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Rainfall Variability and Trend Analysis over Lokoja, Nigeria

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Abstract- Studies on rainfall variability and trends are of great importance, particularly to the nations where rain-fed agriculture is predominant. This study used CRU data *(*CRU_TS 4.01) to examine the temporal variability of rainfall data over Lokoja. Statistical tests were employed to examine variability and trend in monthly, seasonal and annual time series. Analysis of variability showed that the rainy seasons and annual rainfall had less variability (CV < 20), but the variability was high (CV > 30) in some months in the rainy season (April, July and August). Standardised precipitation index showed alternation of wet and dry period conditions had been witnessed in the study area. Trend analysis showed more positive trends had been experienced from 1970 through 2010. The variability in rainfall and the increasing trend may have a tremendous effect on water resources availabilities and vulnerabilities of Lokoja.
Keywords: Lokoja, Mann-Kendall, Rainfall, Trend Analysis

1. INTRODUCTION

Rainfall is a major climatic parameter that influences crop production [1]. In Nigeria, like many other developing nations, agricultural practices depend majorly on rainfall. The variability of rainfall in response to climate change poses a serious threat to food security and water availability [2]. Rainfall variability is the unsteadiness of rainfall occurrence yearly or seasonally above or below a long-term mean value; over a particular period [3]. [4] suggested a need for a detailed analysis of local precipitation variability. Understanding variability in rainfall is a prerequisite to hydro-meteorological applications such as construction of agricultural and hydropower dams, planning for agriculture purpose, forecasting of floods and drought, urbanization, quantification of climate change impact, modeling of hydrological feature, estimation of water balance and irrigation management for viable crop production [5].

It is important to understand rainfall pattern and trend at any place, as it has great importance and relevance in water storage for future use. The issue of water scarcity when needed or availability of less than the required has necessitated the need for proper water resources planning and management [6]. In addition to water scarcity, the extreme climatic event of drought and flood, which has become a reoccurrence event, also calls for concern [7]. [8] claimed that there is a high correlation between rainfall variability and extreme hydrological event occurrence. In the same vein, spatiotemporal patterns of water availability also depend largely on rainfall [9]. There is a need to study the spatial and temporal variability of rainfall over a long time. It allows for better understanding of the effects of climate change on rainfall as well as its probable impact on the water system and the environment [10]. Assessment of rainfall trends and variability study is paramount to understanding the variations in space and time. Trend analysis of precipitation on diverse spatial and temporal scales has become a topical issue among researchers in the past century because of the attention given to global climate change by the scientific community [11]. Some parametric and non-parametric statistical tests have been found relevant in examining the trend of climatic parameters. Though parametric tests are more powerful as compared to non-parametric test, they, however, require independent and normally distributed data series. In contrast, non-parametric test requires only data to be independent data [5]. More so, the non-parameter tests can remove outliers. The most frequently used non-parametric test for analysis of rainfall trend is the Mann Kendal (MK).

Several studies have been carried out on the analysis of precipitation variability throughout the world. [12] studied a series of seasonal and annual precipitation for the period of 1833–1996 from 32 stations. On a seasonal basis, a decreasing trend was significant only for spring in Central-South and autumn in the North. While on an annual basis, the result showed a decreasing trend over Italy in its entirety, but it was statistically significant only in the Central-South. [13] examined trends in annual mean and monthly precipitation series on a long-term basis (1929 to 1993) in Turkey. Their results showed some significant trends, especially in the mean annual precipitation and in some months (January, February and September). The study by [14] also showed a significant decrease in the main rainy season (June to September) in the southwestern and central parts of Ethiopia. [15] examined the spatiotemporal patterns of monthly and annual precipitation in Nigeria between 1901 and 2000. They noted a variation in the rainfall patterns and submitted that while the 1950s was the wettest decade, the driest was 1980s. [16] studied the rainfall trend from 1953 to 2002 in northern Nigeria and reported an increase in the annual trend of rainfall between 1993 and 2002. All the studies cited above suggested that spatial and temporal variability in the long-term behaviour of rainfall dependent largely on regional characteristics. This study thus aimed at examining rainfall variability and trend analysis over Lokoja, Nigeria

2. MATERIALS AND METHODS

2.1 Study area

Lokoja is situated on the latitude 7°45'N - 7°51'N and longitude 6°41'E - 6°45'E. It lies at an altitude of 45 to 125 meters above sea level and located close to the confluence of River Niger and River Benue [17]. It is the capital city of Kogi State-a state that share boundaries with some states in the southern and northern region of the country and hence a gateway to five of the six geopolitical zones in the country (Figure 1). Lokoja is characterized by a tropical climate that comprises of wet and dry seasons and falls within the Guinea Savannah vegetation belt. It experiences annual rainfall and temperature of about 1150 mm and 27.7°C respectively. It has total land coverage of about 63.82 sq. km. [18]. The area has a land use/land cover characterized by water bodies, wetland resources, vegetation and built-up area, which is massively expanding [19]. It also has dissected undulating plains, high hill masses, and many intermittent valleys and streams crisscrossing the breadth of the town [17].

2.2 Details of data and methods

The observed data used is gridded data. The gridded monthly rainfall data from the Climate Research Unit (CRU_TS 4.01) with a resolution of 0.5 by 0.5 latitude and longitude over the periods 1911 - 2010 was obtained and used for the analysis. The average rainfall amount was computed over the 100 years to examine rainfall anomalies, commonly defined as deviation from the average. For the variability analysis, standard deviation and coefficient of variation (CV) were calculated. Rainfall Anomaly Index (RAI) and the Standardised Precipitation Index (SPI) were computed to examine rainfall frequency and intensity. The coefficient of variation was used to calculate the degree of variability in the rainfall. The value of the CV is directly proportional to the degree of variability. The value of CV is categorised into three; less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$) (Hare, 2003). The Mann-Kendall trend analysis method was applied to examine the trend in annual, seasonal and monthly rainfall data. Mann-Kendall test was formulated by Mann (1945) as a non-parametric test for trend detection and the test statistics distribution given by Kendall (1975) for testing non-linear trend and the turning point. Mann Kendall and Sen Slope estimator were applied to determine the trend direction and magnitude. The detail of rainfall variability index and trend analysis is given below:

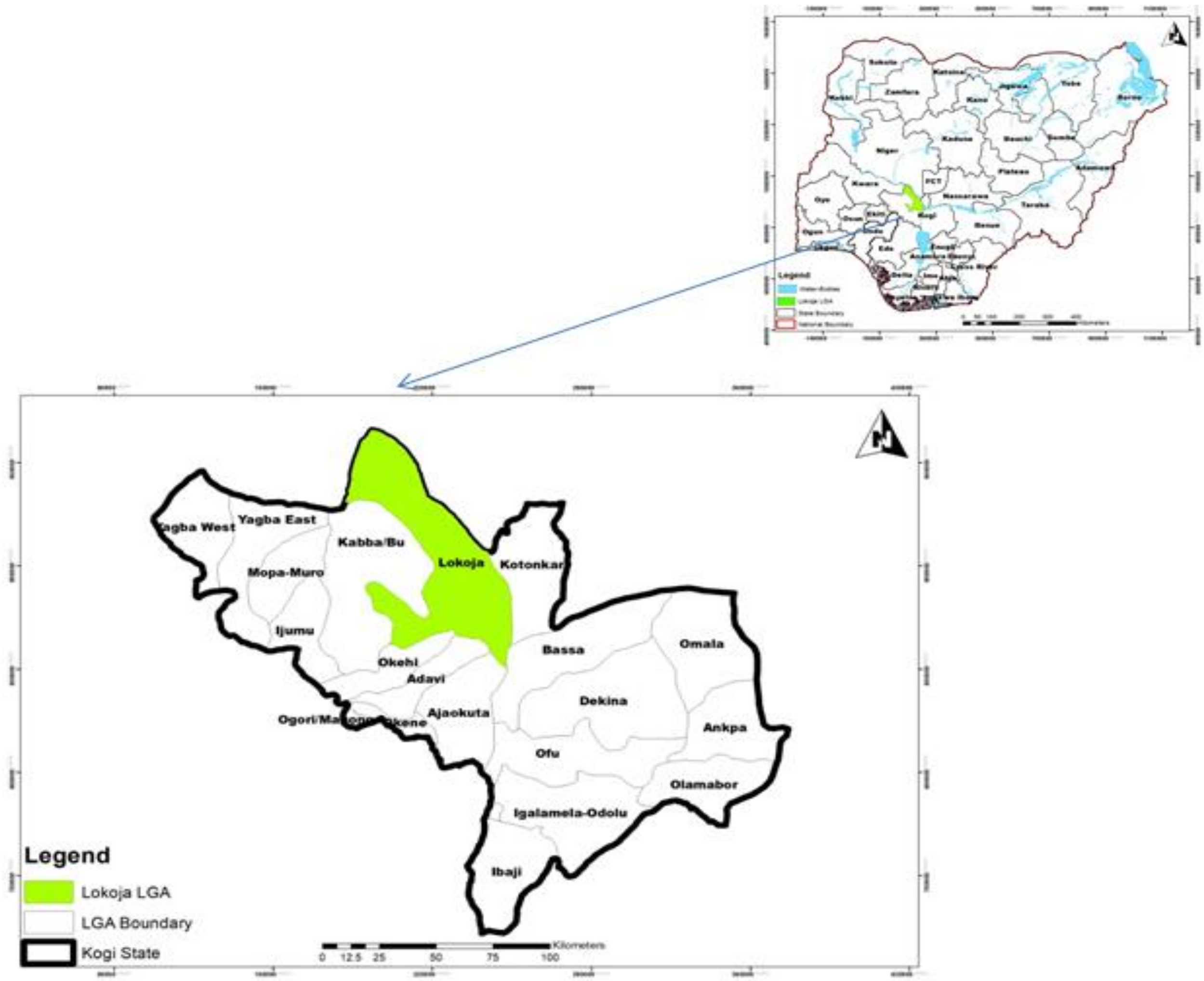

Figure 1: Map of the study area

2.2.1 Rainfall Anomaly Index (RAI)

Annual Rainfall Anomaly Index (RAI) was used to analyse the frequency and intensity of the dry and rainy years. The monthly RAI was also calculated for specific years of the historical series aiming to analyse the distribution of rainfall in the years of the greatest anomaly. According to [20], the RAI constitutes the following equations:

$\text{RAI} = 3\left[\frac{N-\bar{N}}{\bar{M}-\bar{N}}\right]$, for positive anomalies (1)

$\text{RAI} = -3\left[\frac{N-\bar{N}}{\bar{x}-\bar{N}}\right]$, for negative anomalies (2)

Where: N = current monthly or yearly rainfall in mm (or the month/year when RAI will be generated); $\bar{N}$= monthly or yearly average rainfall of the historical series (mm); $\bar{M}$ = average of the ten highest monthly or yearly rainfall of the historical series (mm); $\bar{x}$ = average of the ten lowest monthly or yearly rainfall of the historical series (mm), and positive anomalies have their values above average, and negative anomalies have their values below average. The variability index was computed on a monthly, yearly and seasonal basis (NDJFM: November, December January, February, and March, AMJ: April, May, and June, JASO: July, August, September, and October,) corresponding to the dry season, early rainy season and late rainy season as understood by the local farmers in the study area [4].

Table 1: Classification of Rainfall Anomaly Index Intensity

RAI Range	Classification
Above 4	Extremely humid
2 to 4	Very humid
0 to 2	Humid

-2 to 0	Dry
-4 to -2	Very dry
Below -4	Extremely dry

Source: Costa and Rodrigues (2017)

2.2.2 SPI Drought indices

The Standardised Precipitation Index (SPI) is a useful tool developed by McKee et al. in 1993 for drought monitoring and analysis [21]. It is normally used to assess the length and magnitude of drought events. It has gained the acceptance of the World Meteorological Agency (WMO) as an index to be used for drought monitoring across the world. To compute SPI for a particular location, a long-term historical rainfall record (thirty years or more) is fitted to a probability distribution function (pdf) (generally the gamma distribution), which is then transformed to a normal distribution so that the mean SPI for the location and considered period is zero [22]. Since research has shown that rainfall is subject to the gamma distribution law [22], a process of maximum likelihood estimation of the gamma distribution parameters, ∝ and β, is thus applied to fit the rainfall distribution. Its probability density function defines the equation representing the distribution as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \quad (3)$$

$$for\ x > 0$$

where a and □□are the respective shape and scale parameters, x is the rainfall amount and □(a) is the gamma function. Parameters a and □□of the gamma pdf are estimated for each station and for each time scale of interest (1, 3, 6, 9, 12 months.). Maximum likelihood estimations of a and □□are:

$$\alpha = \frac{1}{4\text{A}}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (4)$$

$$\beta = \frac{x}{\alpha} \quad (5)$$

where $A = In\,(x) - \frac{\sum In\,(x)}{n}$ (6)

x is the rainfall average; and n is the number of observations.

The resulting parameters are then used to find the cumulative probability of an observed rainfall event for the given month and time scale for the location in question. Since the gamma function is undefined for $x = 0$ and a rainfall distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G\,(x) \quad (7)$$

q is the probability of zero rainfall and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in a precipitation time series, then q can be estimated by m/n. The cumulative probability $H(x)$, is then transformed to the standard normal random variable z with mean zero and variance of one [21], which is the SPI value. According to the SPI, a drought event occurs when the index continuously reaches an intensity of -1.0 or less, and the event ends when the SPI becomes positive. The various classifications of drought based on SPI are as shown in Table 2

Table 2: Classification of different Precipitation Indices

SPI Value	Drought Category
> 2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

2.2.3 Trend Analysis

Mann-Kendall was used to determine the monotonic trends in rainfall. To apply the test, the condition that must be satisfied is given as in equation 8:

$$\chi = f(t) + \sum t \quad (8)$$

The MK test statistic 'S' is calculated as follow:

$$\text{S} = \sum_{i=1}^{n-1} \sum_{j=i-1}^{n} sign\,(xj - xi) \quad (9)$$

Where xi and xj are the sequential data values, n is the data set record length, and

$$Sign = \begin{cases} +1 & \Theta > 0 \\ 0 \quad if & \Theta = 0 \\ -1 & \Theta < 0 \end{cases} \quad (10)$$

indicates positive differences, no differences, and negative differences, respectively and S is computed as the sum of the integers. The variance of the expected value of S equals zero (E[S] = 0) for series without trend and is given by::

$$\sigma^2(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \quad (11)$$

Where q is the number of tied groups and t_p is the number of data values in $\boldsymbol{p^{th}}$ group. The test statistics Z is then given as:

$$Z=\begin{cases}\frac{s-1}{\sqrt{\sigma^2(s)}} & S>0\\ 0 \quad if & S=0\\ \frac{s+1}{\sqrt{\sigma^2(s)}} & S<0\end{cases} \quad (12)$$

The Z statistic is used to test the null hypothesis, H0, that the data are randomly ordered in time, with the alternate hypothesis, H1, indicating an increasing or decreasing monotonic trend. The trend analysis was done on three different timescales. The timescale used is based on the assertion of [15] that 1969 is a year with a distinct change in annual rainfall for many regions in Nigeria.

3. RESULTS AND DISCUSSION

3.1 Variability study

Variability study and Trend analysis of rainfall and its spatial and temporal variability in a changing climate is important to access climate-induced changes and suggests adequate water resources management for the future. The data for rainfall over Lokoja from 1911 to 2010 were analysed using basic statistics such as maximum, minimum, standard deviation, standard deviation and coefficient of variation. The statistical analyses for the 100-year time series of rainfall (1911-2010) are presented in Table 2. The mean annual rainfall was 1401.581 mm having a standard deviation of 168.42 mm. The minimum annual rainfall experienced in the area under consideration was 809.9 mm while the maximum was 1778.6 mm. The coefficient of variation (CV) was highest during December 183.28 % followed by January 147.72 %. This was not unexpected as the two months fall in the dry season. Of the months within the rainy season (April-October), August has the highest coefficient of variation (38.61%) while September has the least (16.73%). The results showed that the degree of variability was less only in September (CV < 20), moderate in May, June, and July (20 < CV < 30) while April, July and August have experienced high variability in rainfall over the 100 years considered (1911-1910).

Table 2: Monthly (mm/month) and annual (mm/year) statistics over Lokoja (1911-2010)

Months	Min	Max	Mean	SD	CV (%)
Jan	0	24.80	3.15	4.65	147.72
Feb	0.00	48.40	12.48	12.93	103.61
Mar	2.50	154.50	51.09	28.14	55.09
Apr	20.70	243.50	108.02	38.90	36.01
May	99.10	280.10	171.78	36.93	21.50
Jun	95.50	307.10	198.09	40.62	20.50
Jul	42.30	396.70	210.83	64.23	30.46
Aug	51.10	430.30	205.25	79.25	38.61
Sep	93.60	347.50	259.79	43.46	16.73
Oct	47.50	271.10	159.04	47.67	29.97
Nov	0.30	77.40	18.72	16.65	88.94
Dec	0.00	36.40	3.35	6.15	183.28
Annual	809.90	1778.60	1401.58	168.42	12.02
AMJ	324.00	695.80	477.89	74.50	15.59
JASO	306.90	1146.40	834.90	136.81	16.39
NDJFM	17.70	231.10	88.79	42.33	47.67

On the seasonal timescale, of the two rainy seasons, the variability was highest in JASO (16.39%) and closely followed by in AMJ (15.59%). The coefficient of variation showed that the temporal variability of annual rainfall was the lowest (12.02%). The rainy seasons and annual rainfall fall under the class of less variability. To the total annual rainfall of 1401.58 mm over 100 years, rainfall during September (259.79) and July (210.83) have the highest contributions, with each contributing a respective value of 18.53% and 15.04%. Of the seasons, JASO has the highest contribution (675.86), representing 59.57% of the total annual rainfall (Figure 2 and 3). These findings are in agreement with the reports of [23] and [24].

3.2 Rainfall indices

The result of the rainfall anomaly index showed that the wettest year was 1914 (1.60), and the driest year was 1931 (0.01) (Figure 4). The two, however, fall into the class of humid. Comparison between the two years (wettest and driest) showed that more rainfall was experienced in the early rainy season (AMJ) of the wettest while the driest have more rains during the late rainy seasons (JASO) (Figure 5). The results showed that the index (RAI) fails to detect the dry condition in Nigeria in a century data of rainfall. However, a further study with SPI, showed varying degree of the wet and dry conditions.

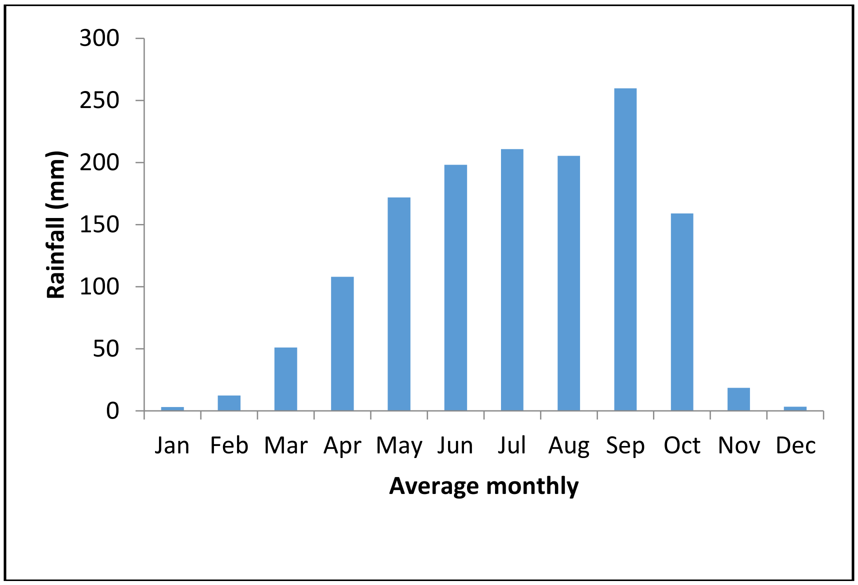

Figure 2: Average Monthly Rainfall over 1911-2010

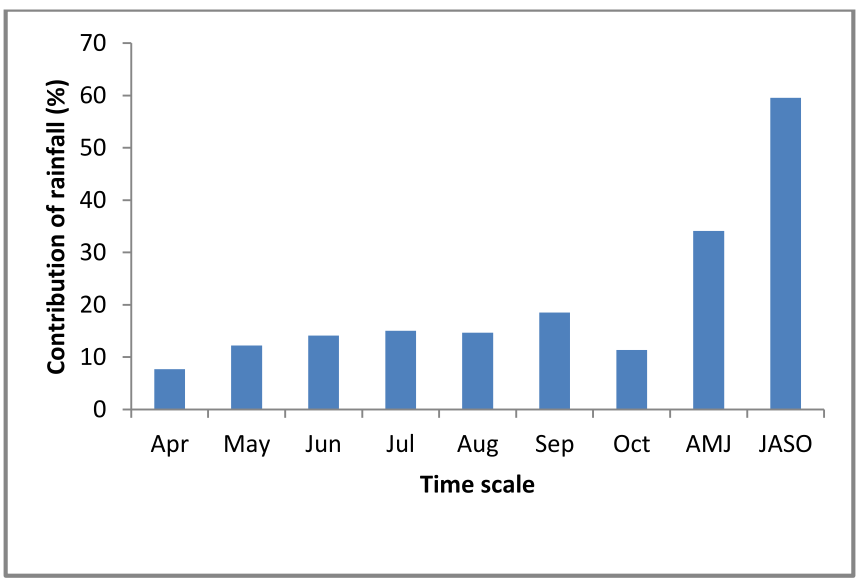

Figure 3: Monthly and Seasonal contribution to the annual Rainfall

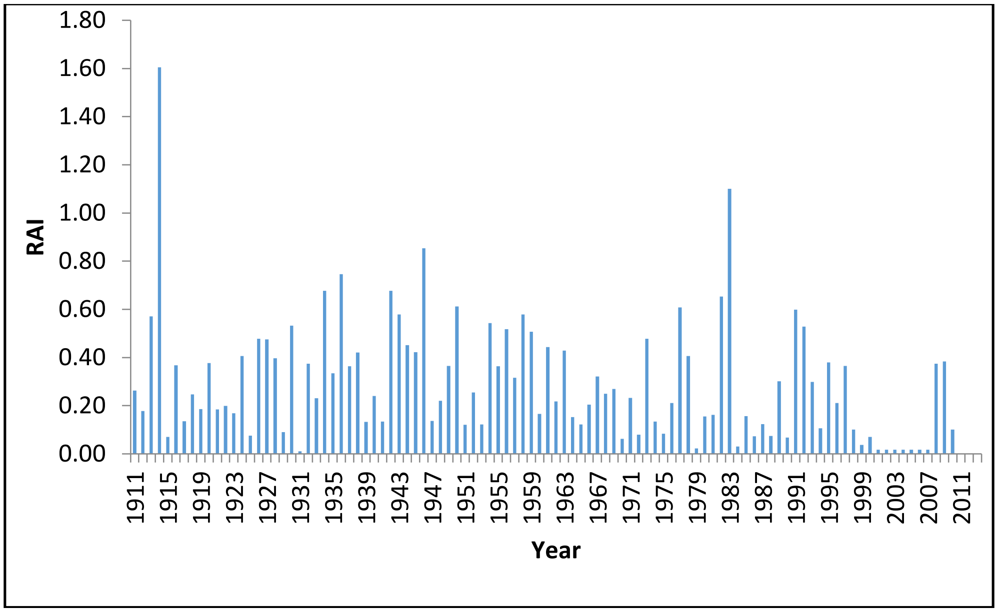

Figure 4: Rainfall anomaly index from 1911-2011

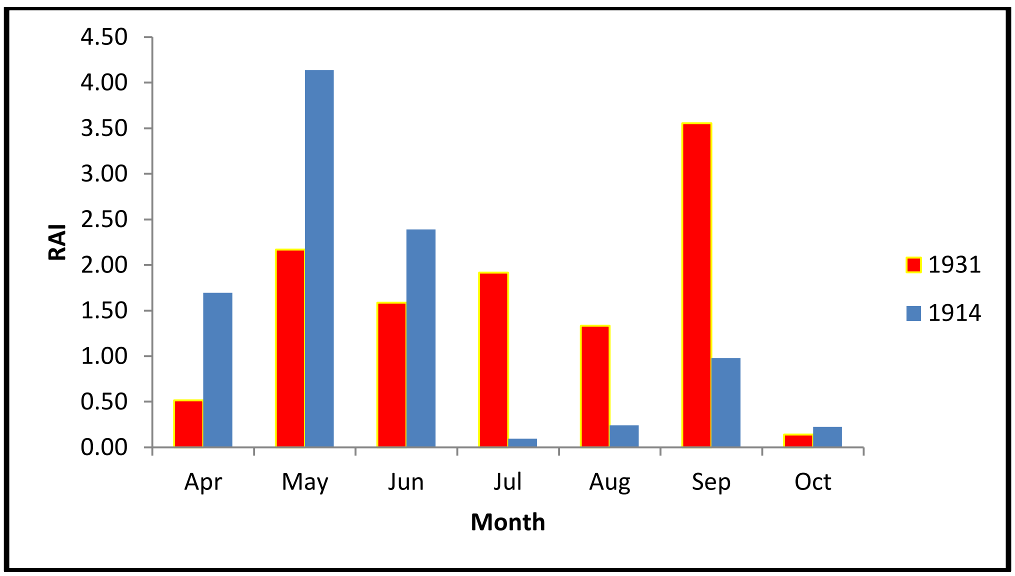

Figure 5: Comparison between the most humid and driest year

The time series plots of SPI showed a lower temporal frequency and longer duration of dry and wet periods on the monthly (Figure 6) and annual (Figure 7) time scale. Of the total timeline, two years (1914, 1983) experienced extreme dry, severe dry was experienced in three years (1936, 1942, 1945) and eleven years (11) experienced moderate dry. Near normal was experienced in the study location for sixty-five (65) years. Extreme wet was only experienced in 1934. Three years (1930, 1954, and 1991) experienced very wet condition; moderate wet was experienced for fifteen years. The annual and 12-month timescale analysis showed that the driest year was 1914 (extremely dry) while the wettest year was 1934 (extremely wet). Between 1916 and 1934 and between 1963 and 1980, Lokoja witnessed wet conditions while between 1942 and 1946 more dry condition was experienced. Alternation of wet and dry period conditions was witnessed between 1950 and 1982. The results of these findings is in line with earlier findings of [25], [26], [15] and [27] who had laid claim to the existence of drought within the period mentioned in this study.

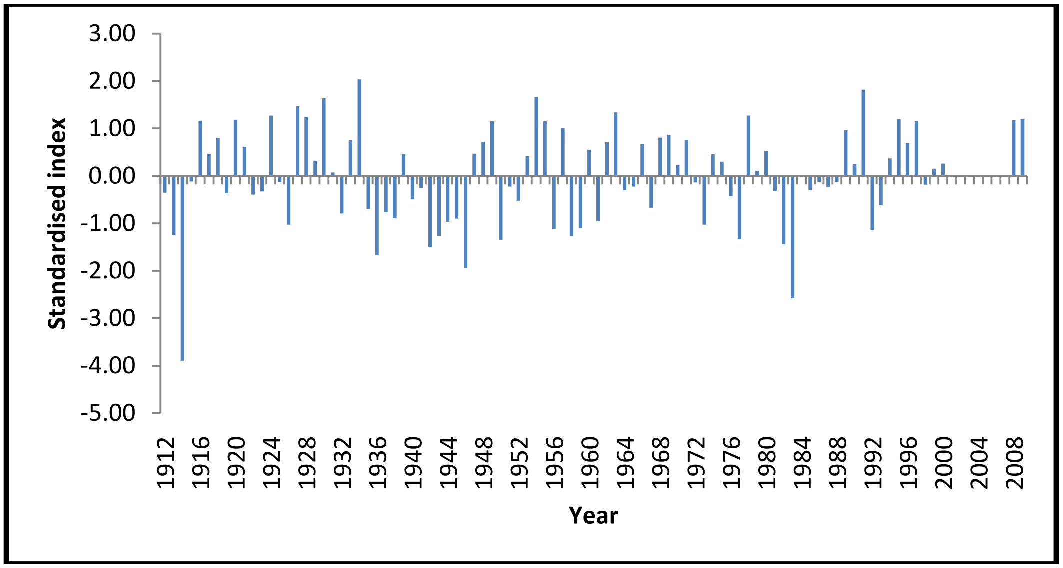

Figure 6: Time series plot of SPI on an annual timescale

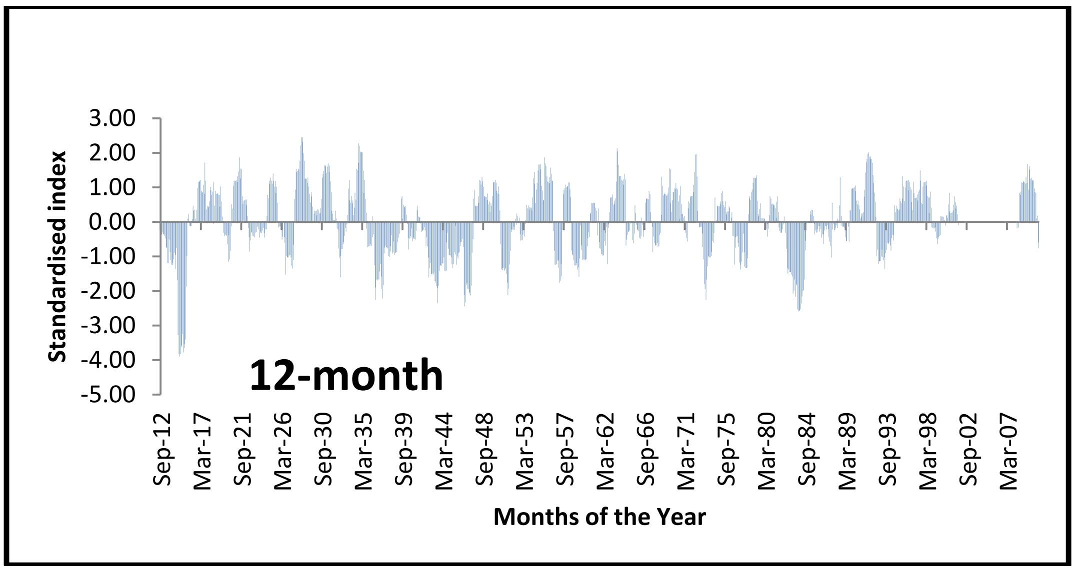

Figure 7: Time series plot of SPI on months of the years' timescale

3.3 Trend Analysis

The results of monotonic trends and slope estimates for different timescales (1911-2010, 1911-1969 and 1970-2010) are presented in Table 3. Monthly trend tests showed a mix of positive and negative trends at Lokoja. During the year 1911-2010, statistically significant positive trends were found in July and August (at 5%), while a significant negative trend was found in November (at 1%). All the months in the dry season experienced negative trends, indicating that the dry seasons are getting drier. Non-significant trends have been experienced in the early rainy season (AMJ) while the late rainy season has experienced a statistically significant trend (5%). Sen's slope estimate (Q) showing the true slope of linear trend (i.e. change per month) is also presented in Table 3. The timeline 1911-1969 and 1970 to 2010 also experienced a mixture of positive and negative trends. More positive trends experienced in the period 1970-2011 compared to 1911-1968; indicate a relative increase in the monthly rainfall during the later climatic period (1970-2010). This could be what manifests through incessant flood witnessed in the area in recent times. This work agrees with the claim of [28] that rainfall is on the increase in most of the stations in Nigeria.

Table 3: Mann-Kendall Trend

	1911-2010		1911-1969		1970- 2010	
Time series	Test Z	Q(mm/month)	Test Z	Q(mm/month)	Test Z	Q(mm/month)
January	-0.72	0.00	-0.26	0.00	0.91	0.00
February	-0.19	0.00	-1.19	-0.06	0.43	0.01
March	-1.66+	-0.15	0.01	0.00	-0.56	-0.03
April	-1.16	-0.16	-0.45	-0.16	0.59	0.12
May	0.21	0.02	-0.58	-0.19	0.01	0.00
June	0.39	0.05	0.76	0.35	0.28	0.06
July	2.56*	0.52	1.22	0.58	1.64	1.09
August	2.16*	0.58	0.03	0.03	0.96	0.96
September	-0.97	-0.15	-0.30	-0.13	-0.06	0.00
October	-0.03	0.00	0.55	0.23	1.26	0.51
November	-2.65**	-0.11	-0.35	-0.05	1.77+	0.14
December	-0.40	0.00	-0.17	0.00	1.74+	0.03
Annual	1.00	0.59	0.22	0.33	1.06	1.19
AMJ	-0.50	-0.13	-0.12	-0.04	0.64	0.36
JASO	2.40*	0.96	0.84	0.75	1.62	1.65
NDJFM	-2.54*	-0.32	-0.65	-0.19	-0.25	-0.04

** trend at 0.01 level of significance, *trend at 0.05 level of significance, + the trend at 0.1 level of significance

4. CONCLUSION

The study investigated variability and trends in rainfall time series for the annual, wet and dry season over Lokoja between 1911 and 2010. The analysis of rainfall showed that September has the highest percentage of monthly contributions (18.53%) to the annual rainfall and the late rainy season (JASO) contributed the highest (59.57%) on a seasonal basis. Rainfall anomaly index (RAI) showed that the wettest year was 1914, and the driest year was 1931. However, both values are humid, suggesting that the index may only be suitable for detecting the wet condition. The Standardised precipitation index showed that all the different classes (from extremely dry to extreme wet) of precipitation indices had been witnessed in Lokoja. The driest years were 1914 and 1983 (both extremely dry), and 1934 was the wettest year (extreme wet). More months showed a decreasing trend of rainfall during the 1911-1969 climatic periods compared to 1970-2010, which is on the increase. The trend suggested a probable temporal increase in rainfall trend, which may have impacts on water resources management, agricultural practices and the socio-economic activity of the area as it is being witnessed through the flood in recent time.

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