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Rainfall Anomalies Pattern in Northwestern Nigeria (NWN)

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Authors' contributions

This work was carried out in collaboration among all authors. Author OGE designed the study, performed the statistical analysis, and wrote the protocol and the first draft of the manuscript. Author BL managed the analyses of the study. Author AAU managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Constant investigation into rainfall anomaly pattern is very crucial as it enables the detection of any departure from normal rainfall condition. When such departure is persistent and statistically significant, it could indicate climate change. This study seeks to investigate anomaly pattern of rainfall in north western Nigeria with the view to determine any extreme departure from established normal rainfall behavior (mean). The study used thirty years (30) rainfall data from 1987 to 2016. The data was obtained from the archives of Nigerian Meteorological Agency (NIMET) for six selected synoptic stations from the region. Purposive sampling technique was adopted in selecting the six synoptic stations given consideration to stations with longer consistent rainfall records. The data was subjected to Standardized Anomalies also known as Standardized Precipitation Index (SPI) to obtain anomaly values. The values were used to plot time series for each station. They were also used to determine the dry or years with drought i.e. negative values and wet or moisture years i.e. positive values. The findings showed that throughout the thirty years period, normal

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conditions dominated the study area with few pockets of dry conditions. The study concludes that rainfall anomalies pattern in north western Nigeria over the thirty years period under investigation was not too far from normal rainfall conditions.

Keywords: Climate; anomalies; fluctuations; time series; drought; moisture.

1. INTRODUCTION

Climate studies are very crucial as it enable the explanation of atmospheric dynamics and its impact on man and his environment. Conversely, the impact of man's activities and other factors in altering known normal and established atmospheric conditions can also be explained. Normal climatic conditions are established by computing the average weather and its fluctuations based on 30 years records [1]. Departures from normal conditions (mean) are known as anomalies (abnormal climatic conditions). Persistent departure from the normal signifies climatic fluctuations, Olaniran [1]. When fluctuations are persistence and are statistically significant for a long time, climate change can be indicated [2] cited in Olalere [3]. Although Landsberg [4] stated that climate change should additionally involves a shift of climatic conditions to a new equilibrium position.

Rainfall is an important parameter in climatic studies. Rainfall is the most variable element of the climate [5]. Rainfall is the key climatic variable that varies with locations, leading to alteration of wet and dry seasons in most areas [6]. Also, in a recent study, Umar [7] established that "annual rainfall pattern over Nigeria had changed from positive in 1931 to 1960 to negative in 1961 to 1990 and back to a positive in the 1991 to 2012". Rainfall pattern could be positive or negative. And examining it deserves urgent and systematic attention for planning, development, utilization and management [8].

Climate change which has become a global challenge in the recent time Kehinde et al. [9] could be understood through the detection of significant statistical anomalies in rainfall behavior over a long time. Climatic variation in north western Nigeria is not altogether new because the area falls within Sudano-Sahelian ecological zone of West Africa. However, since early 1970s, climatic anomalies in the form of recurrent drought, frightening dust storms and rampaging floods have overprinted their rhymes, creating short duration climatic oscillations as against the normal cycles of larger amplitudes. Thus, the last forty seven years have witnessed four severe droughts, numerous dust storms and three killer floods [10]. These in turn have severe effects on agriculture, water supply, human lives and properties. The climate of the region has become indeed unpredictable; hence investigation of rainfall anomaly pattern in the region will help to detect the degree of climate variance from normal trend.

Rainfall anomaly in Africa most especially in the Sahelian region of West Africa has been documented by several researchers [11,12,13, 1]. It was established that negative anomalies prevailed since the late 1960s and the situation deteriorated up to the 1980s. In Nigeria, the period 1921-2000 witnessed a countrywide occurrence of droughts during two periods: first from the 1930s to 1950 and recently from 1970 to the mid-1990s [1]. The drought events persisted more in northern Nigeria over the last three decades. Olaniran noted drought in Sahelian zone from 1970-1977 and from 1980 till 1990 while the most recent drought in the Sudan zone lasted from 1981-1990. This agreed with Abubakar and Ismail, (2019) who in addition found 1980s to witness the highest intensity of drought. The period 1921-2000 also witnessed two distinct wet episodes: 1921-35 and 1951-70. Thereafter, i.e. from the mid-1970s to 2000, the occurrences of wet episodes were a localized affair being regionally restricted rather than occurring countrywide. As with the dry episodes, the wet episodes prior to the mid 1970 were also more pronounced, in terms of duration, in northern Nigeria than in southern part [1]. Earlier studies on rainfall anomalies were limited to year 2000 and their scopes were of large spatial extent encompassing NWN. This study seeks to breach the gap in literature with the view to investigate the current pattern of rainfall anomalies in north western Sudano-Sahelian zone of Nigeria.

1.1 Study Area

Fig. 1 shows the location of the study area which is between latitudes 10^0N and 13^0N and longitudes 3^0E and 12^0E [14]. The study area (North Western Nigeria) shares border with Niger Republic in the north, Benin Republic in the west, Yobe and Gombe States in the northeast, Bauchi state in the east, Plateau state in southeast, Federal Capital Territory and Nasarawa in the south and Niger State in the southwest. The Northwest has a land area of approximately 221,438 Km^2 and a population of about 35,786,969 (NPC, 2006).

The climate of the region is Tropical Continental (Dry) climate also known as Sudan climate, classified by Koppen as $A_{W.}$ [15]. The area from its southern part is situated along the dry sub-humid with annual rainfall totals of over 1000mm; while in its northern part is semi-arid with annual rainfall ranging from 600 to 800mm. The extreme northern part is arid zone with annual rainfall between 400mm to 600mm, [16]. Most of the rainfall is received in August with single maximum regime [17]. Humidity is generally low throughout the year; relative humidity in January is about 20-40%, and it rises to 50-60% in July. Temperature is high throughout the year. Highest temperature is recorded from late March to May ranging from 33^0C to 43^0C, while lowest temperature is recorded during the hamattan period, dropping to less than 20^0C especially in the morning and night. The type of climate describe above gives rise to vast tropical grassland of Northern Guinea, Sudan and Sahel Savanna, [3].

2. METHODOLOGY

2.1 Type and Sources of Data

The meteorological parameter used in this study was rainfall data obtained from the Nigeria Meteorological Agency (NIMET) which archives meteorological data in Nigeria. The data is for six synoptic stations in the North Western Nigeria namely: Kaduna, Yelwa, Kano, Gusau, Katsina, and Sokoto. The data covers a period of thirty years (1987 – 2016). A purposive sampling technique was adopted in selecting the six synoptic stations given consideration to stations with longer consistent rainfall records.

2.2 Standardized Precipitation Index (SPI)

Standardized precipitation index (SPI) propounded first by T. B. McKee, N. J. Doesken and J. Kleist in 1993. The index is based only on precipitation and can be used to monitor conditions on a variety of timescales. It uses rainfall parameter as a sole climatological input for the computation [18]. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any station with precipitation records, [19]. Rainfall anomalies are presented as long term mean deviation score divided by standard deviation.

Standardized anomaly is given as:

$$\frac{(x - \bar{x})}{STD} \qquad \text{(i)}$$

Where x is the annual rainfall total
$\bar{x}$ is the mean of the entire series
STD is the standard deviation

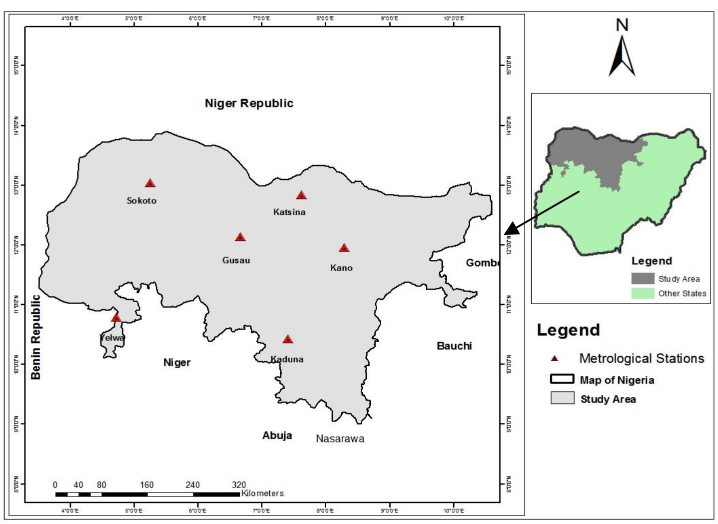

Fig. 1. Map of the study area and the locations of synoptic stations adopted from Olalere, [3]

Arithmetic mean is given as:

$$X = \frac{\sum_{j}^{n}=ixj}{n} = \frac{\sum x}{n} \quad \text{(ii)}$$

Where X = mean or arithmetic mean
$\sum_{j}^{n} = ixj$ is summation (sigma)
Xj is the variables
n is the total number of variables

Standard deviation is defined as the square root of the average of the squares of the deviations from the arithmetic mean given as follows:

$$\delta = \frac{\sqrt{\sum_{i=1}^{n}=(xi-\bar{x})^2}}{n} \quad \text{(iii)}$$

Where δ is the standard deviation
n is the number of observations
Σ is the summation of square of all deviation from the arithmetic
X_1 is the value of an observation
$\bar{x}$ is the arithmetic mean

Annual rainfall anomaly values were computed for all the stations and used in plotting time series for each station so as to present the inter annual characteristics of rainfall for the study area. Anomaly trend was determined by the relationship between rainfall and time. The standardized anomaly is adopted to determine the dry (- ve values) and wet (+ ve values) years.

3. RESULTS AND DISCUSSION

3.1 Rainfall Distribution in North Western Nigeria

3.1.1 Long term mean monthly and annual rainfall distribution in the six synoptic stations

Rainfall distribution over north western Nigeria follows the mechanisms that regulate the arrival and cessation of rainfall in West Africa. The most pronounced and well understood among them is the northward and southward movement of the ITD. Its northward movement begins from February introducing rains to southern West Africa including north western Nigeria. The amount of rainfall increases monthly as the ITD advances northward with less than 50mm in February, March and April, and above 50mm from May except for Katsina with 38mm average monthly rainfall. It reaches its peak in August with the average of 281.3mm when the ITD begins its southward migration as rain declines in all the stations. Fig. 2a to 2f shows that increase in monthly rainfall from the onset until the peak is reached is more gradual than the decrease from when the peak is attained to when rain stops. It is worth noting that all the stations in north western Nigeria showed uni-modal rainfall (single peak) as revealed in Fig. 2a to 2f.

Annual rainfall in the six stations varies spatially as none of the stations showed similar pattern of distribution for the whole period of the study. Table 1 shows the mean, median, maximum and minimum amounts of rainfall received within the period under study. Kaduna, Kano, Yelwa and Gusau have the highest Mean Annual Rainfall values of 1235.8mm, 1114.2mm, 1082.0mm and 926.62mm respectively while Sokoto and Katsina have the lowest Mean Annual Rainfall values of 686.18mm and 579.9. The range is greater in the northern part of the study area like Kano (1283.4 mm) than the southern part like Yelwa (632.8 mm).

From Fig. 2a to 2f and other literatures, rainfall is expected to arrive in April and ceases in October, highest amount of rain is recorded in August and the pattern shows a single maximum. In water resource, planning and management, Kano, Katsina, Guasau and Sokoto have five effective months from May to September for the recharge of surface as well as underground reservoirs, though effective months fluctuate between four and five in Katsina. Kaduna and Yelwa has six effective months of rainfall. A month is effective when the total monthly rainfall exceeds 50 mm (Adejuwon, 2010).

3.2 Rainfall Anomaly Pattern in North Western Nigeria

Fig. 3a to 3f presents a clear picture of rainfall fluctuations in the sampled stations in the study area. It can be seen that the temporal rainfall distribution varies greatly. Actual rainfall as revealed by the anomalies fluctuates along the horizontal axis to which the series has been fitted. With this, the relationship between the long-term mean and changes from one year to another is established.

Table 1. Descriptive statistics of the six stations

Stations	Mean (mm)	Median (mm)	Maximum (mm)	Minimum (mm)	Range (mm)
Kaduna	1235.80	1222.05	1780.8	793.4	987.4
Yelwa	1082.00	1076.25	1419.2	786.4	632.8
Kano	1114.20	1083.95	1789.4	506	1283.4
Gusau	926.62	912.1	1503.8	615.9	887.9
Katsina	579.90	598.8	1310.2	259.8	1050.4
Sokoto	686.18	677.85	1146.7	327.9	773.8

Source: *Author's Computation, 2021*

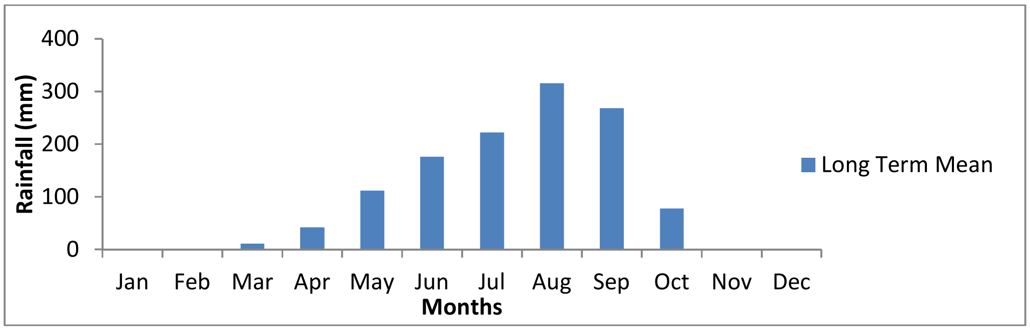

Fig. 2a. Long term mean monthly rainfall distribution for Kaduna

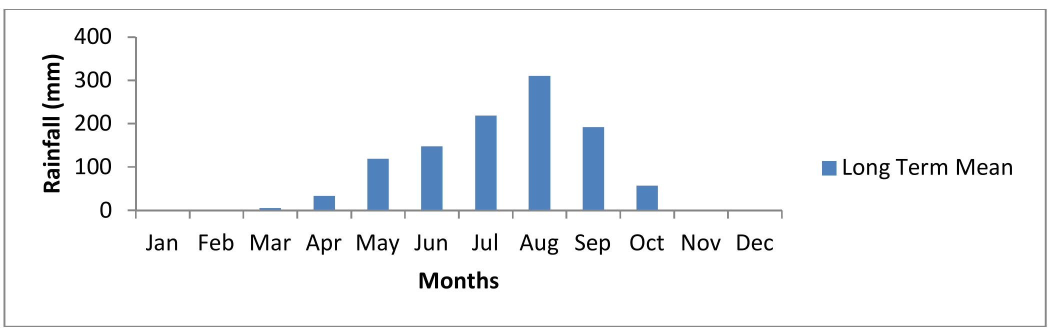

Fig. 2b. Long term mean monthly rainfall distribution for Yelwa

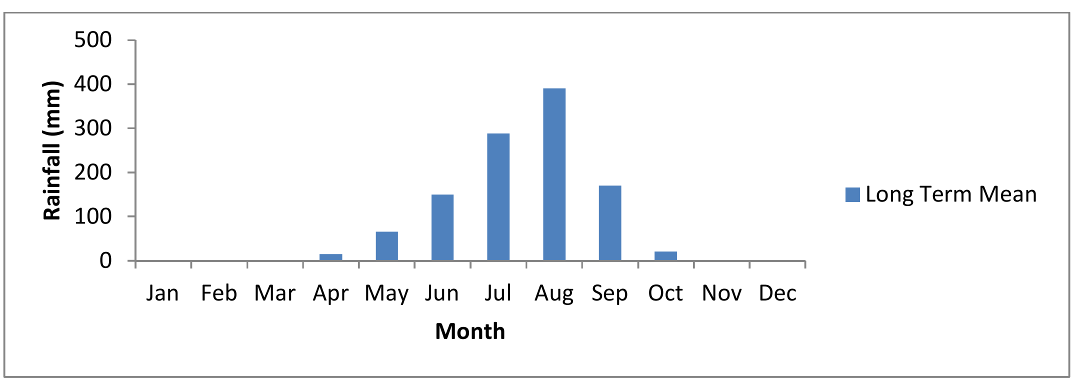

Fig. 2c. Long term mean monthly rainfall distribution for Kano

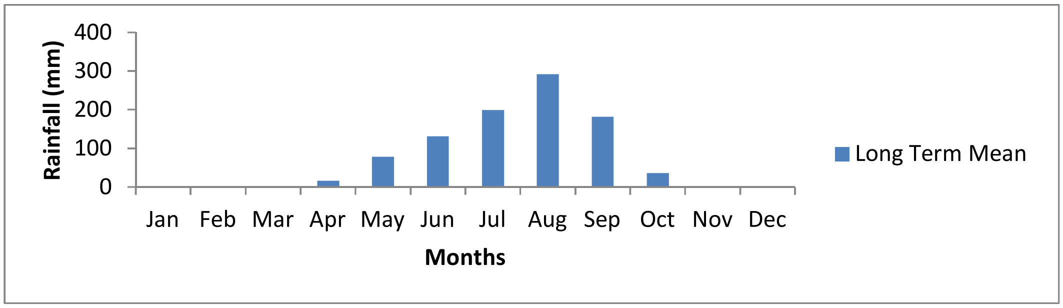

Fig. 2d. Long term mean monthly rainfall distribution for Gusau

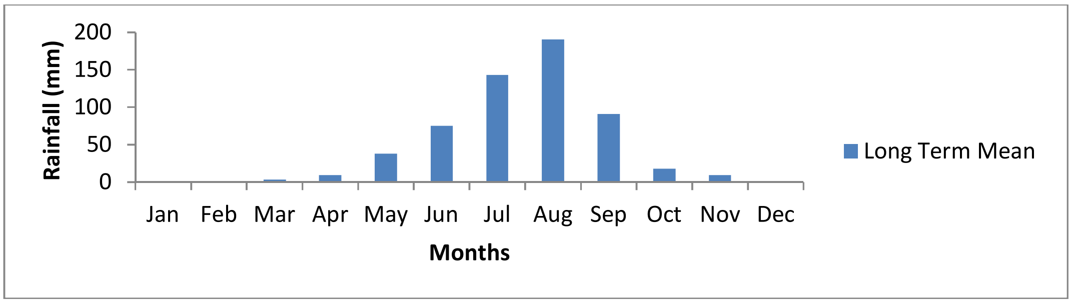

Fig. 2e. Long term mean monthly rainfall distribution for Katsina

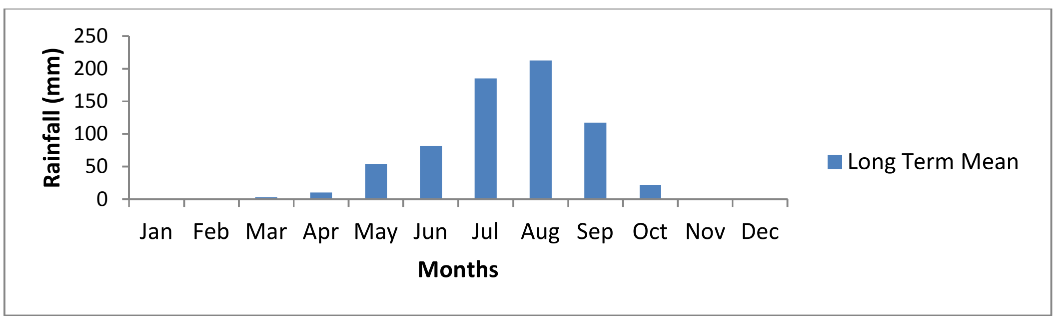

Fig. 2f. Long term mean monthly rainfall distribution for Sokoto

As revealed in Fig. 3, the behavior of annual and inter-annual rainfall in the study area is characterized by undulation along the mean. Positive and negative values are seen to be interrupting to reveal inter-annual rainfall behavior. Information on water status of a particular year can be determined using the threshold mark of (-3) for extremely dry and (+3) for extremely wet; (-2) indicate severe dryness and (+2) for severe wetness; (-1) shows moderate dryness and (+1) indicate moderate wetness (After Nicholson, 2000), cited by Dakagan [20].

The popular concept of climate is that it is some sort of average weather and its fluctuation based on 30 years record. Computation based on this record defines the "normal" climatic conditions [1]. Thus, the "normal" or long term (30 years) annual rainfall mean of six selected stations (Kaduna, Kano, Katsina, Gusau, Sokoto and Yelwa) in North Western Nigeria based on 1987-2016 rainfall data are: 1235.8mm, 1114.2mm, 579.9mm, 926.6mm, 686.2mm and 1082mm respectively. With establishment of these "normal" conditions, any particular year at the stations can be described in terms of its departure from the "normal". These departures are referred to as anomalies. A persistent departure from the normal e.g. above average rainfall constitutes a climatic fluctuation. If the fluctuations persisted for a long time and were, further more statistically significant, it can be said that, there had been a climate change [2] cited in [1].

Table 2 represents temporal pattern of rainfall anomalies across the stations. It vividly captured the magnitude of inter-annual fluctuations giving clear picture of the degree of fluctuations in moisture status of individual year as either being normal, moderately wet or dry, severely wet or dry and extremely wet or dry. With this, each year can be evaluated as having normal, wet or dry moisture level.

The SPI values in Table 2 shows that the 30 years period under study is dominated by years with normal conditions in all the six stations. Drought years are concentrated in the first decade in Kano, Katsina and Sokoto stations with two or more successive years experiencing dryness. A situation of two or more successive years of drought will negatively impact crop production and availability of water for domestic and industrial use. Farmers will have to depend solely on irrigation and lowland farming. Dry years are scattered over the 30 years in Gusau station with each decade having a situation of drought in a year but the second decade has a record of two drought years. Yelwa station has its drought years concentrated more in the first and second decades with a pocket of dryness in the third decade. Drought years in Kaduna station are concentrated in the second and third decades. The moisture years in Gusau are concentrated in the first decade with three consecutive wet years. Kano, Katsina and Sokoto have their wet years scattered over the second and third decades. Wet years in Yelwa are distributed over the three decades. Wet years are recorded in second and third decade in Kaduna station but more concentrated in the third decade. The last four years of the third decade are wet years in Kaduna. Two or more consecutive years of wetness will impact crop production positively as well as make water resources abundant for domestic and industrial usage. It will also enhance inland water transportation. However, in years where situation of wetness that extremely fluctuate from normal is recorded flooding may be inevitable which could result to destruction of lives and properties as well as washing away of cultivated crops.

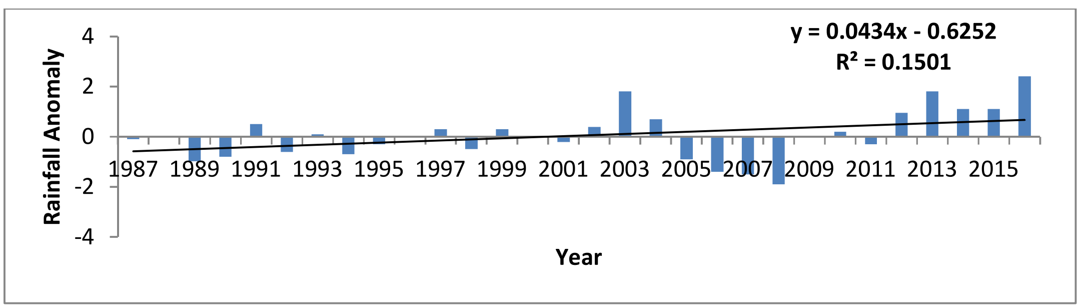

Fig. 3a. Rainfall anomaly pattern in Kaduna, 1987 – 2016

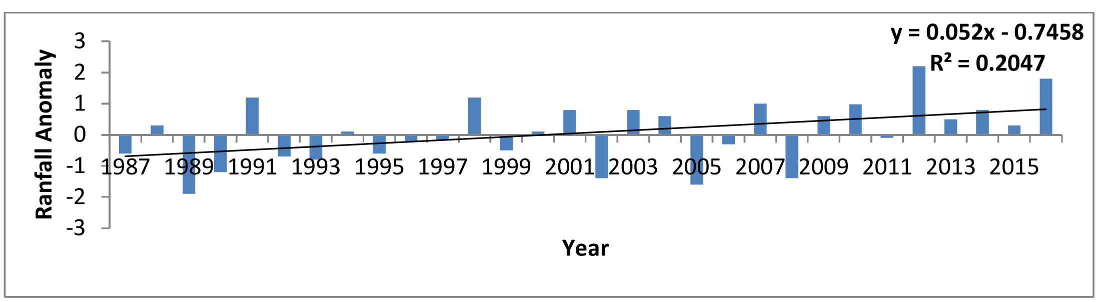

Fig. 3b. Rainfall anomaly pattern in Yelwa, 1987 - 2016

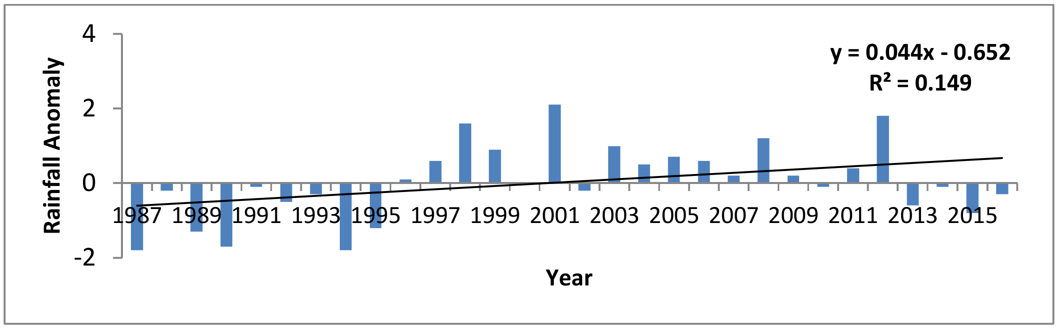

Fig. 3c. Rainfall anomaly pattern in Kano, 1987 – 2016

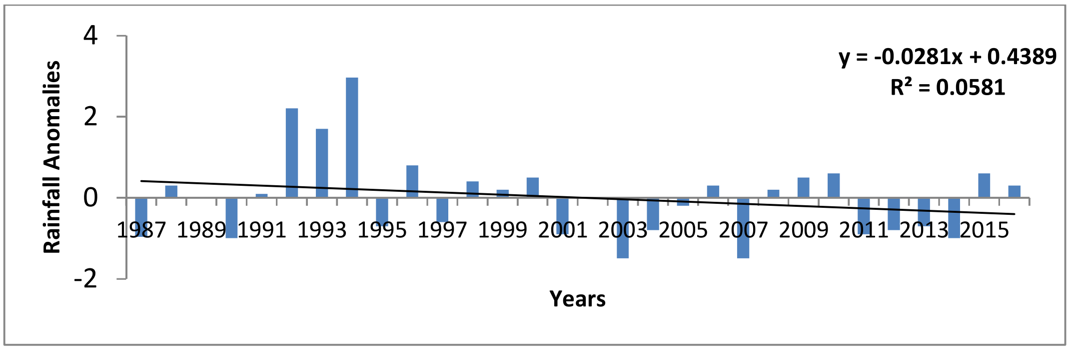

Fig. 3d. Rainfall anomaly pattern in Gusau, 1987 – 2016

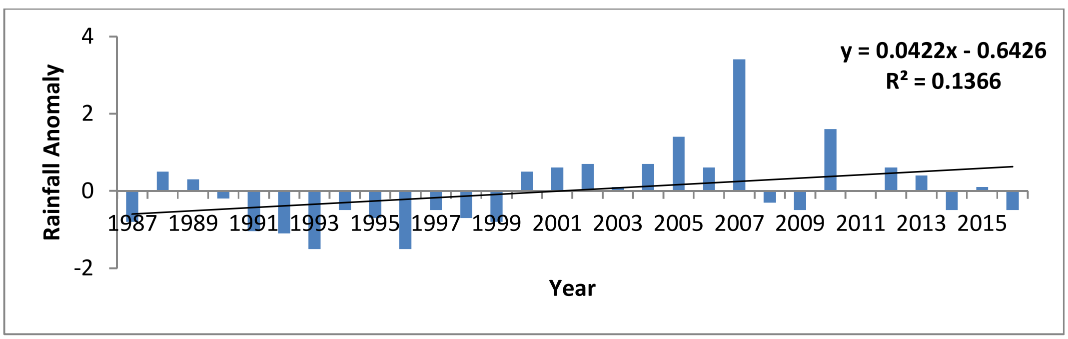

Fig. 3e. Rainfall anomaly pattern in Katsina, 1987 – 2016

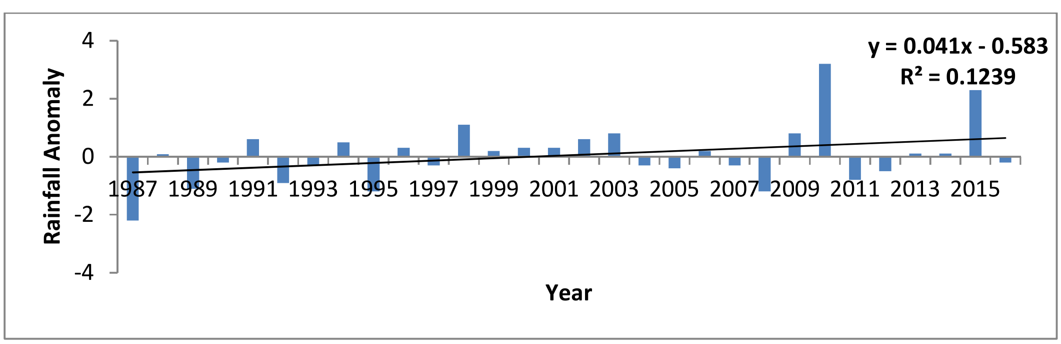

Fig. 3f. Rainfall anomaly pattern in Sokoto, 1987 – 2016

Table 2. Inter-annual pattern of rainfall anomalies across the stations

Year	Kaduna	Kano	Katsina	Gusau	Sokoto	Yelwa
1987	-0.1	-1.8	-0.8	-0.96	-2.2	-0.6
1988	-0.03	-0.2	0.5	0.3	0.08	0.3
1989	-0.97	-1.3	0.3	-0.01	-1.1	-1.9
1990	-0.8	-1.7	-0.2	-1	-0.2	-1.2
1991	0.5	-0.1	-1.0	0.1	0.6	1.2
1992	-0.6	-0.5	-1.1	2.2	-0.9	-0.7
1993	0.1	-0.3	-1.5	1.7	-0.3	-0.8
1994	-0.7	-1.8	-0.5	2.96	0.5	0.1
1995	-0.3	-1.2	-0.7	-0.7	-1.2	-0.6
1996	-0.04	0.1	-1.5	0.8	0.3	-0.2
1997	0.3	0.6	-0.5	-0.6	-0.3	-0.2
1998	-0.5	1.6	-0.7	0.4	1.1	1.2
1999	0.3	0.9	-0.8	0.2	0.2	-0.5
2000	0	0	0.5	0.5	0.3	0.1
2001	-1.3	2.1	0.6	-0.9	0.3	0.8
2002	0.4	-0.2	0.7	0	0.6	-1.4
2003	1.8	0.99	0.1	1.2	0.8	0.8
2004	0.7	0.5	0.7	-0.8	-0.3	0.6
2005	-0.9	0.7	1.4	-0.2	-0.4	-1.6
2006	-1.4	0.6	0.6	0.3	0.2	-0.3
2007	-1.5	0.2	3.4	-1.5	-0.3	1
2008	-1.9	1.2	-0.3	0.2	-1.2	-1.4
2009	0	0.2	-0.5	0.5	0.8	0.6
2010	0.2	-0.1	1.6	0.6	3.2	0.98
2011	-0.3	0.4	0	-0.9	-0.8	-0.1
2012	0.95	1.8	0.6	-0.8	-0.5	2.2
2013	1.8	-0.6	0.4	-0.7	0.1	0.5
2014	1.1	-0.1	-0.5	-1	0.1	0.8
2015	1.1	-0.8	0.1	0.6	2.3	0.3
2016	2.4	-0.3	-0.5	0.3	-0.2	1.8

***Source**: Olalere, 2019*

4. CONCLUSION

This study investigated the anomaly pattern of rainfall in North West geopolitical zone of Nigeria using thirty years rainfall data (1987-2016). The SPI values showed that the thirty years period studied is dominated by normal condition years in all the six stations with few conditions of dryness and wetness recorded in the stations at different decades.

Drought years are concentrated in the first decade in Kano, Katsina and Sokoto stations; first and second decades in Yelwa station; third decade in Kaduna station and the three decades in Gusau station.

The wet years are concentrated in the first decade in Gusau, second and third decades in Kano, Katsina and Sokoto; second and third decades in Kaduna and the three decades in Yelwa.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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