SPATIO-TEMPORAL ANALYSIS OF RAINFALL TRENDS AND IN NORTHWESTERN NIGERIA

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ABSTRACT
The rainfall trends in Northern Nigeria are still poorly understood despite the significance of rainfall to agriculture. This study focused on spatio-temporal analysis of rainfall trends in Northwestern Nigeria. In order to achieve this, rainfall data for Kaduna, Kano, Yelwa, Katsina, Sokoto,and Gusau from 1956 to 2015 were used. Standardized coefficient of Skewness and Kurtosis for the six meteorological stations was employed to test the normality of the data. In order to examine the trend, 10-year running mean and linear trend lines were calculated and plotted using Microsoft Excel Statistical tool (2013). The rainfall series was also sub-divided into 10 years non-overlapping sub-periods and Cramer's test was then used to compare the means of the sub-periods with the mean of the whole record period. The result revealed that rainfall amount is generally increasing in the northwestern part of Nigeria in recent years; and that the amount is unevenly distributed. The study recommends that more opportunities should be provided by the government for professionals to study and develop realistic methods for utilization of ground water without socio-economic concerns, as well as managing flood events. In such a case, it would be possible to counter drought and flood crises occurrence in the northwestern zone and other areas having the same climatic conditions.

Keyword: Northwest zone, rainfall, running mean, sub-periods and trends

INTRODUCTION

Evidence show that climate change is increasing rainfall variability and the frequency of extreme events such as drought, floods, and hurricanes [1]. It was predicted that Africa is likely to warm across all seasons during this century with annual mean surface air temperatures expected to increase between 3^0C and 4^0C by 2099, roughly 1.5 times the average global temperatures [2]. Projections in East Africa suggest that increasing temperatures due to climate change will increase rainfall by 5-20 percent from December to February, and decrease rainfall by 5-10 percent from June to August by 2050 [1, 3]. Fluctuations of climatic elements, particularly rainfall in northern Nigeria is not new especially in the northwestern ecological zone which comprises the northern Guinea, and Sudan-Sahel ecological zones of West Africa [4, 5].

Rainfall variability is a major characteristic of the Sahelian climate, the last 40 years (since 1969) have witnessed dramatic reductions in mean annual throughout the region [3, 6, 7, 8, 9, 10, 11]. According to [1, 12] a rainfall decrease of 29-49 percent has been observed in the 1968-1997 period compared to the 1931 – 1960 baseline period within the Sahel region. In Northwest zone of Nigeria, particularly, rainfall shows a vivid effect on agriculture. Rain is essential to agriculture because without water no plant can survive. Thus, a regular rainfall is essential for healthy plants, too much or very little rainfall can harm plants and agriculture. Extreme weather events have attracted considerable attention in recent years because of the large losses of life as well as tremendous increase in economic losses caused by such extreme events [1, 13].

Available literature on Nigeria shows the existence of spatial differences in the nature of disasters [14]. While oil and gas pollution is largely a Niger Delta problem, drought and quelea birds infestation occur in the Northern States [14, 15]. Several studies in the Northern region have indicated that the onset of the raining season is highly variable and unpredictable [16, 17, 18, 19].

One of the several hypotheses put forth to explain the decline of rainfall in West Africa and Nigeria in particular is the reduced northward excursion of the Inter-Tropical Discontinuity (ITD) during the raining season [20, 21, 22]. In addition, [22] noted that the displacement of ITD south of its normal position would result in drier years. The ITD is situated well to the north of West Africa in July and August thereby allowing Nigeria to be totally under the influence of Tropical Maritime Air mass [19]. In agreement with these views, [23, 24, 25] concluded that a reduced summer incursion of ITD would correspondingly result in a decrease in the Sahelian rainfall.

With further significant variations in the climate of the Sahel being predicated by the General Circulation Models (GCMs), it is important that scientific studies be undertaken at regional level so as to provide society with accurate information on the real and potential impacts of extreme climate variability, as well as, the mitigation and adaptation options available. At a time when the world is grappling with diverse environmental problems including global warning, ozone depletion, acid rain, killer hurricanes, destructive thunderstorms, recurrent drought and major flood episodes, any effort at finding explanations to these and other problems should be quite significant, since the environmental, social and economic cost of extreme climatic variability is bound to be enormous from the standpoint of society and human activity. This study therefore examined the spatio-temporal trends of rainfall in Northwestern Nigeria.

STUDY AREA

Northwest zone of Nigeria is located between Latitudes 9^{o} $02^{'}$N and 13^{o} $58^{'}$N and Longitudes 3^{o} $08^{'}$E and 10^{o} $15^{'}$E. The area so defined covers a land area approximately 212,350km^{2} (Table 1). Northwest zone of Nigeria shares borders with Niger Republic in the northern part, Benin and Niger Republic in the Western part, Niger State and FCT to the south, and Yobe, Bauchi and Plateau States to the East.

The climate of northwestern Nigeria is the tropical wet-and-dry type (Koppen's Aw climate type). The wet season starts from April through October with a peak in August, while the dry season extends from November of one calendar-year to April of the next [39]. The annual average rainfall varies from about 2000 mm in the southern part of the region to about 500 mm in the northern part of the study area.

Table 1: Land Area of Northwest Zone by States

States	Square kilometers
Jigawa	23,287
Kaduna	42,481
Kano	20,280
Katsina	23,561
Kebbi	36,985
Sokoto	27,825
Zamfara	37,931
Total	**212,350**

Source: Office of the Surveyor-General

The rainfall intensity is very high between the months of July and August (ranging from 60mm hour^{-1} to 99mm hour^{-1}). The pattern of rainfall in this region is highly variable in spatial and temporal dimensions with an inter-annual variability of between 15 and 20% [40].

MATERIALS AND METHODS

Data Collection

Monthly rainfall data for period of 60 years (1956-2015) was obtained from the archive of Nigerian Meteorological Agency. The data were collected for six synoptic stations namely: Kano, Gusau, Sokoto, Katsina, Kaduna and Yelwa in the Northwest zone of Nigeria (Table. 2). These stations were selected because they are synoptic stations in the drought prone region of the country [26], and they equally satisfied the general criteria used by the European Climate Assessment and Dataset [27] that: (1) data must be available for at least 40 years, (2) missing data must not be more than 10% of the total, (3) missing data from each year must not exceed 20%, (4) more than three months consecutive missing values are not allowed, and lastly, the data were tested and found to be normally distributed.

Table 2: Metrological stations in the Northwest Zone of Nigeria

Stations	Station No.	Latitude	Longitude	Altitude	Period	No. of years
Kano	1206.03	12ºº03'N	08º32'E	475.80m	1956-2015	60
Gusau	1206.14	12º10'N	06º42'E	468.00m	1956-2015	60
Sokoto	1205.51	12º55'N	05º12'E	309.00m	1956-2015	60
Katsina	1307.04	13º01'N	07º41'E	516.63m	1956-2015	60
Yelwa	1004.54	10º53'N	04º45'E	224.00m	1956-2015	60
Kaduna	1007.34	10º36'N	07º27'E	644.96m	1956-2015	60

Source: Nigeria Meteorological Agency (NIMET).

Data analysis

The standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics as defined by [28] was used to test for the normality in the seasonal (April to October) rainfall series for each of the stations. These are the months during which most of the stations in the region receive over 85% of their annual rainfall totals [3, 8, 29, 30]. The standardized coefficient of Skewness (Z_1) was calculated using:

$$Z_1 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^3 / N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^2 / N \right)^{3/2} \right] \Big/ \left(6/N \right)^{1/2} \quad \text{……………………… eq. 1}$$

and the standardized coefficient of Kurtosis (Z_2) was determined as:

$$Z_2 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^4 / N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^2 / N \right)^{2} \right] - 3 \Big/ \left(24/N \right)^{1/2} \quad \text{……………….. eq. 2}$$

where $\bar{x}$ is the long term mean of x_i values, and N is the number of years in the sample. If the absolute value of Z_1 or Z_2 is greater than 1.96, a significant deviation from the normal curve is indicated at 95% confidence level.

To examine the nature of the trends in the rainfall series, 10-year running mean was calculated and plotted using Microsoft Excel Statistical tool (2013). This was used in smoothening the time series. Linear regression was also used to determine the linear trends of the rainfall for the six stations. It is computed as:

$$y = a + bx \quad \text{……………………………..……… eq. 3}$$

where a the intercept of the regression line on the y-axis; b is the slope of the regression line. The values of a *and* b can be obtained from the following equations:

$$a = \frac{\sum y - b\left(\sum x\right)}{n} \quad \text{….…………………………..…. eq. 4}$$

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \quad \text{……………………….…. eq. 5}$$

The rainfall series was sub-divided into non-overlapping sub-periods (1956-1965, 1966-1975 through to the last sub-periods 2006-2015). Cramer's test [31] was then used to compare the means of the sub-periods with the mean of the whole record period. In applying Cramer's test, the mean **(** $\bar{x}$ **),** and the standard deviation (δ *),* were calculated for each station in the study area for the total number of years *(N),* under investigation. The purpose of this statistic was to measure the difference in terms of a moving *t*-statistic, between the mean **(** $\bar{x}k$ **)**, for each successive n-year period and the mean ($\bar{x}$) for the entire period. The t-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1 + \tau_k^2\right)}\right)^{1/2} \tau_k \quad \text{...................................... eq. 5}$$

where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad \text{……………………………..….. eq. 6}$$

where $\bar{x}$k is the mean of the sub-period of n–years. $\bar{x}$ and δ are the mean and standard deviation of the entire series respectively, and t_k is the value of the student *t*–distribution with *N–2* degrees of freedom. This is then tested against the "students" *t*−distribution table at 95% confidence level appropriate to a two-tailed form of test. When t_k is outside the bounds of the two-tailed probability of the Gaussian distribution (equal to 1.96 at 95% confidence level), a significant shift from the mean is assumed.

RESULTS AND DISCUSSION

Rainfall Normality

The results of the Standardized Coefficient of Skewness (Z_I) and Kurtosis (Z_2) for the six stations are presented in Table 3. The results of Z_1 and Z_2 of data for the stations revealed that the rainfall data of all the stations were normally distributed at 95% confidence level with exception of Z_2 for Kaduna and Yelwa. Therefore, no transformation was made to the rainfall series.

Table 3: Standardized Coefficients of Skewness and Kurtosis for the Six Meteorological Stations

Statistics	Kaduna	Kano	Yelwa	Katsina	Sokoto	Gusau
Mean ($\bar{x}$)	1244.19	929.42	981.37	595.18	651.43	910.19
Standard Dev. (δ)	231.86	325.43	183.31	162.21	146.74	170.29
Skewness (Z_1)	1.26	0.78	0.51	0.20	0.74	1.21
Kurtosis (Z_2)	4.61*	0.12	2.19*	-0.36	1.19	1.84
Minimum Value	848.9	434	496.25	262	373.2	675.7
Maximum Value	2246.9	1869.3	1556.2	979	1150.6	1507.1

*Significant at 95% confidence level
Source: Fieldwork (2017)

Spatial Variation of the Rainfall

The highest mean annual rainfall of 1244.19 mm for the 60 years under investigation was recorded in Kaduna while the lowest mean annual rainfall of 595.18 mm was recorded in Katsina (Table 3). The maximum value of rainfall (2246.9 mm) was recorded in the year 1966 in Kaduna while a minimum value of 262 mm was recorded in the year 1993 in Katsina. The annual standard deviation, which has the potential to provide a result of deviation from normal, shows that Kano is having the highest standard deviation of 325.43 mm while Sokoto had the lowest standard deviation (146.74 mm). Generally, the station that recorded the highest amount of rainfall during the study period is Kaduna which is followed by Yelwa, Kano and Gusau, while Katsina recorded the least amount of rainfall during the 60 years under investigation.

Annual rainfall trend and fluctuation

Figure 1 (a-f) shows the graphical presentation of the annual rainfall trends and for the six stations smoothened out with the 10-year running means. Generally, the 10-year running means for all the stations was above the long-term mean from the early 2000s to the end of the study period. The only exception is Kaduna in which the 10-year running mean was along the long-term mean from the beginning of the data (1956) to the end (2015) indicating a normal condition. The linear trend lines for all the stations generally show an increasing trends. It is therefore clear from the results of the 10-year running mean and the linear trend lines that the rainfall has been increasing in recent years.

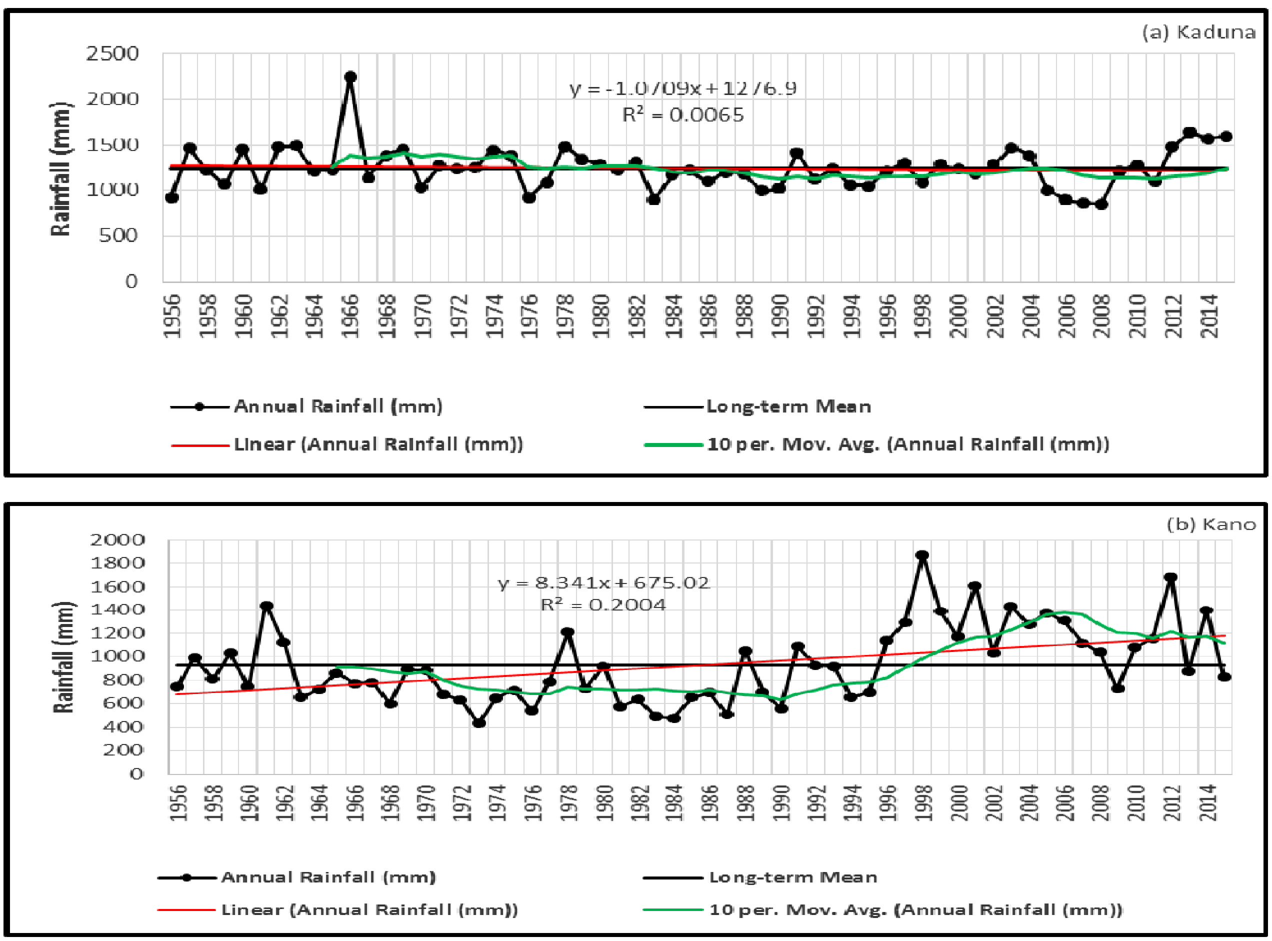
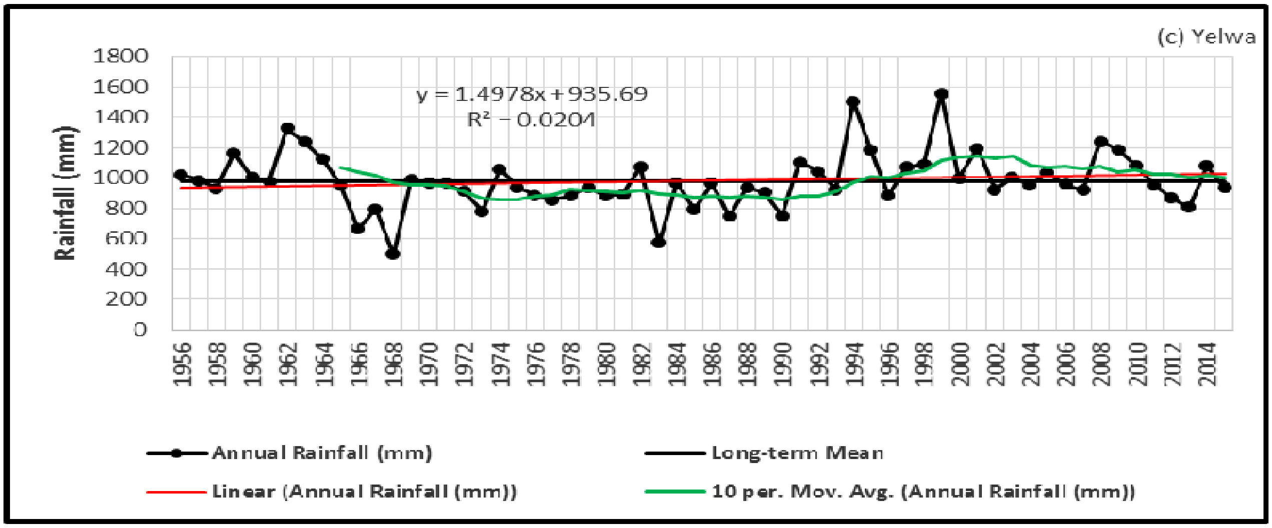
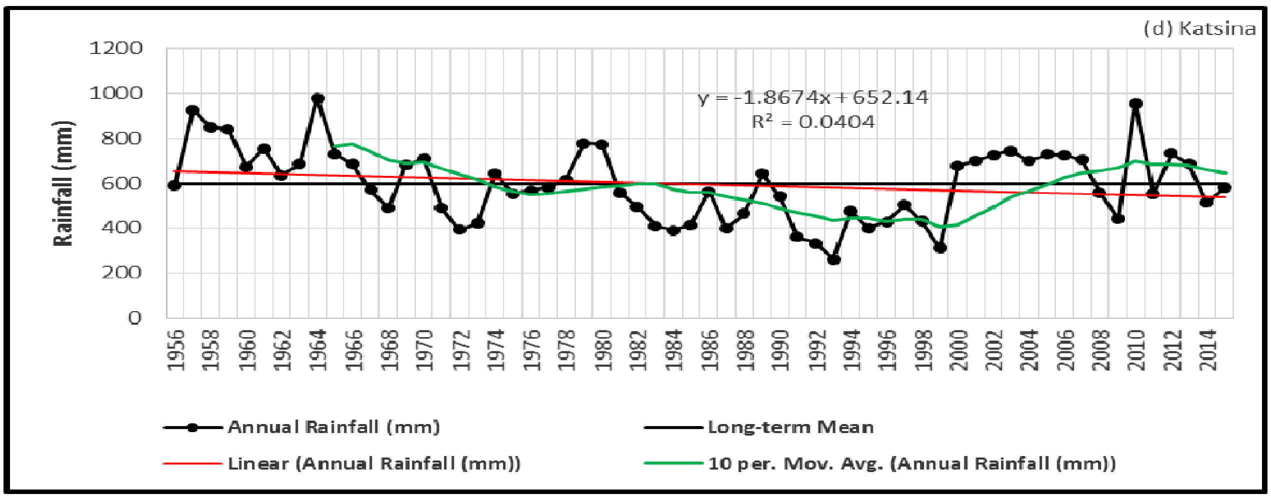
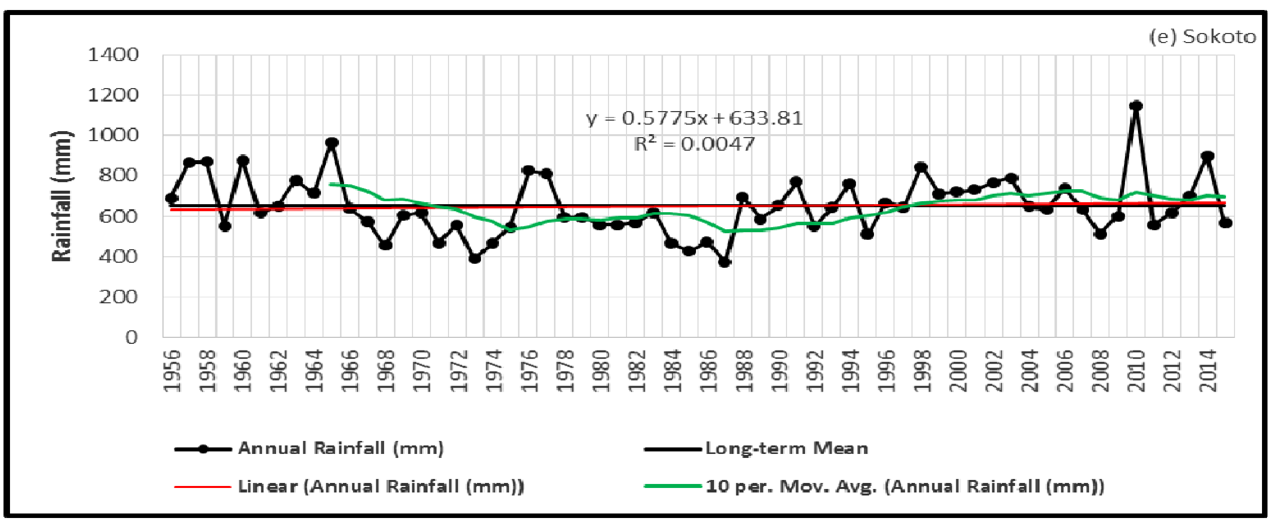


Figure 1: Rainfall Trends and Fluctuation for (a) Kaduna; (b) Kano; (c) Yelwa; (d) Katsina; (e) Sokoto; and (f) Gusau







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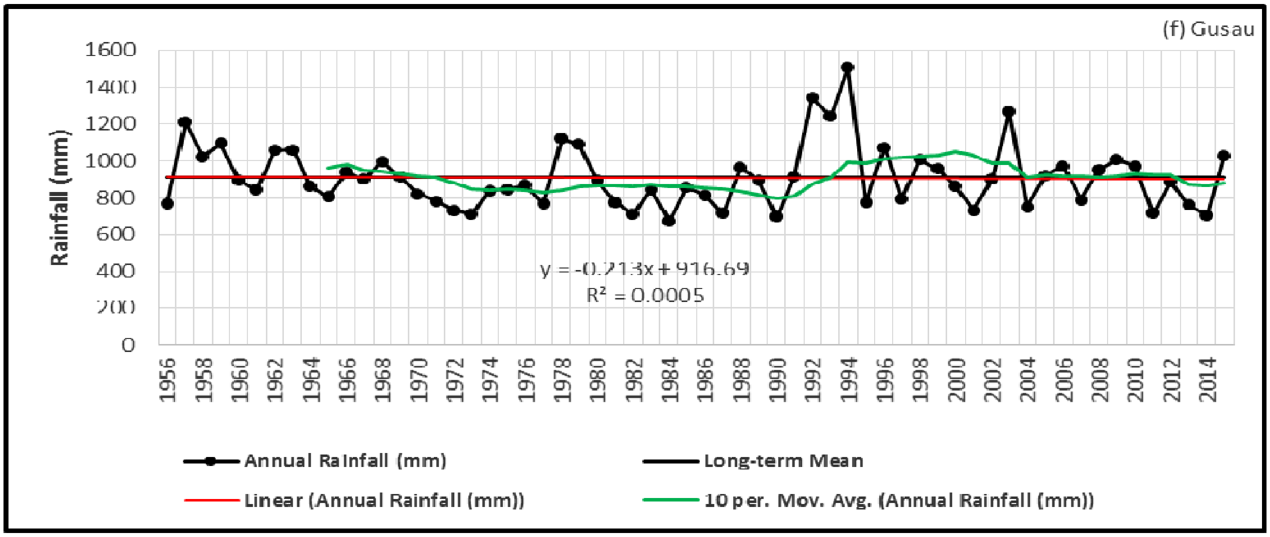

Figure 1: Continued

The result of Cramer's test for variability in the 10-year non-overlapping sub-period of annual rainfall in the six stations is presented in Table 4.

Table 4: Variability in 10 year non-overlapping sub-period analysis of rainfall (Cramer's Test)

Sub-period	Kaduna	Kano	Yelwa	Katsina	Sokoto	Gusau
1956-1965	0.15	-0.18	1.52	2.47*	2.01*	0.98
1966-1975	1.76	-1.94	-1.91	-0.65	-2.15*	-1.18
1976-1985	-0.69	-1.95	-1.71	-0.76	-1.08	-0.97
1986-1995	-1.42	-1.42	0.48	-2.32*	-1.09	1.40
1996-2005	0.00	2.71*	1.51	-0.01	1.38	0.32
2006-2015	0.05	1.73	0.42	1.00	1.02	-0.61

*Significant at 95% confidence level

Source: Fieldwork (2017)

The result revealed five significant cases at 95% confidence level in all. Two significant cases in the sub-period 1956-1965 for Katsina and Sokoto. These two sub-periods for Katsina and Sokoto were significantly wetter at 95% confidence level than the long term condition. All other stations in that sub-period (1956-1965) had a normal condition. The sub-period 1966-1975 had one significant case for Sokoto while the sub-period 1986-1995 had one significant case for Katsina. These two stations (Sokoto and Katsina) were significantly drier at 95% confidence level than the long-term condition as indicated by their negative t*k* values. These periods coincided with the droughts of the 1970s and 1980s that ravaged the northern part of the country. A closer examination of the three sub-periods (1966-1975, 1976-1985, and 1986-1995) showed that out of the 18 cases, only *tk* values of Kaduna (1966-1975), Yelwa and Gusau (1986-1995) were positive. This is an indication of dryness for the three periods. This finding agree with previous studies conducted by [13, 29, 32, 33] that a long run of dry years since the early 1970s has also been confirmed for the zone. [34]. Sub-period 1996-2005 was significantly wetter at 95% confidence level than the long-term conditions for Kano. A critical examination of the last two sub-periods (1996-2005 and 2006-2015) revealed that all the *tk* values were positive with the exception of Katsina (1996-2005) and Gusau (2006-2015) that were having negative *tk* values. This implies that rainfall in the Northwest zone of Nigeria is increasing in recent years. This is in agreement with studies of [30, 35, 36] that the late 1990s have been witnessing increasing annual rainfall totals. However, this result is not in agreement with the conclusions drawn by [3, 6, 8, 37, 38] that the drought-prone areas of northern Nigeria have been experiencing a decreasing trend in the frequency of wet conditions and increasing aridity in the decades 1971-2000. The decreasing frequency of wet conditions may be as a result of the fact that the study was based on data covering up to 2000; but studies that use recent data covering up to 2015 may arrive at the same result with the present study [Notably, 30 and 36].

CONCLUSION AND POLICY RECOMMENDATION

Different statistical methods were used to depict spatial and temporal trend of rainfall in the northwestern part of Nigeria. The result revealed that rainfall in the northwestern part of Nigeria is unevenly distributed. It decreases from the Southern part of the study area to the Northern part. The 10-year running means and the linear trends generally showed that rainfall amount is increasing in recent years. The non-overlapping sub-period analysis also revealed that the last two sub-periods (1996-2005 and 2006-2015) have witnessed increase in rainfall.

This study recommends that more opportunities should be provided by the government for professionals to study and develop realistic methods for utilization of ground water without socio-economic concerns, as well as managing flood events. In such a case, it would be possible to counter drought and flood crises occurrence in the northwestern zone and other areas having the same climatic conditions.

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