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Characteristics of Rainfall Variations in Kaduna State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author BKY designed the study. Author IZ performed the statistical analysis. Authors BKY and AFA wrote the protocol. Author BKY wrote the first draft of the manuscript. Authors BKY and IZ managed the analyses of the study. Authors SY and AFA supervised the work and directed the protocol. All authors read and approved the final manuscript.

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ABSTRACT

Rainfall trend and variation characteristics across Kaduna State in selected locations in the Southern, Northern and Central Kaduna State within 50 years period (1966-2015) from the Mann-Kendall test and variance coefficient revealed a significant monotone positive trend in only two out of the eleven (11) locations, while one location revealed an insignificant monotone negative trend. Kauru, where the trend was decreasing, is now witnessing an increasing trend of 113.333 mm of rainfall per year, and Kaduna North witnessing an increase of 58.889 mm per year. The increasing trend comes in the fourth decade (1996-2005). The result of the variance coefficient ranges from 0.065 to 0.351, which shows that there are no much variations in the total amount of rainfall between the locations. The estimator Sen's slope has been calculated for the five decadal periods showing rising slope magnitude in some locations. In (1996-2005) decadal period, Kauru Sen's revealed 113.33, Kaduna North 58.889, Saminaka 52. In (1966-1975) decadal period, Kafanchan revealed 67.429. Some locations are shown rising insignificant decreasing trend magnitude. Decadal period of (1996-2005), Zaria revealed -55.33, Kafanchan -49.429. The decadal period of (2006-2015), Kaduna North shows -51.667, Kaduna South -51.875. These results were quite

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significant as the decades where Mann-Kendall has shown a negative trend, similar trends were observed for the Sen's Slope and vice versa.

Keywords: Mann kendall test; Sen' slope; rainfall; spatial trend; Kaduna; Nigeria; temporal.

1. INTRODUCTION

The earth climate is dynamic and naturally varies on seasonal, decadal, centennial, and longer timescale. Each "up and down" fluctuation can lead to conditions which are warmer or colder, wetter or drier, more stormy or quiescent [1,2].

Perhaps the well-understood occurrence of rainfall variability is the naturally occurring phenomenon known as El-Nino Southern Oscillation (ENSO), an interaction between the Ocean and the atmosphere over the tropical Pacific Ocean that has important consequences for weather around the globe [3,2,4].

Pronouncing long term-trend has been observed in precipitation amount in places; significantly wetter in eastern North and South America, Northern Europe and Central Asia. These changes are associated with increased water vapour in the atmosphere arising from the warming of the World's Ocean, especially at lower latitudes [5]. One of the most significant climatic variations in the African Sahel since the late 1960s has been the persistent decline in rainfall. The Sahel is characterized by strong climatic variations and an irregular rainfall that ranges from 200 mm and 600 mm with a coefficient of variation ranging from15 to 30 percent [6,7]. According to Inter-Governmental Panel on Climate Change (IPCC), rainfall decrease of 29-49% has been observed in the 1968-1997 period compared to the 1931-1960 baseline period within the Sahel region [8].

Observation from West Africa indicates a significant decline in rainfall level since the early 1960s [3]. [9] Noted that the year 1994 was the wettest year since the late 1960s and may represent a break in the multi-decadal drought regime. However, 1995 and 1996 suggest continuations [8]. This continuation drought episode spans most of last three decades with a decline in rainfall levels that is large enough to suggest a significant change in normal regional climate for this century [3,10]. Whether or not these long episode of deficient rainfall will continue to remain to be seen. Nevertheless, these observations have motivated many studies on rainfall, drought, and climate variability over West Africa [11,9,12,13,10].

[14] Observed Rainfall trend across Sri Lanka using 100 years data. Some part recorded decreasing trend, some increasing trend, while some location shows no coherent trend. They also show that the trend characteristics vary with the duration of the data analyzed. [15] examined the trend analysis of rainfall over Jordan packing three close by locations. Their study covered a period of 81 years (1922-2003). Although, different trends for different seasons across the three stations were observed, however, one of the stations showed a decline in both the rainy and the total amount of rainfall after the mid-1950s. In Turkey, [16] examined the trend in precipitation within 64 year period (1922-1993) of rainfall for 96 stations. The overall result indicates a downward trend.

[17] Examine spatial-temporal variation and prediction of rainfall in Northeastern Nigeria, using gridded 0.5° to 0.5° NCEP and CRU data version. Result showed that spatial and temporal variability of rainfall increase northwards in each of the months in wet season (May to October), and the regression slope obtained shows that the decrease in monthly rainfall and frequency in the wet season is mostly in the month following the onset of rainfall (May, June, and July). The study therefore aimed at assessing the characteristics of rainfall variations in Kaduna State 1966-2015).

2. MATERIALS AND METHODS

Eleven locations across Kaduna State were chosen for the study. They include: Birnin Gwari (Lat. 10°- 35', Long. 6°- 34'), Kaduna North (Lat. 10°- 31', Log. 7°- 26') Kauru (Lat. 10°- 35', Long. 7°- 26'), Saminaka (Lat. 10°- 23', Long. 8°- 42'), Kangimi (Lat. 10°- 40', Long. 8°- 42'), Zaria (Lat. 11°- 09', Long. 7°- 47'), Ikara (Lat. 11°- 11', Long. 8°- 15'), Kaduna North (Lat. 9°- 36', Long. 8°- 18'), Kaduna South (Lat. 10°- 30', Long. 7°- 26'), Kafanchan (Lat. 9°- 36', Long. 8°- 18'), Kagarko (Lat. 9°- 29', Long. 7°- 40'), Zonkwa (Lat. 9°- 48', Long. 8°- 18') [18]. Rainfall data spanning a period of 50 years, (1966-2015) were

used. The data were obtained from 10 stations of Kaduna State Water Board, and 1 station from Institute of Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, making a total of 11 stations. The obtained data were in monthly and yearly values from which decadal were calculated. Fig. 1 showed the selected stations.

2.1 Rainfall Trend Analysis

To examine the rainfall trend of the study area, the Mann-Kendall test was used. The Mann-Kendall test is a statistical test widely used analysis of the trend in climatologic and hydrologic time series [2,19,12,13]. The test is used for analysis of trends in this study.

Let X_1……X_2……..Xn represents n data points where Xj represent data point of time j. then the Mann-Kendall statistics (S) is defined by equation 3 as

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sign\,(xj - xk) \qquad (1)$$

$When$:

$$Sign\,(xj - xk) = 1 \;\; if \;\; xj - xk > 0$$
$$= 0 \;\; if \;\; xj - xk = 0$$
$$= -1 \;\; if \;\; xj - xk < 0$$

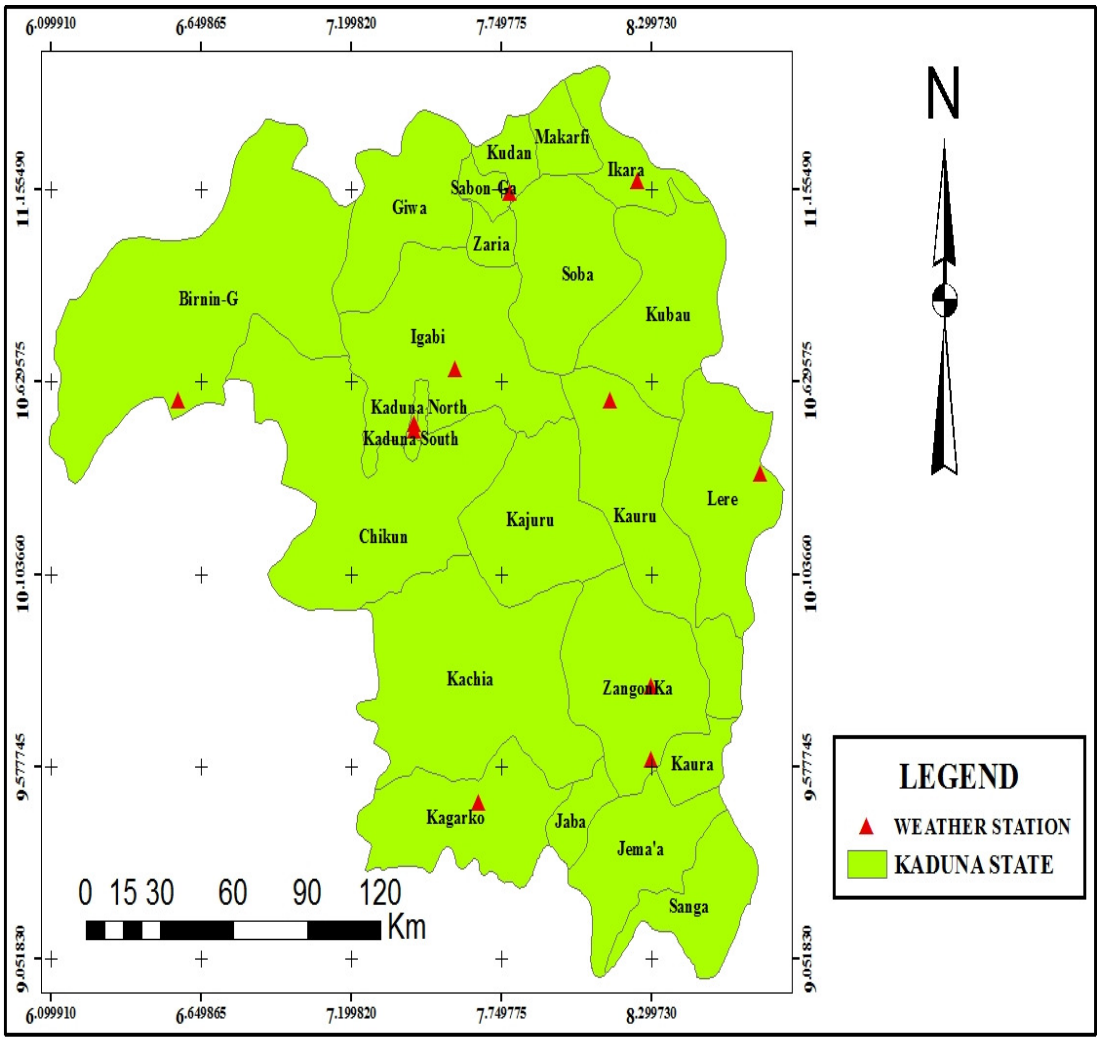


Fig. 1. The selected 11 weather stations

The probability associated with "S" and the sample size "n" is computed to quantify the significance of the trend, to do this, the variance of S, VAR(S) is calculated by equation 2.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} tp\,(+p-1)(2tp+5)\right] \quad (2)$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and tp is the number of data points in the path group. The computed normalized test statistics Z is defined by equation 3 and 4.

$$Z = \frac{S-1}{[VAR\,(S)]^{\frac{1}{2}}} \quad if\ S > 0 \quad (3)$$

$$if\ S = 0$$

$$Z = \frac{S+1}{[VAR\,(S)]^{\frac{1}{2}}} \quad if\ S < 0 \quad (4)$$

3. RESULTS AND DISCUSSION

The result of the mean value for the total amount of rainfall in the first decade (Table 1), for the eleven locations namely are; Kangimi (1430.7 mm), Ikara (1181.3 mm), Zaria (877.8 mm), Saminaka (1478.8 mm), Birnin Gwari (1287.4 mm), Zonkwa (1096.6 mm), Kauru (976.6 mm), Kaduna South (1374.4 mm), Kaduna North (1374.9), Kagarko (1581.7 mm) and Kafanchan (2074.2 mm) respectively.

The coefficient of variation (CV) which depicts the ratio of the standard deviation SD to mean for the five decadal periods ranges from 0.065 to 0.351, indicating that there is no much variation in the total amount of rainfall between the parameters under review.

In the first decade (1966-1975), minimum rainfall in Zonkwa (904 mm) is lower than that of Birnin Gwari (1057 mm), Kaduna South (1167 mm), Kaduna North (1168 mm), Saminaka (1291 mm), Ikara (992 mm), Kangimi (1131 mm). The same is applied to maximum rainfall and mean of the decade. In the second decadal regime (Table 2), there is little improvement where Zonkwa minimum (1062 mm) is higher than Kaduna North minimum (968 mm), Kaduna South minimum (963 mm), Ikara minimum (983 mm), and Kangimi minimum (1040 mm), but lower than Saminaka minimum (1141 mm) and Birnin Gwari and (1172 mm) respectively. However, from the decade (Table 2), Kangimi location showed a significant decreasing trend of (-0.67*).

Kaduna State is located in the North-Western part of Nigeria. Kafanchan that is located in the Southern part of the state has the highest amount of rainfall recorded: it has the highest value in the minimum (1837 mm), maximum (3236 mm), and mean (2298.7 mm) values respectively, see Table 5. Zaria which is located in the Northern part of the State has the least amount of rainfall. It minimum rainfall is the lowest (530 mm), it means is the lowest (877.8 mm) see Table 1, and maximum is the lowest for four decadal periods except for the decadal regime of 1996-2005 where maximum rainfall for Zaria (1947 mm) was higher than that of Birnin Gwari (1693 mm) and Ikara (1753 mm) see Table 4.

Table 1. Statistical characteristics of the first decadal (1966-1975) rainfall for eleven (11) locations of Kaduna State

Location	Min	Max	Range	Mean	SD	CV	Z	Slope
Ikara	992.0	1644.0	652.0	1181.3	185.1	0.16	0.24	27.25
Zaria	530.0	1042.0	512.0	877.8	149.1	0.17	0.42	30.00
Saminaka	1291.0	1863.0	572.0	1478.8	214.7	0.15	0.38	12.00
Kangimi	1131.0	1694.0	563.0	1430.7	226.5	0.16	0.47	37.67
B/Gwari	1057.0	1600.0	543.0	1287.4	178.9	0.14	0.02	10.00
K/South	1167.0	1592.0	425.0	1374.4	134.5	0.10	-0.24	-22.67
K/North	1168.0	1591.0	423.0	1374.9	133.9	0.10	-0.20	-22.33
Zonkwa	904.0	1230.0	326.0	1096.6	111.2	0.10	-0.24	-11.33
Kauru	798.0	1099.0	301.0	976.6	89.9	0.09	0.45	18.50
Kafanchan	1546.0	2573.0	1027.0	2074.2	364.1	0.18	0.33	67.43
Kagarko	1329.0	1867.0	538.0	1581.7	167.1	0.11	0.38	27.22

The location that showed a strange result with respect to its geographical location site is Kauru and Zonkwa. The minimum rainfall in Kauru (704 mm) is smaller than Birnin Gwari, Ikara, Saminaka, Kangimi, Kaduna South, and Kaduna North that are in the Northern and Central part of Kaduna State. The minimum rainfall are: Birnin Gwari (1012 mm), Ikara (925 mm), Saminaka (1098 mm), Kangimi (713 mm), Kaduna South (963 mm) and Kaduna North (965 mm) see Table 3.

From Table 2: Zonkwa maximum (1454 mm) is the lowest between the eleven (11) locations, but revealed little changes in it decadal mean, where the decadal mean of Kaduna South (1156.5 mm), Kaduna North (1190.9 mm) and Kangimi (1242 mm) are smaller than the decadal mean of Zonkwa (1250.9 mm), and Zonkwa mean smaller than Ikara mean (1339.9 mm), Saminaka (1443.3 mm) and Birnin Gwari (1417.1 mm) respectively. The same is applied to the third decade (1986-1995), that is decadal mean of Kaduna South (1159.9), Kaduna North (1150.8), and Kangimi (1186.0) are smaller than the decadal mean of Zonkwa (1202.8), and Zonkwa mean smaller than Ikara (1252.4), Saminaka (1476.1) and Birnin Gwari (1244.4) see Table 3. It is only in the fourth decade (1996-2005) Table 4, that Zonkwa rainfall statistics; minimum, maximum and mean succeeded Kafanchan. This decade can be termed as a wettest decade (Nicholson, 2008). However, subsequent decade suggests continual drought [8].

From the results of the analysis, it showed that in some decades, some part of Northern Kaduna State, for instance; Saminaka, and some part of Kaduna Central, for instance; Birnin Gwari and Kaduna South received rainfall higher than some part of Southern Kaduna State, for instance; Zonkwa and Kauru see Table 3. Saminaka minimum (1098 mm) and Birnin Gwari minimum (1012 mm) is higher than Kauru minimum (940 mm) and Zonkwa minimum (704 mm) respectively. The same is applied to mean of the decade. Kafanchan rainfall minimum, maximum and mean appeared to be the highest in all the five decadal statistics.

Table 2. Statistical characteristics of the second decadal (1976-1985) rainfall for the eleven (11) locations of Kaduna State

Location	Min	Max	Range	Mean	SD	CV	Z	Slope
Ikara	983.0	1747.0	764.0	1339.9	228.2	0.17	-0.24	-30.00
Zaria	542.0	1196.0	654.0	883.1	190.1	0.22	-0.16	-7.17
Saminaka	1141.0	1673.0	532.0	1443.3	158.0	0.11	0.20	17.38
Kangimi	1040.0	1622.0	582.0	1242.0	147.0	0.12	0.67*	-27.00
B/Gwari	1172.0	1699.0	527.0	1417.1	171.0	0.12	-0.20	-21.25
K/South	963.0	1595.0	632.0	1156.5	175.4	0.15	-0.36	-20.60
K/North	968.0	1596.0	628.0	1190.9	159.7	0.13	-0.38	-13.50
Zonkwa	1062.0	1454.0	392.0	1250.9	125.4	0.10	-0.07	-5.00
Kauru	990.0	1627.0	637.0	1268.8	187.8	0.15	-0.20	-13.71
Kafanchan	1783.0	2631.0	848.0	2156.1	289.7	0.13	-0.24	-27.14
Kagarko	1307.0	2214.0	907.0	1724.6	334.8	0.19	-0.07	-10.38

**Significant at 0.05*

Table 3. Statistical characteristics of the third decadal (1986-1995) rainfall for eleven (11) locations of Kaduna State

Location	Min	Max	Range	Mean	SD	CV	Z	Slope
Ikara	925.0	1746.0	821.0	1252.4	233.9	0.19	-0.42	-57.50
Zaria	748.0	1096.0	348.0	949.0	97.3	0.10	-0.02	-3.60
Saminaka	1098.0	1957.0	859.0	1476.1	275.1	0.19	0.07	20.25
Kangimi	1073.0	1339.0	266.0	1186.0	76.6	0.07	-0.42	-13.33
B/Gwari	1012.0	1640.0	628.0	1244.3	199.7	0.16	-0.33	-32.25
K/South	964.0	1365.0	401.0	1150.8	126.0	0.11	-0.24	-11.67
K/North	965.0	1370.0	405.0	1159.9	120.7	0.10	-0.07	-9.00
Zonkwa	940.0	2000.0	1060.0	1202.8	278.8	0.23	-0.11	4.00
Kauru	704.0	1453.0	749.0	1025.8	205.5	0.20	-0.42	-42.17
Kafanchan	1237.0	2332.0	1095.0	1839.7	325.4	0.18	0.07	18.60
Kagarko	1359.0	1792.0	433.0	1559.4	156.1	0.10	0.33	37.25

The Mann-Kendall Z for the fourth decadal (1996-2005) locations (Table 4) are; Kangimi (0.07), Ikara (0.24), Zaria (-0.38), Saminaka (0.33), Birnin Gwari (-0.38), Zonkwa (0.07), Kauru (0.56*), Kaduna South (0.33), Kaduna North (0.51*), and Kafanchan (-0.42) respectively. Despite the fact that Kafanchan has the highest total rainfall yet it has not shown any significant (monotone) trend in the five decadal (50 years) period. Kauru that has the lowest minimum rainfall and located in the Southern part of Kaduna state and Kaduna North that is located in the Kaduna Central showed significant (monotone) positive trend.

Kafanchan, a location in the Southern part of Kaduna state where rainfall is experienced more than the Northern part and Central part of the State continue to experience normal rainfall whereas Kauru and Kaduna North experience significant (monotone) positive trend, this is in contrast with the earlier work of [3] which shows Kafanchan. The phenomenon whereby a location in the Southern part of the study area, and a location in the Central part of the State experienced significant (monotone) positive trend over a period of time, than Kafanchan; a location that rainfall is always in the highest amount could probably be linked to the dynamics of the West African monsoon [3]. Although the West African Monsoon system is not fully understood since it's a function of many interwoven dynamic components. However, the occurrence of an abrupt change in rainfall has been observed [20]. It is shown that there is an increasing trend in the amount of rainfall in Kauru and Kaduna North; a location in the Southern part of Kaduna State, and a location in the Central part of the State. Thus the Climate in some locations in Kaduna State is changing. Similar climate changes with respect to increasing trend in rainfall have been observed in India. [21] reported an increasing trend in both West coast and Central India. Also observed an increasing trend in the frequency and magnitude of extreme rain events and warn over expected rainfall hazards in India.

From the five decadal statistical tables (Tables 1 - 5) it showed that in the first decade; Kangimi, Ikara, Zaria, Saminaka Birnin Gwari, Kauru and Kafanchan shows insignificant positive trend while Kaduna South, Kaduna North, and Zonkwa showed an insignificant negative trend. In the second decade, Saminaka revealed an insignificant positive trend, Kangimi revealed insignificant (monotone) negative trend, while the other eight locations revealed an insignificant negative trend. In the third decade, Kafanchan, Zonkwa and Saminaka revealed insignificant positive trend while Kangimi, Ikara, Birnin Gwari, Zaria, Kauru, Kaduna North and Kaduna South reveal an insignificant negative trend. In the fourth decade, Ikara, Saminaka, Zonkwa and Kaduna South revealed an insignificant positive trend, while Kangimi, Zaria, Birnin Gwari, Kauru, Kaduna North and Kafanchan revealed an insignificant negative trend. The fifth decade revealed Kangimi, Zaria, Kafanchan and Kauru location having an insignificant positive trend, while Ikara, Saminaka, Birnin Gwari, Kaduna North, Kaduna South and Zonkwa have an insignificant negative trend.

Table 4. Statistical characteristics of the fourth decade (1996-2005) rainfall for the eleven (11) locations of Kaduna State

Location	Min	Max	Range	Mean	SD	CV	Z	Slope
Ikara	955.0	1753.0	798.0	1392.0	247.1	0.18	0.24	33.50
Zaria	711.0	1947.0	1236.0	1125.3	320.7	0.29	-0.38	-55.33
Saminaka	1361.0	2052.0	691.0	1684.9	226.3	0.13	0.33	52.00
Kangimi	1024.0	2219.0	1195.0	1557.1	319.2	0.21	-0.07	-11.33
B/Gwari	1140.0	1693.0	553.0	1399.7	181.5	0.13	-0.38	-35.00
K/South	1294.0	2138.0	844.0	1715.5	248.7	0.15	0.33	46.50
K/North	1293.0	2331.0	1038.0	1799.0	277.5	0.15	0.51*	58.89
Zonkwa	1532.0	2445.0	913.0	1952.9	307.2	0.16	0.07	16.63
Kauru	750.0	2051.0	1301.0	1348.5	474.0	0.35	0.56*	113.33
Kafanchan	1517.0	2590.0	1073.0	2106.4	277.1	0.13	-0.42	-49.43
Kagarko	1273.0	2544.0	1271.0	1716.7	420.4	0.25	-0.11	-13.38

**Significant at 0.05*

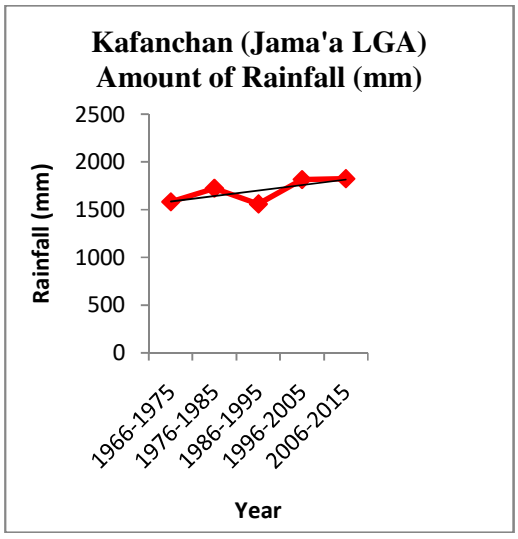
The estimator Sen's Slope has been calculated for the five decadal periods. It showed rising slope magnitude in some locations. In 1996-2005 decadal period (Table 4), the Sen's Slopes are; Kauru (113.33), Kaduna North (58.89), Saminaka (52). In 1966-1975 decadal period (Table 1); Kafanchan (67.429). These were the locations that revealed rising slope magnitude. Some locations are shown rising insignificant decreasing trend magnitude. In 1996-2005 decadal period (Table 4), Zaria (-55.33), Kafanchan (-49.429). Also, in the decadal period of 2006-2015 (Table 5), Kaduna North has (-51.667), Kaduna South has (-51.875).

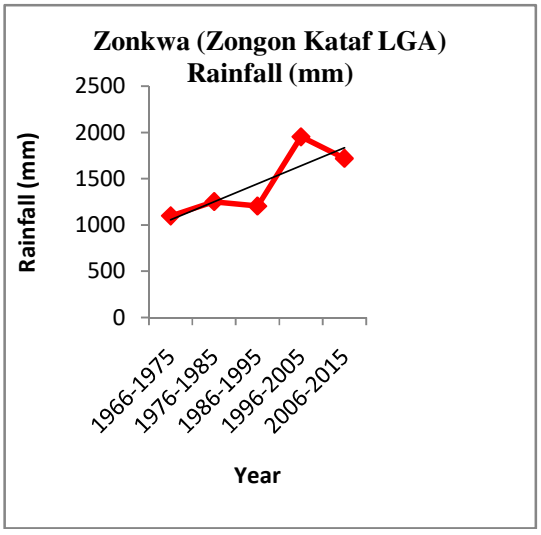
The result of this decadal analysis was quite significant as the decades where Mann-Kendall trend analysis has shown a negative trend, similar negative trends were observed for Sen's Slope and vice versa. See Tables 1-5. These results are in consonance with the work of [21] on the application of the non-parametric test for trend detection of rainfall in the largest Island of Bangladesh where result of Mann-Kendall trend analysis showed negative trend in some months, similar negative slope has been observed for the Sen's Slope and vice versa.

Fig. 2 showed increased rainfall in all the four Southern part of Kaduna stations, but Zonkwa and Kauru revealed high increasing trend than Kafanchan and Kagarko. The Northern part of the state (Fig. 3) also showed increasing trend, but in the Central part of the state, the increasing trend was shown in three locations of the stations under review, while one location (Kangimi) revealed a decreasing trend, see Fig. 4.

Table 5. Statistical characteristics of the fifth decadal (2006-2015) rainfall for eleven (11) location of Kaduna State

Location	Min	Max	Range	Mean	SD	CV	Z	Slope
Ikara	1200.0	2156.0	956.0	1502.5	273.0	0.18	-0.11	-19.25
Zaria	932.0	1499.0	567.0	1159.9	157.2	0.14	0.16	18.67
Saminaka	1664.0	2260.0	596.0	1902.3	153.0	0.08	-0.16	-10.83
Kangimi	713.0	1418.0	705.0	1170.1	194.4	0.17	0.29	23.00
B/Gwari	1166.0	1777.0	611.0	1412.7	183.0	0.1	-0.16	-15.88
K/South	1010.0	1872.0	862.0	1435.8	235.9	0.16	-0.11	-65.00
K/North	1062.0	1873.0	811.0	1421.7	269.0	0.19	-2.44	-51.88
Zonkwa	1248.0	2084.0	836.0	1718.2	267.4	0.16	-0.11	-19.25
Kauru	1234.0	2257.0	1023.0	1619.5	330.3	0.20	0.11	16.00
Kafanchan	1837.0	3236.0	1399.0	2298.7	394.2	0.17	0.11	11.50
Kagarko	1368.0	2232.0	864.0	1825.4	244.0	0.13	-0.51	62.29





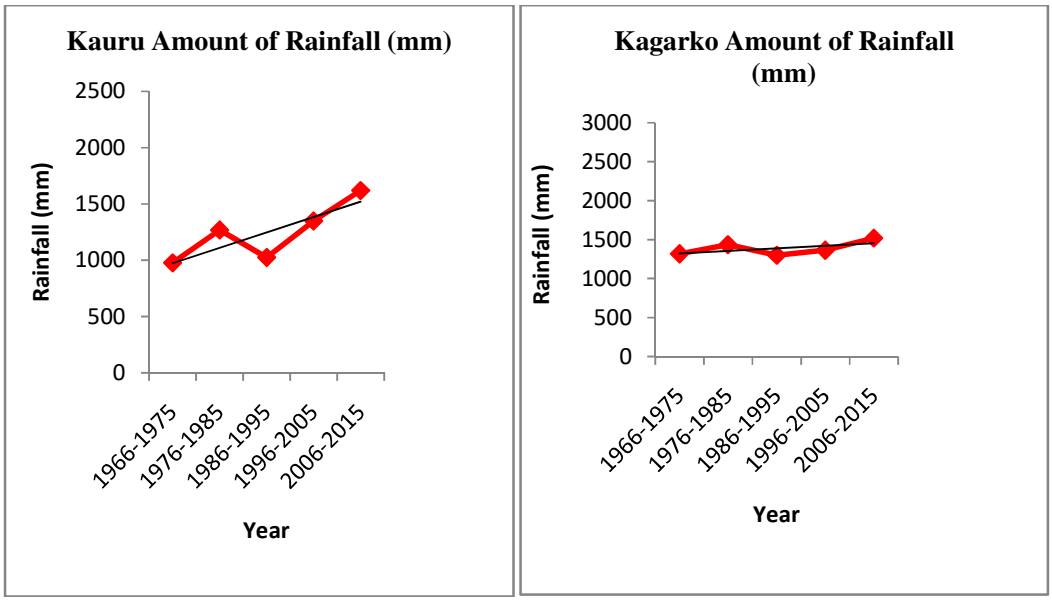


Fig. 2. Trend in rainfall of Southern part of Kaduna State

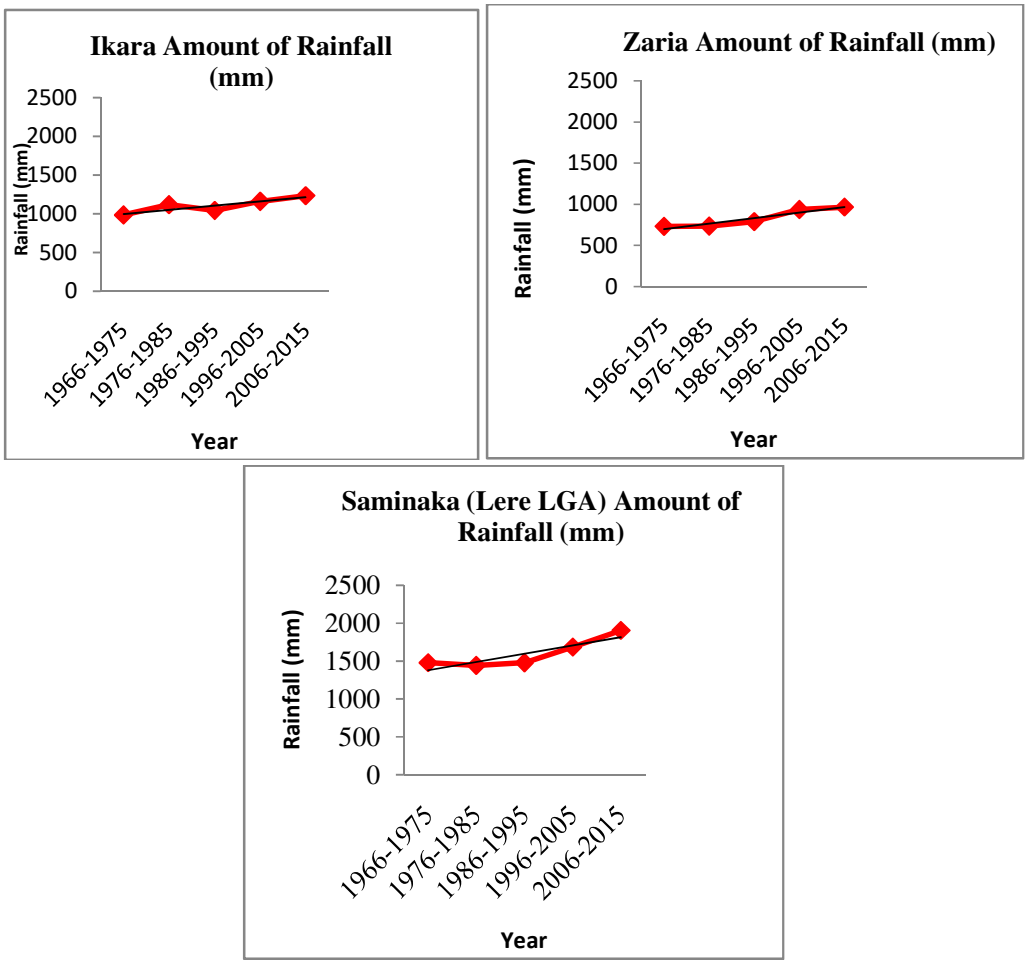


Fig. 3. Trend in rainfall of Northern part of Kaduna State

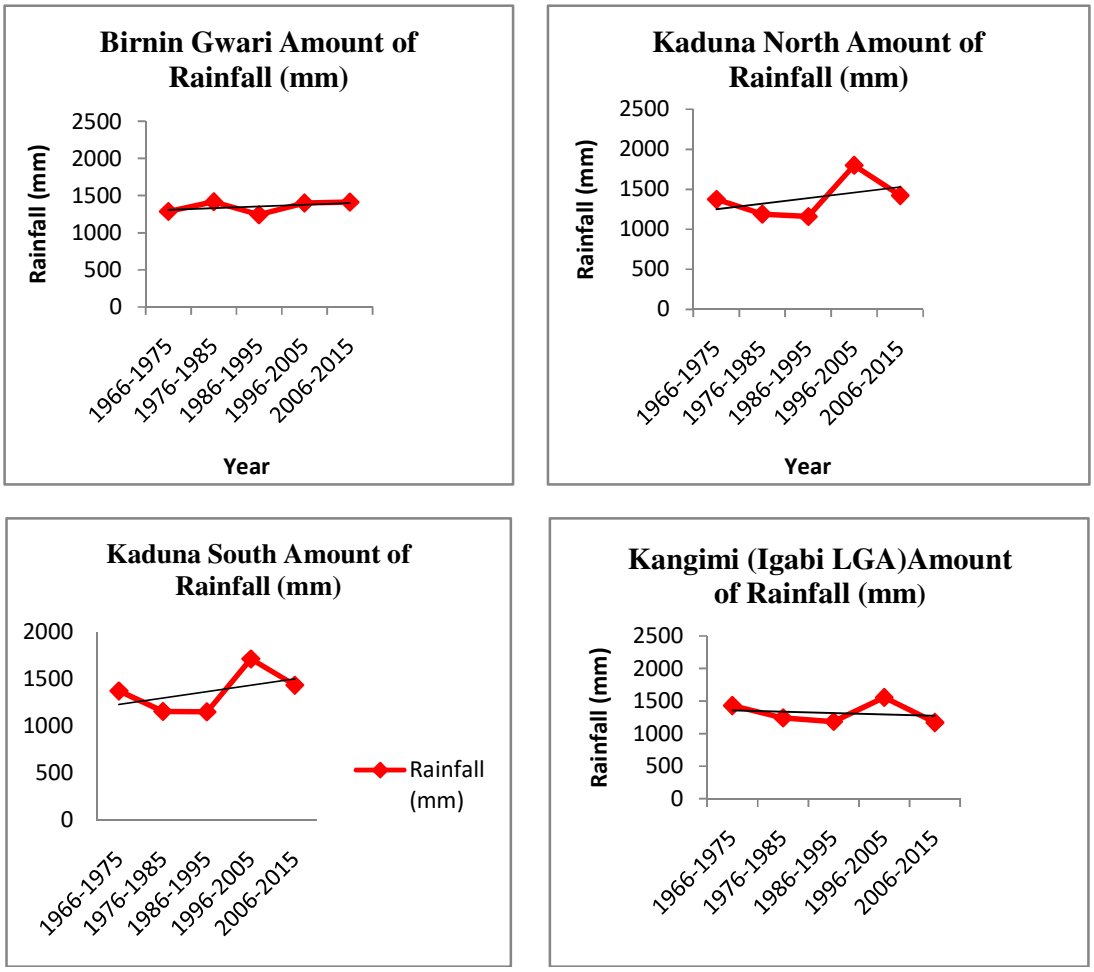


Fig. 4. Trend in Rainfall of Central part of Kaduna State

4. CONCLUSION

Rainfall in Kaduna State has shown some degree of recovery since the extreme dry episode of the 1970s and 1980s. However, a certain characteristic of the rainfall regime appears to have changed. In this study, it showed that not all Southern part of Kaduna State received rainfall higher than the Northern and Central part of Kaduna State as Kafanchan was the only area in the Southern part of the State that received the highest amount of rain for the whole period of the study, Zonkwa and Kauru received rainfall lower than some locations in the Northern and Central part of Kaduna State. For the whole period of the study, there is no year in which rainfall in Kauru (a location in the Southern part of Kaduna State) happens to be higher than rainfall in Saminaka (a location in the Northern part of the State). Zonkwa rainfall which is a location in Southern part Kaduna State succeeded Kafanchan only in the fourth decadal rainfall regime but all the years that followed after 1966, rainfall in some part of Northern and Central Kaduna state is higher than rainfall record in Zonkwa. With the exception of Zaria and Kafanchan that have unique amount of rainfall, that is Zaria having the lowest amount of rainfall and Kafanchan having the highest amount of rainfall, all other rainfall locations across the State are highly variable in their mean as no location has decadal mean higher than other locations for the five consecutive decades. Some decades have decadal mean higher than others and vice versa. The variability in rainfall of these locations and the decline of rainfall in Zaria and some locations in the Southern part of the study area may be attributed to West African monsoon. However, it remains important since it

satisfies the agricultural activities of locations [22].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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