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SPATIO-TEMPORAL VARIATION OF RAINFALL AND ITS IMPLICATION FOR AGRICULTURE IN THE SUDANO-SAHELIAN ZONE OF NIGERIA

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Abstract

The paper examines the evolving patterns and trends characterizing rainfall distribution in the Sudano-Sahelian zone of Nigeria. The emerging patterns and trends are then compared to the Intergovernmental Panel on Climate Change (IPCC) model for Sub-Saharan Africa which coincides with the study area is part. The data utilized in the study are monthly rainfall records and number of rainy days (1984-2014). These data were obtained from the database of the Nigerian Meteorological Agency (NIMET). Descriptive statistics of the long-term characteristics of rainfall were computed for all the stations. Computer-generated graphs were also plotted for the long-term monthly as well as seasonal/annual rainfall characteristics as well as Rainfall Anomaly Time series in order to present the inter-annual characteristics of rainfall and by extension moisture distribution for the study area. Results obtained from the study shows that variability in annual rainfall totals is lower than those of monthly totals; there is tendency for variability of annual totals to increase as totals decrease; there has been a general trend towards aridity in most of the stations studied; all the rainfall anomaly time series, when smoothed with five-year running means, revealed patterns characterized by oscillations and the fluctuations are characterized by strong persistence and temporal dependencies. Uncertainty in the onset, cessation and length of the rainy season which has serious implications for agriculture. It is recommended that farmers and other stakeholders avail themselves of this information for better agricultural planning and better productivity.

Key words: *Anomaly, Fluctuations, dry lands, Variability*

1. INTRODUCTION

Rainfall exhibits notable spatial and temporal variability. Inter-annual rainfall variability is large over most of Africa and, for some regions; multi-decadal variability is also substantial. In West Africa (4°-20°N; 20°W-40°E), a decline in annual rainfall has been observed since the end of the 1960s,with a decrease of 20 to 40% noted between the periods 1931-1960 and 1968-1990 (Chappell and Agnew, 2004; Nicholson, 2005).

Advances in our understanding of the complex mechanisms responsible for rainfall variability have been made (see Warren *et al.*, 2006; Washington and Preston, 2006; Christensen et al., 2007). Understanding how possible climate regime changes (e.g., in El Nino-Southern Oscillation (ENSO) events) may influence future climate variability is critical. The drying of the Sahel region since the 1970s has, for example, been linked to a positive trend in equatorial Indian Ocean sea-surface temperature (SST), while ENSO is a significant influence on rainfall at inter-annual scales (Christensen *et al.,* 2007). In the same region, the intensity and localization of the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ) also influence rainfall variability(Nicholson and Grist, 2003), as well as SSTs in the Gulf of Guinea, and a relationship has also been identified between the warm Mediterranean Sea and abundant rainfall (Rowell, 2003). The influence of ENSO decadal variations has also been recognized in South-west Africa, influenced in part by the North Atlantic Oscillation (NAO) (Nicholson and Selato, 2000).

Several studies also have highlighted the importance of terrestrial vegetation cover and the associated dynamic feedbacks on the physical climate (see Christensen et al., 2007).An increase in vegetation density, for example, has been suggested to result in a year-round cooling of 0.8°C in the tropics, including tropical areas of Africa (Bounoua *et al.,* 2000).

Better quantitative estimates of Saharan dust loadings and controls on emissions have now emerged from both satellite and field campaigns (e.g. Washington and Todd, 2005; Washington *et al.,* 2006).

Changes in extreme events, such as droughts and floods, have major implications for numerous Africans and require further attention. Droughts, notwithstanding current limitations in modeling capabilities and understanding of atmospheric system complexity, have attracted much interest over the past 30 years (AMCEN/UNEP, 2002), particularly with reference to impacts on both ecological systems and on society.

Droughts have long contributed to human migration, cultural separation, population dislocation and the collapse of prehistoric and early historic societies (Pandey *et al.,* 2003). One-third of the people in Africa live in drought-prone areas and are vulnerable to the impacts of droughts (World Water Forum, 2000). In Africa, for example, several million people regularly suffer impacts from droughts and floods. These impacts are often further exacerbated by health problems, particularly diarrhea, cholera and malaria (Few et al., 2004). During the mid-1980sthe economic losses from droughts totaled several hundred million U.S. dollars (Tarhule and Lamb, 2003). Droughts have mainly affected the Sahel, the Horn of Africa and southern Africa, particularly since the end of the 1960s (Christensen *et al.,* 2007).

Floods are also critical and impact on African development. Recurrent floods in some countries are linked, in some cases, with ENSO events. When such events occur, important economic and human losses result in the areas that are affected (Obasi, 2005). Even countries located in dry areas (Algeria, Tunisia, Egypt, Somalia) have not been flood-free (Kabat *et al.,* 2002).

Most of the reviews of climate variability in Nigeria (Adejuwon *et al*., 2006; Ati, 2009; Buba, 2014; Ogunbenro and Morakinyo , 2014 and Oyewole *et al*., 2014), dwelt extensively on rainfall distribution, aspects of climate variability that could significantly affect crop yield and those that determine water supply. Temperature does not pose any limitation on agriculture in the tropics, but rainfall is seen as a critical element in that regard. This validates the statement by Riehl (1954) that 'the growing season lasts thermally, the whole year'. The assertion is applicable to Nigeria by virtue of its being located within the tropical region. As a result, the weather forecaster is seldom asked what the temperature will be: but everyone wants to know about the expected rainfall that spells success or failure for crops.

All the views expressed above are true of the prevailing situation over the Sudano-Sahelian zone of Nigeria. This paper therefore provides an update of current rainfall behavior and patterns especially in the face of emerging trends associated with climate change. The objective of this paper is to highlight fluctuations and possible changes in rainfall series across the region on seasonal and annual time scales. In particular, it assesses whether changes are evident in rainfall patterns and if they may be linked to the general trends of global warming and climate change. The spatial organization of the rainfall variations and changes are also studied with the aim of assessing the part played by regional and local geographic factors. The analysis is expected to shed light on the status of climatic resource and its suitability for agriculture in the region.

2. MATERIAL AND METHODS

The data used for the purpose of this study was obtained from the archives of Nigerian Meteorological Agency (NIMET). The data consist of monthly rainfall records dating back to 1952 and covering 10 stations spread over the study area (see Fig. 1).The location of the stations adequately represents a fair coverage of the study area and its regional climate patterns.

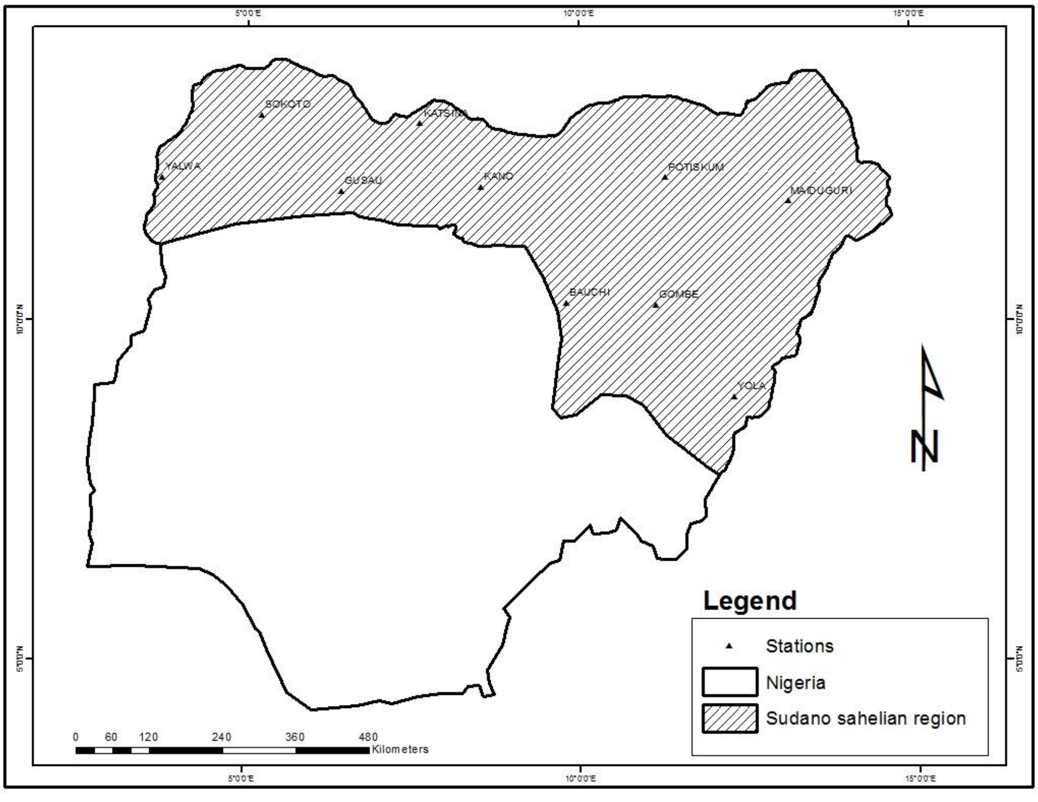

Figure 1: Some Meteorological Stations Located in the Sudano-Sahelian Zone of Nigeria

NIMET uses standard instruments and routine for recording meteorological data as set by the World Meteorological Organization (WMO). These stations therefore possess the most reliable and readily available rainfall records for the region.

Descriptive statistics of the long-term monthly and annual rainfall characteristics were computed for all the stations considered in the study. This was done with a view to facilitating the understanding of spatial and temporal rainfall variations in the Sudano-Sahelian zone of Nigeria.

The long-term mean monthly rainfall values were also used to produce graphs which describe the main features of seasonal rainfall in the study area (see Figure 2). In a like manner, the long-term monthly averages of rainfall were tabled according to the location of the meteorological station in the study area. Variability indices were computed as standard deviation and coefficient of variation.

Rainfall is expressed as standardized departure – departure from the long-term mean divided by standard deviation. This was computed for individual stations distributed over northern Nigeria. The departures provide a sound basis for examining the nature of inter-annual rainfall over the study area, on station by station basis. It also gives information about the water status on annual basis in terms of whether a year can be described as extremely dry (-3) or extremely wet (+3). The classes of ±2 indicates severe conditions, while the ±1classes indicate mildly wet or dry. (After Nicholson, 2000b). This was used to plot time series for each station in order to present the inter-annual characteristics of rainfall for the study area. Moving averages were also computed and superimposed on the time series in order to enhance the identification of fluctuations in the inter-annual behavior of rainfall for the respective locations.

In addition, regression analysis was used with a view to establishing possible linear trends. Regression lines were further superimposed on the individual time series to provide insight on the direction and strength of the trend. The coefficients of determination were computed in addition, to provide a basis for the trends observed in the time dependent behavior of rainfall at the respective stations.

3. RESULT AND DISCUSSION

3.1 Monthly Rainfall Climatology

The onset of the rainy season is entrenched in the mechanism that determine the climates of West Africa in general and the study area in particular as highlighted in section 2. The monthly rainfall amount as the season progresses until a peak is reached in August which rhymes with the most northerly position of the ITD. Subsequently, Monthly rainfall amount declines in September and ceases in October. Lately however, onset of rainfall in the study area has been more uncertain, which has been blamed on climate change. Rainfall ceases in September in the Sudano-Sahelian zone, and the same explanation given with respect to onset above obtains.

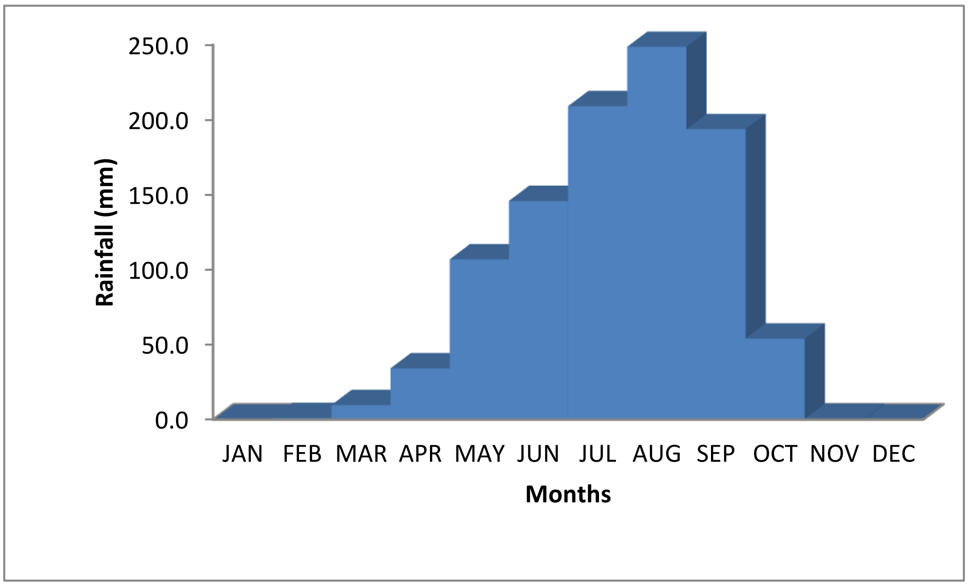

Figure 2a: Long-term Monthly Rainfall at Yelwa

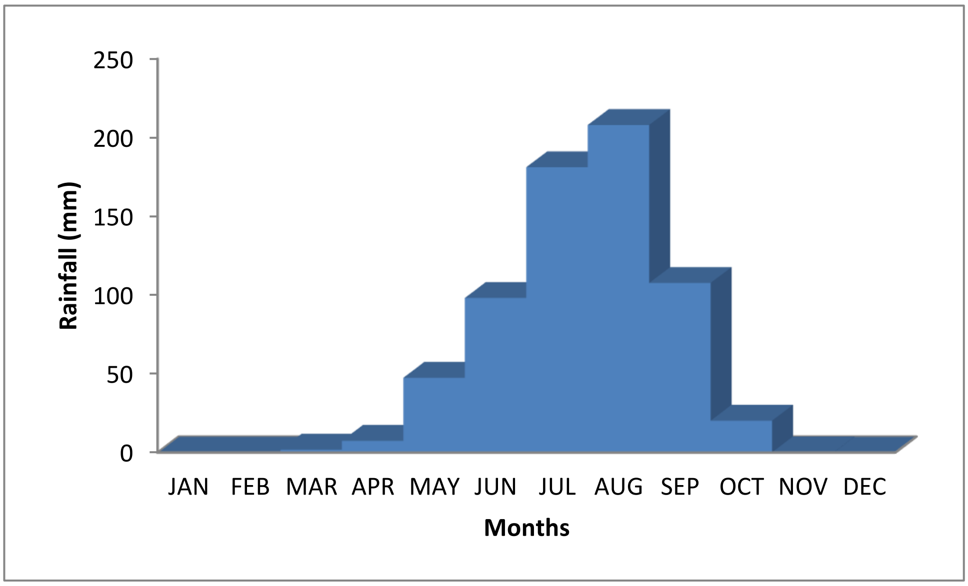

Figure 2b: Long-term Monthly Rainfall at Sokoto

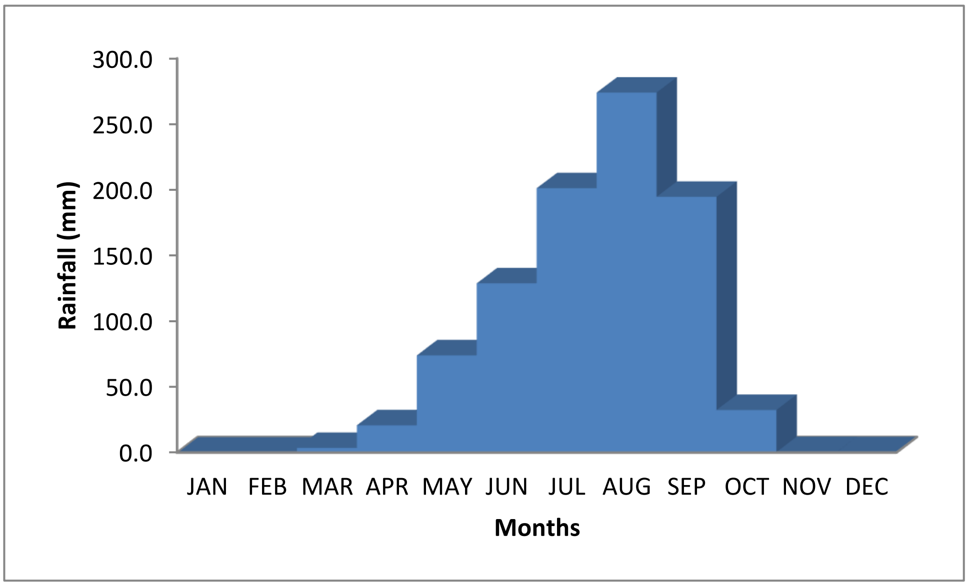

Figure 2c: Long-term Monthly Rainfall at Gusau

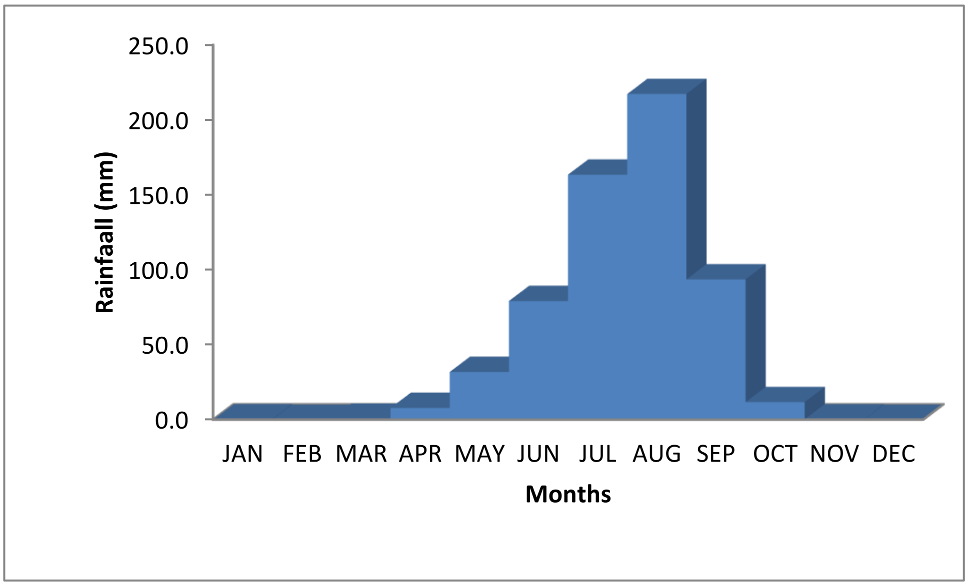

Figure 2d: Long-term Monthly Rainfall at Katsina

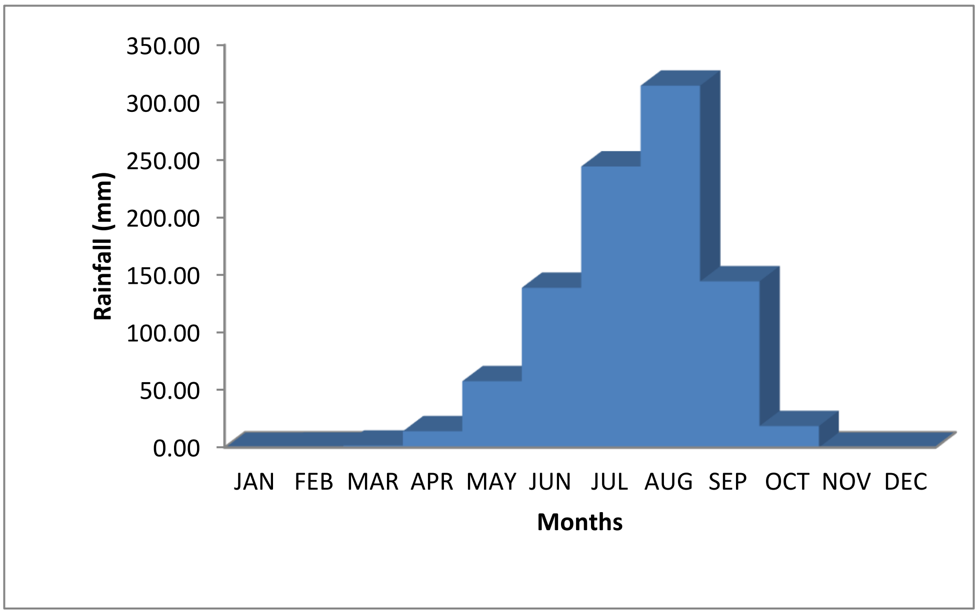

Figure 2e: Long-term Monthly Rainfall at Kano

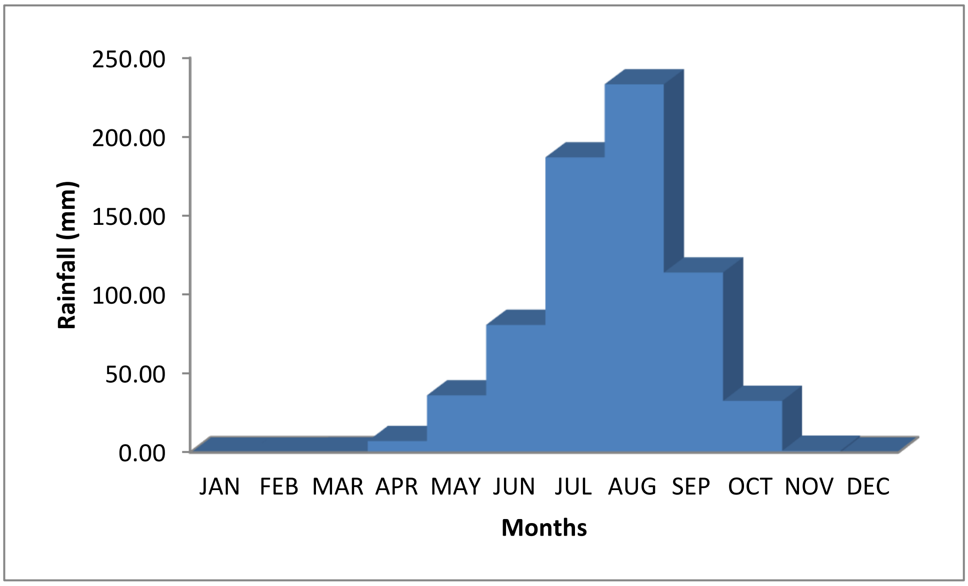

Figure 2f: Long-term Monthly Rainfall at Potiskum

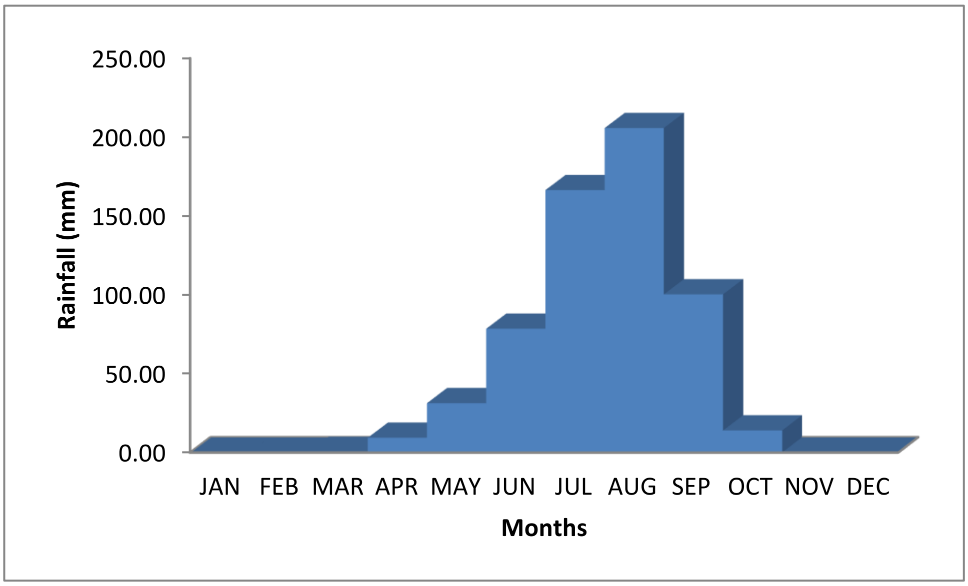

Figure 2g: Long-term Monthly Rainfall at Maiduguri

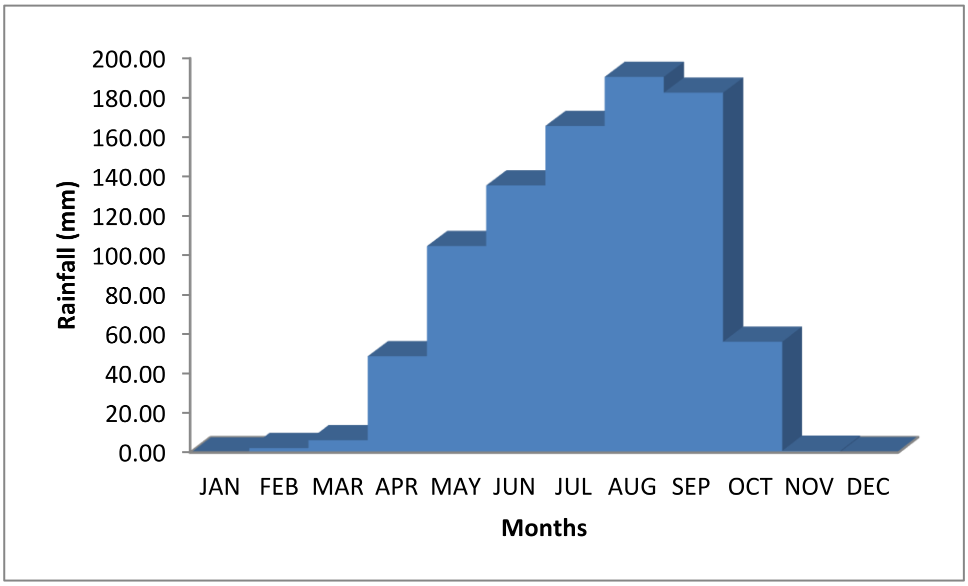

Figure 2h: Long-term Monthly Rainfall at Yola

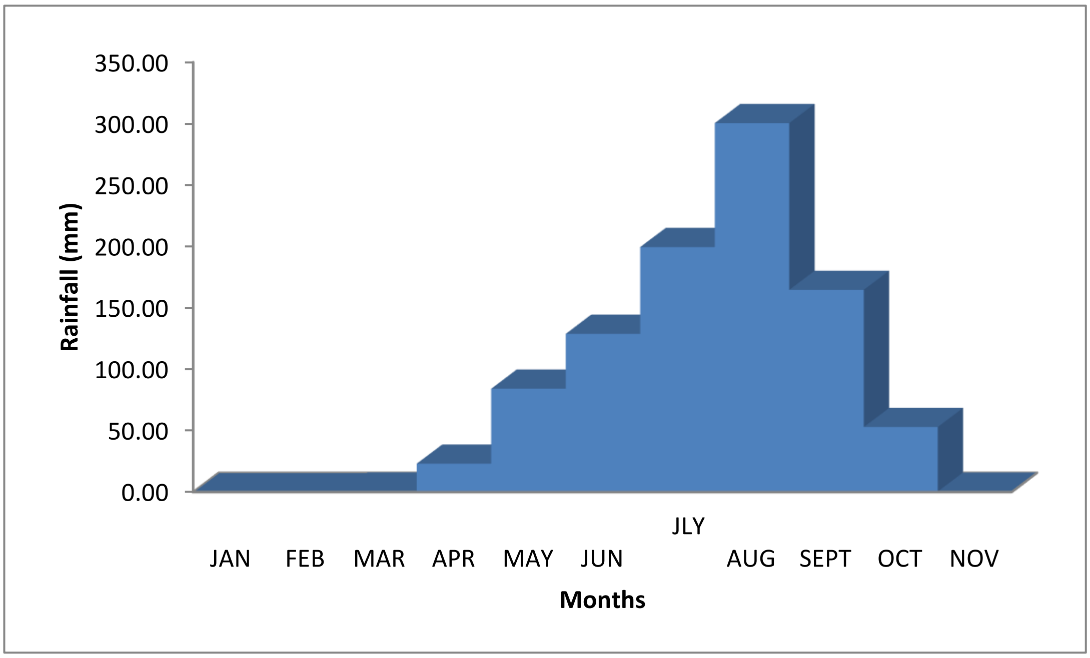

Figure 2i: Long-term Monthly Rainfall at Gombe

In the light of the presentation above, the rainy season over the study area lasts 5 to 7 months on the average. Variation is observed in rainfall duration in relation to different locations in the Sudano-Sahelian zone. Whereas the rains start earlier and stop later in the southernmost parts of the study area, it starts later and ceases earlier in the northernmost parts of the region. This situation is still controlled by the climatic factors that control the distribution of rainfall over the study area.

Closely related to the duration of the rainy season is the amount of rainfall received by stations in the study area. Rainfall amounts continue to increase with the advancement of the rainy season until a peak is reached in August. Rainfall amount then decreases subsequently until it eventually ceases. It can also be seen from Figure 2 that the increase in monthly rainfall amount, from the onset until the peak is reached, is more gradual than the decrease from when the peak is attained to when the rains stop (Buba, 2000).

Monthly rainfall distribution in the study area is characterized by one peak (single maximum) in all the stations. It can also be observed from both Table 1 and Figure 2 that all stations have one peak which is usually attained in August. So far, no shift in the monthly characteristics of rainfall has been observed in the area.

3.2 Annual Rainfall Characteristics

Rainfall in the study area is characterized by strong inter-annual variability. Table 1 presents a descriptive statistics of annual rainfall for the stations considered in this study. Mean rainfall was found to vary from 1056mm to 615mm in the Sudano-Sahelian zone. Whereas mean annual rainfall varies significantly from one station to another (spatially), inter-annual (temporal) variation for individual stations is relatively small. The highest coefficient of variation of (29 %) was recorded in Kano and Katsina, while the lowest figure of 23 was observed at Sokoto.

Table 1: Descriptive Statistics of Annual Rainfall in the Sudano-Sahelian Zone

Climate Zone	Rainfall Station	Mean Rainfall (mm)	Standard Deviation	Coefficient of Variation
Sudano-Sahelian	Sokoto	674.92	154.8	22.94
	Katsina	630.20	184.02	29.20
	Maiduguri	615.09	155.24	25.24
	Potiskum	717.97	186.24	25.94
	Kano	876.80	257.47	29.36
	Yelwa	1009.01	189.47	18.78
	Gusau	907.76	234.44	25.83
	Bauchi	1056.46	174.37	16.50
	Yola	928.41	185.18	19.95

Figure 3 presents a clear picture of rainfall fluctuation in the selected stations covering the study area. It can be seen that the temporal distribution of rainfall is quite variable. Actual rainfall, as indicated by the anomalies, fluctuates around the horizontal axis to which the series have been fitted. This demonstrates the relationship between the long-term mean and changes from one year to the other and the magnitude of the inter-annual variation. This gives a clear picture of fluctuation in moisture status of individual years as being normal, moderately wet or dry, severely wet or dry and extremely wet or dry. By this it becomes possible to assess any year or couple of years as having normal, high or low moisture levels. All the stations considered commonly exhibit these fluctuations which is in conformity the general nature of inter annual rainfall in the tropical region.

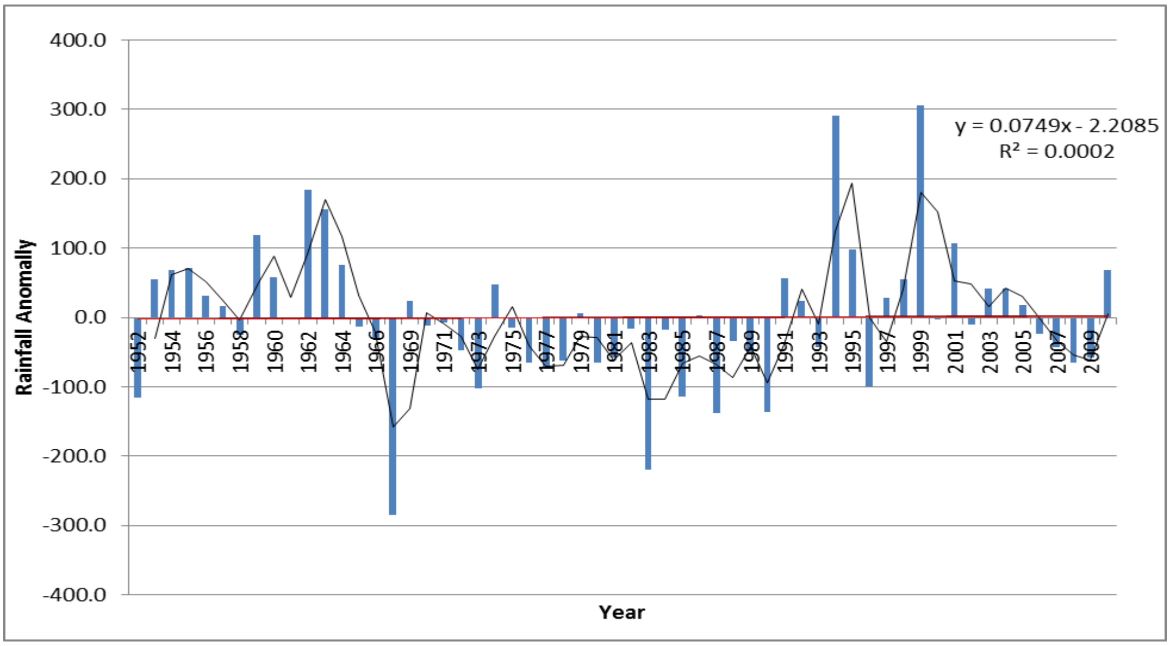

Figure 3a: Rainfall Anomaly at Yelwa (1952 to 2010)

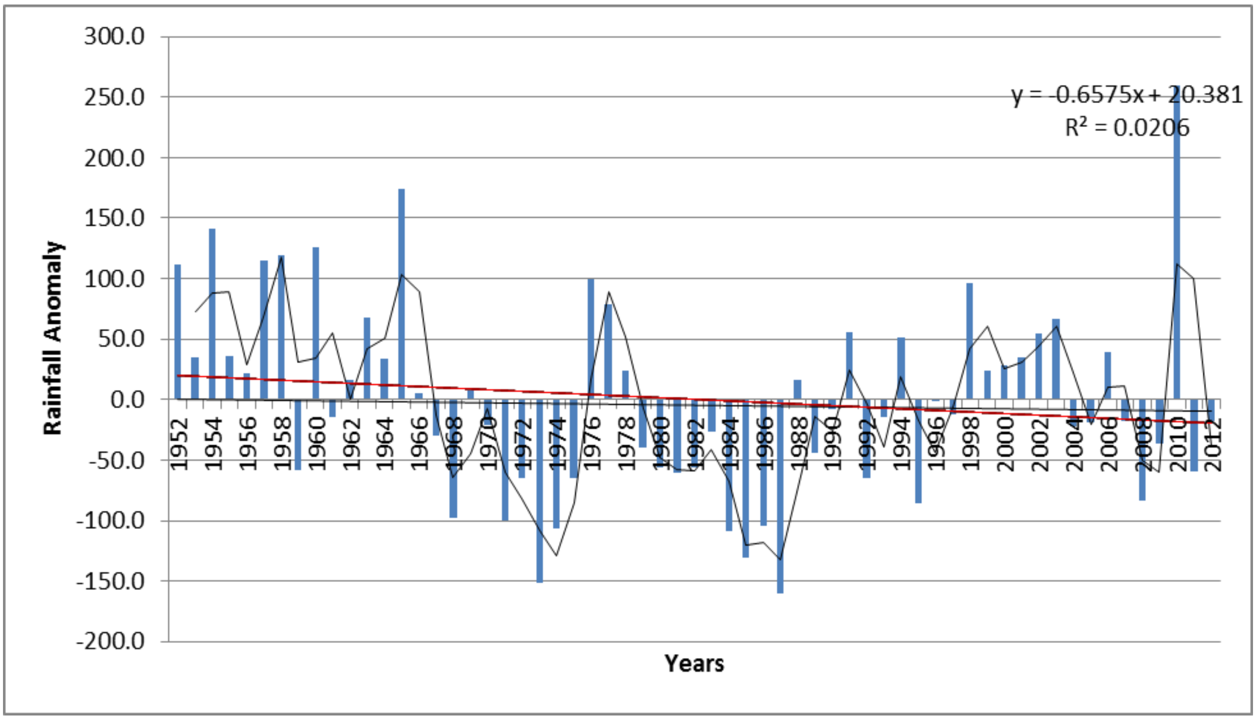

Figure 3b: Rainfall Anomaly at Sokoto (1952 to 2012)

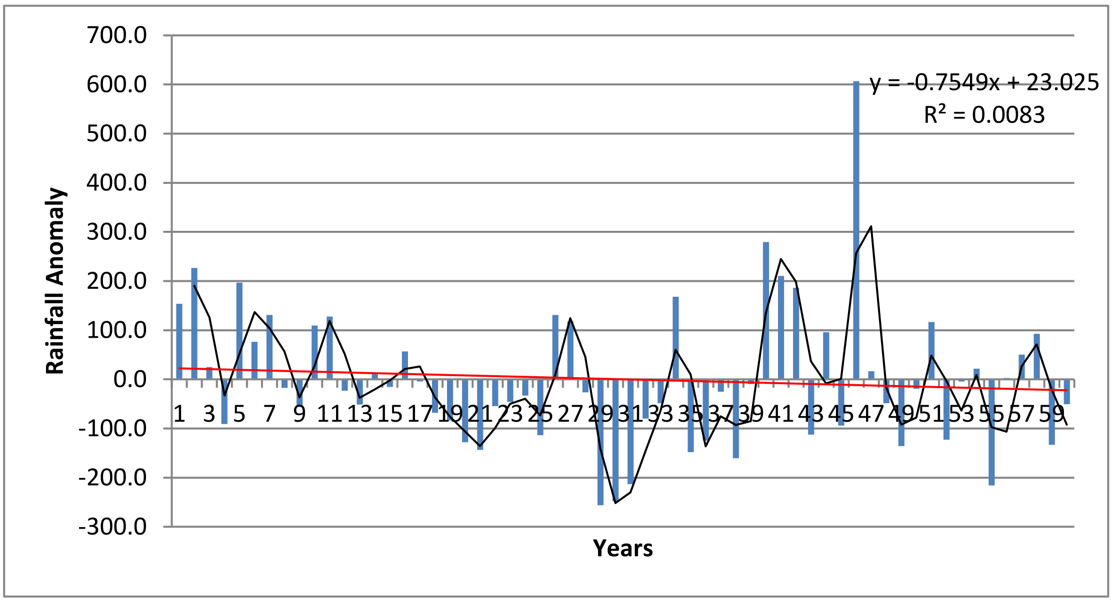

Figure 3c: Rainfall Anomaly at Gusau (1952 to 2012)

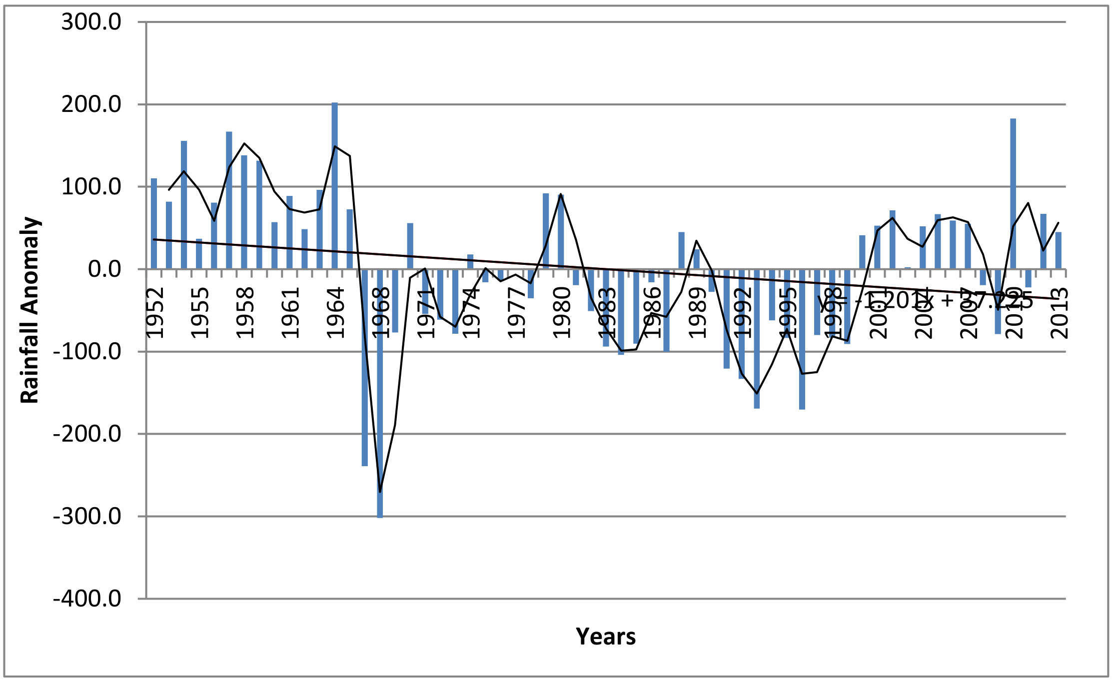

Figure 3d: Rainfall Anomaly at Katsina (1952 – 2013)

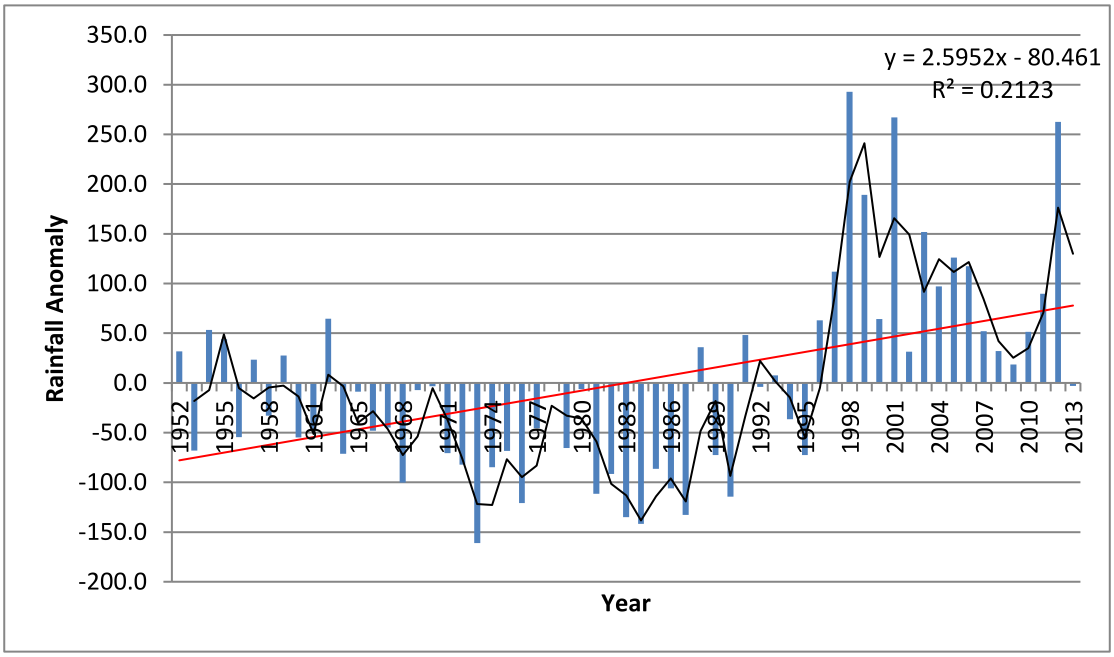

Figure 3e: Rainfall Anomaly at Kano (1952 – 2013)

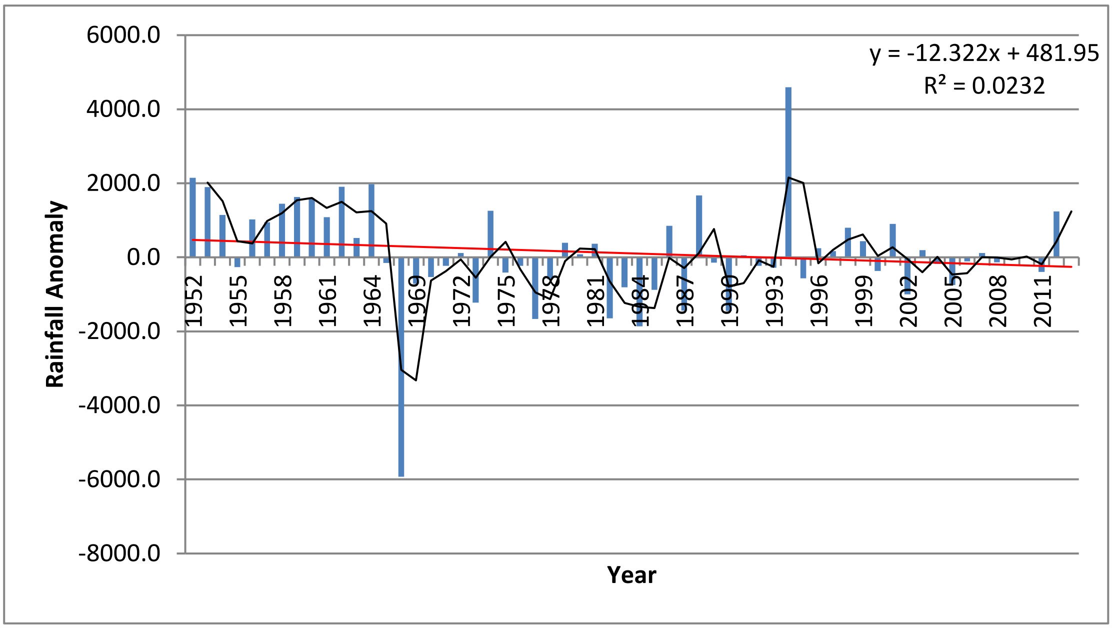

Figure 3f: Rainfall Anomaly at Potiskum (1952 – 2012)

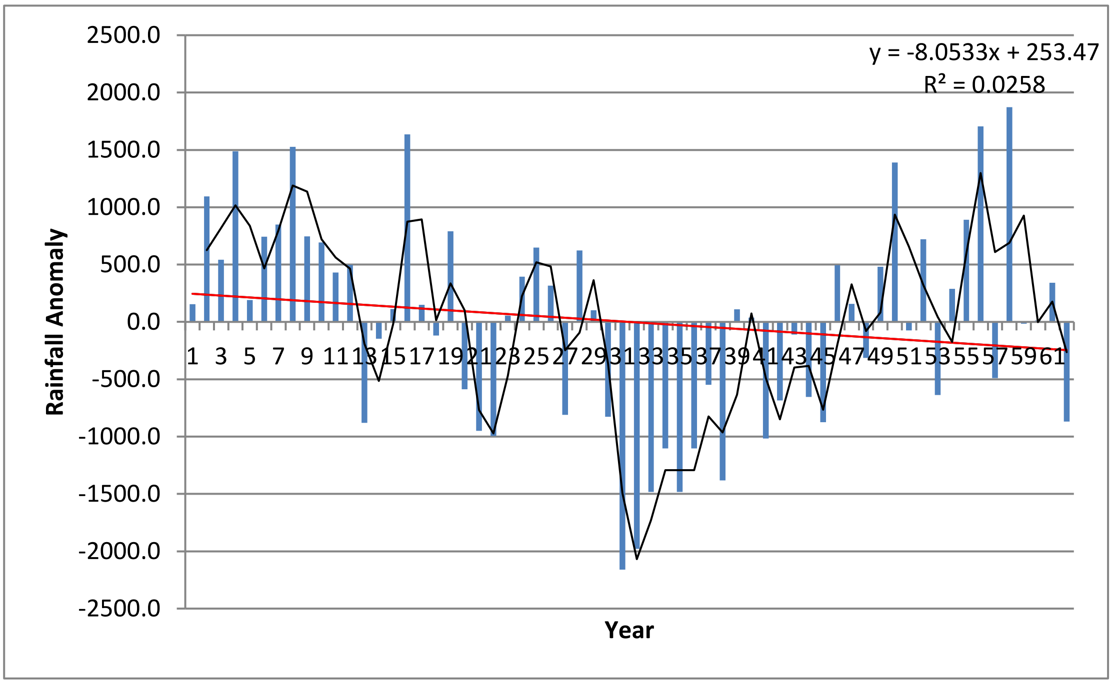

Figure 3g: Rainfall Anomaly at Maiduguri (1952 – 2013)

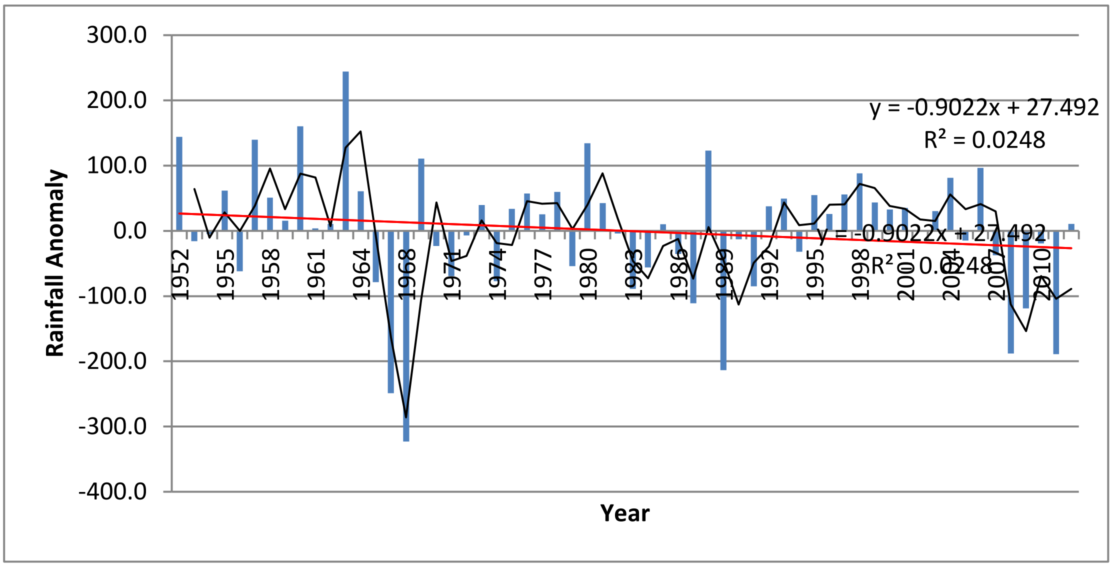

Figure 3h: Rainfall Anomaly at Yola (1952 – 2012)

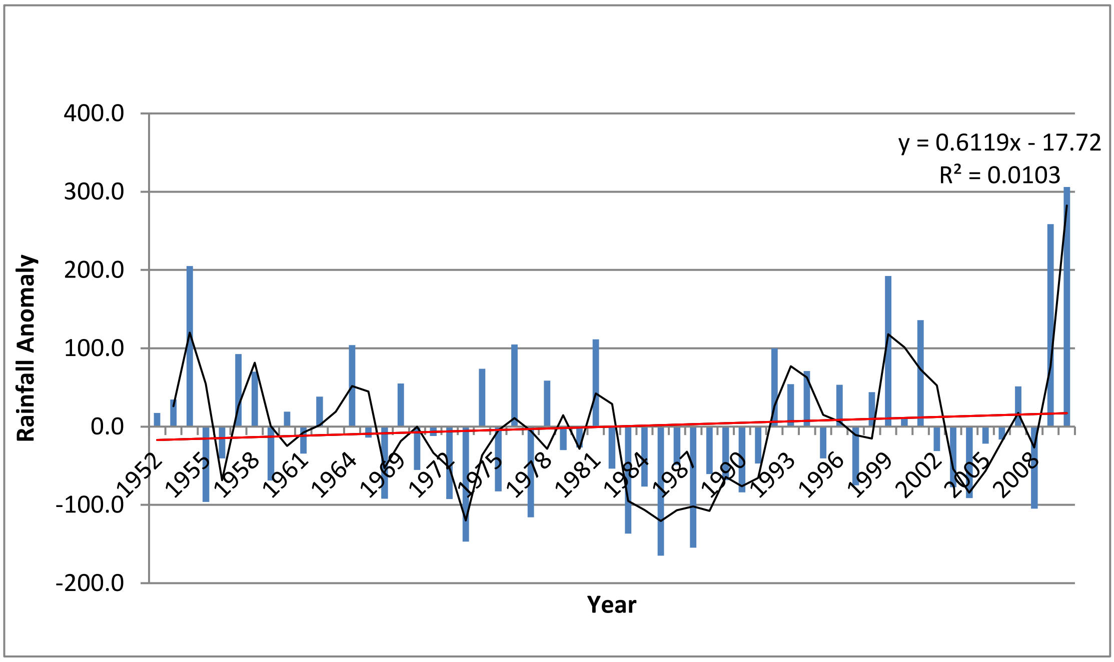

Figure 3i: Rainfall Anomaly at Bauchi (1952 – 2010)

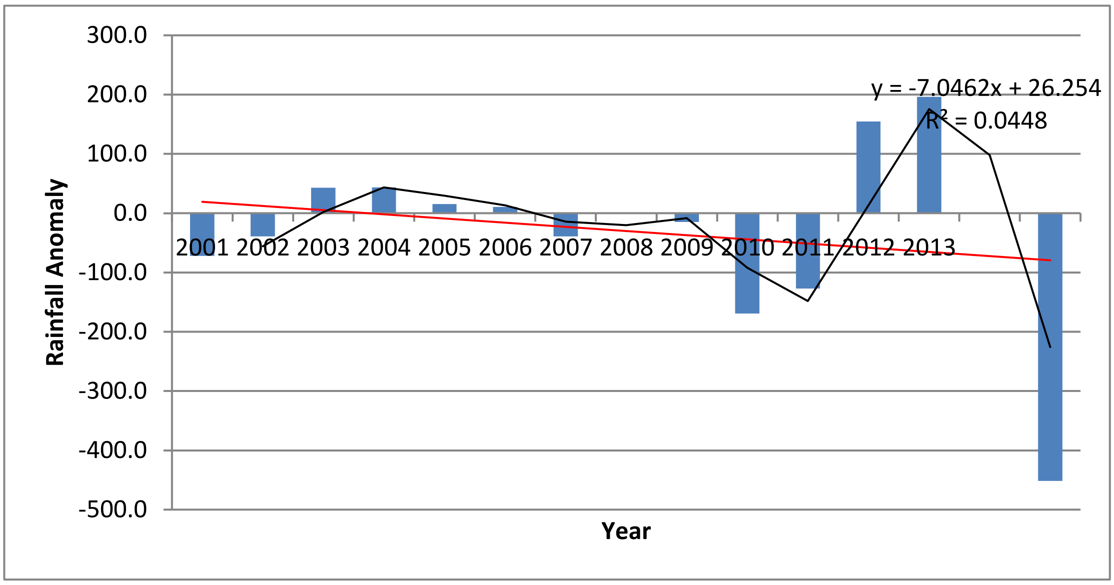

Figure 3j: Rainfall Anomaly at Gombe (2001 – 2013)

A further investigation of the time series, using the five-year running mean showed a tendency for periods of above normal rainfall to alternate with periods of below average rainfall (see Figure 3). However, periods with sustained negative rainfall anomaly have persisted from 1968 until the early 1990s, after which positive anomalies persisted up to the turn of the twenty-first century.

The result of regression analysis is summarized in Table 2; 'r' is the correlation coefficient, while b is the slope of the regression equation. Figure 7 also presents the best-fitting lines. The dominance of negative signs is indicative of a general trend towards aridity. None of the correlation coefficients in Table 2 was found to be statistically significant. This may be due to the fact that the analysis covered long periods with irregular moisture conditions. The trend towards aridity however, as indicated by the "b" values, characterizes most of the stations sampled. Exceptions to this are the b values for Kano and Yelwa. It was further observed that the trend towards aridity seem to assume higher magnitudes at locations in the Sudano-Sahelian Zone. Although the time series showed a general decline in rainfall over time, results of the regression analysis indicated that such descending trends are no statistical significance.

Table 2: Correlation and Regression Coefficient of Rainfall

Climate Zone	Climate Station	Correlation Coefficient (r)	Regression Coefficient (b)
Sudano-Sahelian	Sokoto	0.01	-1.717
	Katsina	0.14	-4.915
	Nguru	0.07	-4.191
	Maiduguri	0.01	-1.815
	Potiskum	0.01	-3.581
	Kano	0.00	1.589
	Yelwa	0.00	0.063
	Gusau	0.00	-2.897

3.3 Rainfall Variation and Agricultural Productivity

The trends and patterns considered is a clear indication that rainfall, and by extension moisture supply is characterized by significant variation. However, most seasons and years can be classified as normal or near normal with respect to moisture distribution. This point of view holds in term of both seasonal and inter-annual condition which ultimately favors agriculture. The remaining seasons and years can be classified as either dry or wet (with varying magnitudes).

Uncertainties regarding climate change, however, are more in terms of magnitude rather than direction. With respect to moisture, the projections are for an increase rather than decrease which conforms to the Intergovernmental Panel on Climate Change (IPCC) models. There was an observed trend towards aridity in the study area. There is an indication that this trend will be put on hold or may slightly reverse as the century progresses. There are possibilities, however, that the additional water need created by higher temperatures may not be met the increases in rainfall. This may have negative effect on agricultural productivity.

There has been an increase in variability of length of growing season in response to the trend in rainfall. This is because the natural variability of rainfall has become more susceptible to the trends probably due to additional human influence superimposed on natural changes. The effect of such entrenched rainfall variability must have effect on crop yield. The severity of impacts of climate variability and change on crop yield in relation to activities of rainfall vary from place to place and from year to year.

In view of the sensitivity of crops yields to this variability, farmers should be encouraged to adopt options that will increase agricultural efficiency, such as application of predicted rainfall onset and cessation dates, and length of the growing season in selecting crop varieties to plant.

4. CONCLUSION AND RECOMMENDATION

Rainfall in the Sudano-Sahelian zone of Nigeria is highly variable in time and space and subject to depletion or enhancement due to both natural and anthropogenic causes. Synoptic factors influence rainfall variability over the study area, especially ocean-atmosphere interactions feedback mechanism. Although stations sampled are not very dense, the method adopted for the analysis of data generated has proved appropriate in identifying the trends, anomalies and variations in rainfall characteristics over the study area. The study shows variability in annual rainfall totals to be lower than those of monthly totals; there is tendency for variability of annual totals to increase as totals decrease; there has been a general trend towards aridity in most of the stations studied; all the rainfall anomaly time series, when smoothed with five-year running means, revealed patterns characterized by oscillations and the fluctuations are characterized by strong persistence and temporal dependencies. Uncertainty in the onset, cessation and length of the rainy season which has serious implications for agriculture is also evident.

It is therefore recommended that farmers and other stakeholders in the region should avail themselves of this information for better agricultural planning and better productivity. This underscores the need for these findings to be publicized among farmers, agricultural extension workers and researchers.

Tolerant crop varieties suitable for this climatic resource base should be developed made available to farmers in this region so as to ensure continual agricultural production.

Further research should be carried out in the area with a view to monitoring possible effect of climate change on rainfall variability in the region.

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