).

zone respectively overlaid on the change point series of Pettit. There are similarities in change points, and transitions among the three climatic zones; for example, an upward shift (dry to wet) was observed around 1970 in the three zones which shows that the change point analysis capture the rainfall recovery from 1960s drought.

Generally, there were upward and downward shifts during the study period over all the zones; over the Guinean zone, there was partial recovery in 1942 and lasted for about 30 years before another change point in 1970. Over Savanna, there was relative dryness since early 1920s but transits in 1970. Over the Sahel, there was downward and upward shift in 1950 and 1969 respectively. The change points were clearly significant over the Sahelian zone 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 Sahelian zone have been established in several studies (Nicholson, 1986; Omotosho, 2008; Oluleye, 2009). Also, the role of latitudinal location of African Easterly Jets in Sahelian zone rainfall production mechanism were pointed out in few studies (Grist and Nicholson, 2001; Omotosho, 2008).

5. Conclusion

Analysis of graphs and statistical tests have showed prolonged variability in averaged annual rainfall received over each climatic zone across the three (3) partitions of climate periods and such variation and changes were statistically established. The change point analysis shows transitions from dry to wet over the three zones between 1969 and 1972. There were observed jumps with no skewness in averaged zonal rainfall distribution across the climatic periods which establish variability and change in zonal rainfall received over Nigeria.

However, the supposed redistribution of rainfall due to global warming imposes a change in zonal rainfall received, and this follows with erratic rainfall pattern which could alter agricultural practices in Nigeria. Such prolonged variability also extends its socioeconomic importance to the groundwater resources and hydrological sector. Beside reducing over dependence on rain-fed agriculture, it is recommended that farmers should plant drought resistant crops or early maturing crop varieties especially in the Sahelian zone. This can be achieved by investment and development of agricultural technologies that are environmentally sensitive. Other adaptive measures for climate users include streamlining farming calendars with the changing rainfall climate period or irrigated agriculture. It is believed that these recommendations among others could help avert the impending food insecurity in Nigeria.

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