Nigerian Journal of Engineering
Faculty of Engineering
Ahmadu Bello University
Samaru-Zaria, Nigeria

Vol. 26, No. 2, August 2019
ISSN: 0794 - 4756

RAINFALL VARIABILITY AND TREND ANALYSIS IN MAKURDI METROPOLIS, BENUE STATE, NIGERIA

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ABSTRACT
This study analyses Makurdi rainfall data from 1955 to 2015, for the purpose of detecting the rainfall variability, trends, and assessing its implications on flood occurrence. Data on daily rainfall and flood occurrences were collected from relevant government agencies. Rainfall trends were analyzed using Mann–Kendall, Spearman's rank correlation and Student's t tests, both giving almost similar results for the three methods. Rainfall variability was analyzed using standardized precipitation index (SPI). The result of the analysis indicated that 1955 and 1993 were the wettest years, while 1958 and 2003 were the driest. Also, September was the wettest, closely followed by August, while December was the driest. A negative (decreasing) statistically insignificant trend for the total annual rainfall data from 1955 to 2015, but positive (increasing) statistically insignificant trend for the extreme annual rainfall was observed. The findings revealed that extreme rainfall events corresponded to flood occurrence. Thus, the annual rainfall total is not necessarily an important cause of increased flood frequency, but the fraction of it that occurs as extreme rainfall. It is recommended that effective mitigation measures should be put in place for likely floods that may arise owing to the anticipated extreme rainfall magnitudes in the coming years in Makurdi.
Keywords: *Rainfall, Trend, Variability, Extreme Rainfall, Flood, Mitigation.*

INTRODUCTION
Rainfall is one of the prime indicators of climate change and its aberration causes many environmental extreme events such as floods and droughts (Pranuthi *et al.,* 2014). Particularly, variations in rainfall over different time-scales and amounts bring enormous economic, environmental, social and political repercussions (Kwarteng *et al.,* 2009; Lima *et al.,* 2010). This is because rainfall influences other hydrological processes like runoff, soil moisture and groundwater reserves.

The occurrence of environmental extremes, particularly flood, is not a recent phenomenon in Nigeria (Mmom and Ayakpo, 2014), and diverse studies have established a strong relationship between floods and rainfall (Jeb and Aggarwal, 2008; Babatolu *et al.,* 2014). Makurdi is one of the flood prone areas in Nigeria; the town is potentially susceptible to flooding in the event where there is a prolonged or intense downpour which could cause flash floods and raise the volume of the river Benue to tremendous levels making it over spill its banks (Abah, 2013; Bulaman and Embulo, 2015). According to Ocheri and Okele (2012) flooding has almost become an annual event leading to loss of lives and destruction of properties worth millions of naira in the town.

Several studies have been conducted on rainfall and flood events in Makurdi, probably because of the geographical location of the town; in a flood plain (Ocheri and Okele, 2012; Ologunorisa and Tersoo, 2006; Shabu and Tyonum, 2013; Odunuga *et al.,* 2015).The Spearman's rank correlation was adopted for trend analysis of rainfall in the study area by Ologunorisa and Tersoo (2006), however, Croux and Dehon (2010)stated that the Mann-Kendall is preferred to the Spearman's correlation in terms of robustness and statistical efficiency. Likewise, Miao *et al.* (2012) argued that the Mann-Kendall test is best for trend detection because there are very few underlying assumptions about the structure of the data, making them robust against departures from normality. They also added that, Kendall is preferred to the simple or seasonal regression tests when data are skewed, cyclic, and serially correlated. Similarly, inference from the works of Yue and Wang (2002) corroborates that Mann-Kendall test possesses the useful property of other nonparametric tests in that, it is invariant to (monotonic) power transformations such as those of the ladder of powers. Although these different researches have assisted in providing some information about the occurrence of extreme rainfall in the area, they have not adequately analyzed the rainfall trends. Besides, the study has been done for over a decade, and the flooding scenarios in the town has since become even more server and often in the last decade as reported by (Ocheri and Okele, 2012; Aderogba, 2012; Daura and Mayomi, 2015). Therefore, it is important to investigate the rainfall trend and variability incorporating recent rainfall data. Variations in rainfall over different time-scales bring enormous economic, environmental, social and political effects; thus, it is crucial to investigate the temporal and spatial variation of rainfall and its attendant effects on the environment.

This study examines Makurdi rainfall data from 1955–2015 for annual variability and trends using the standardized precipitation index (SPI), Spearman's rank correlation, Mann–Kendall test and a parametric based Student t-test.

METHODOLOGY
Study Area
The focus of this study is Makurdi, the capital of Benue State, Nigeria. The town is located between latitudes 7°37' and 7°47' North and longitude 8°27' and 8°40' East within the floodplain of the lower River Benue valley, and situated at elevation 104m above sea level. Owing to constancy in isolation with the maximum of 32°C and a mean minimum of 26°C, the temperatures are generally high throughout the year with the hottest months been March and April. The mean

monthly relative humidity varies from 43% in January to 81% in July-August period (Tyubee, 2009).

The physiographical characteristics span between 73 m to 167 m above sea level (Ocheri and Okele, 2012). A huge part of the town is waterlogged and flooded during extreme rainfall due to the geographical location of the town (i.e. on the flood plain). The town is drained basically by the Benue River and its tributaries, such as Rivers Idye, Genebe, Urudu, Kpege and Kereke (Ocheri *et al.,* 2010).

Data Collection

The data used for this work were from secondary sources. Daily rainfall data for Makurdi with station number (0708.43) at latitudes 7°41' N and longitude 8°37'E, spanning from 1955 to 2015 was obtained from the Nigeria Meteorological Agency (NIMET) Oshodi, Lagos. The statistics on flood occurrence in Makurdi was collected from the archives of the National Environmental Standards and Regulations Enforcement Agency (NESREA) Markurdi branch, and other pertinent sources like [Ocheri and Okele, 2012; Ologunorisa and Tersoo, 2006; Shabu and Tyonum, 2013; Aderogba, 2012; Daura and Mayomi, 2015]. The Mean rainfall for the study period (1955 to 2015, exempting 1965, 1966 and 1977) was 1208.94 mm with a standard deviation of 221.55 mm and skewness of -0.06. The maximum annual rainfall through the study period was 1729.9 mm, which occurred in 1993 and the minimum annual rainfall through the study period is 678.1 mm, which occurred in 1958.

Data Analysis Techniques

Homogeneity test

Homogeneity test was carried out for data validation purpose. For statistical analysis, rainfall data should ideally possess property of homogeneity (Easterling *et al.*, 2000). Metadata inspection and Student's t test for stability of means were used for this study.

Metadata inspection

Metadata inspection was aimed at identifying changing points visible by physical inspection of the data. The time series was plotted on a linear scale and inspected for inconsistencies, which were screened out. Similarly Microsoft excel 2010 was adopted for all data analysis.

Student's t test

The Student t-test for homogeneity assesses whether the means of two groups are not statistically different from each other (null hypothesis H0: $\mu_1 = \mu_2$). The rainfall data was divided into two and tested with the t-test statistic. The t-test statistic has a Student's distribution; it is defined as given by Equation 1(Longobardi and Villani, 2009).

$$t_{n1,n2} = \frac{\bar{X}_1 - \bar{X}_2}{S}\sqrt{\frac{n_1 n_2}{n_1 + n_2}} \quad (1)$$

where, n_1 ,$n_2$are the sample sizes; $\bar{X}_1$, $\bar{X}_2$ are the respective sample means; and, S is the sample variance, calculated as shown in Equation 2. The degree of freedom v for an eteroshedastic (unequal variances) case was used, and is expressed in Equation 3.

$$S = \sqrt{\frac{n_1 S_1{}^2 + n_2 S_2{}^2}{v}} \quad (2)$$

$$v = \frac{\left[{S_1}^2/n_1 + {S_2}^2/n_2\right]}{\frac{\left({S_1}^2/n_1\right)^2}{n_1 - 1} + \frac{\left({S_2}^2/n_2\right)^2}{n_2 - 1}} \quad (3)$$

The calculated t value was then compared with the critical t (tv,α) value at a 5% level of significance. If the calculated t value is above the threshold chosen for statistical significance then the null hypothesis, H0 ($\mu_1 = \mu_2$), that the two groups do not differ is rejected in favor of an alternative hypothesis, which states that the groups do differ (Ha: $\mu_1 = \mu_2$).

Variability

Variability is a measure of how far a set of values is spread out. The distribution and occurrence of rainfall is not uniform; rather it has spatial as well as temporal variations. This variability of rainfall in time and space makes rainfall occurrence very difficult to predict (Pranuthi *et al*., 2014), thus specialized indicators like standardized anomaly index (SAI) and the standardized precipitation index (SPI) are required. Standardized precipitation index (SPI) was used to assess the variability. SPI as described by (Balogun *et al.*, 2016) was computed using Equation 4, and SPI classification is shown in Table 1.

$$C_v = \frac{x - \bar{x}}{\sigma} \quad (4)$$

Table 1: Standardized annual precipitation index

Classification	**SPI**
Near normal	-0.99 to 0.99
Moderately wet years	1.0 to 1.49
Moderately dry years	-1.0 to -1.49
Very wet	1.5 to 1.99
Severely dry years	-1.5 to -1.99
Wet extreme	$\geq +2.0$
Dry extreme	≤ -2.0

Source: (Balogun *et al*., 2016)

Rainfall trend analysis

The monthly, seasonal, annual long term and short term, and extreme annual rainfall were analyzed for trends using the Mann-Kendall, Spearman's rank correlation and Student's t test.

Mann-Kendall test

Mann-Kendall test is a non-parametric test, meaning; it does not assume any particular form for the unknown distribution function. It has been commonly used for trend detection because of its robustness for non-normally distributed and censored data (Miao *et al*., 2012).The Mann–Kendall test statistic "S" was calculated using Equation 5 (Longobardi and Villani, 2009; Rahman and Begum, 2013).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \quad (5)$$

where;

$$sgn(X_j - X_i) = \begin{cases} +1 \ldots (X_j - X_i) > 0 \\ 0 \ldots (X_j - X_i) = 0 \\ -1 \ldots (X_j - X_i) < 0 \end{cases} \quad (6)$$

When n ≥ 8, the S statistic is approximately normally distributed with zero mean, the variance is estimated using Equation 7. Where n is the data record length. The standardized Z statistic follows a normal standardized distribution expressed in Equation 8.

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (7)$$

$$Z = \begin{cases} \frac{S-1}{\sigma} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sigma} & if \quad S < 0 \end{cases} \quad (8)$$

A positive value of "Z" signifies an upward trend, while a negative "Z" value signifies a downward trend. A significance level α is also utilized. If "Z" is greater than "Z1-α/2", then the trend is considered as statistically significant, where "Z1-α/2" is the critical value from standard normal distribution.

Spearman's rank correlation

Spearman's correlation coefficient also called Spearman's rho test (ρ) is a statistical measure of the strength of a monotonic relationship between paired data. It is a non-parametric method used to identify and test the strength of a relationship between two sets of data. Spearman's formula for rank correlation is given by Equation 9 (Spiegel *et al.*, 2009).

$$\rho = 1 - \frac{6\sum d^2}{n^3 - n} \quad (9)$$

where;

P is the coefficient of rank correlation;

d is the differences between the ranks of corresponding values of X and Y; and, n is the number of pairs of values (X, Y) in the data.

The standardized test statistic "t" is computed using Equation 10.

$$t = \rho \left(\frac{n-2}{1-\rho^2}\right)^{0.5} \quad (10)$$

The test statistic "t" has Student's t-distribution, with v = n - 2 degrees of freedom, where n is the number of elements in a sample. Like the Mann-Kendall test a positive value of "t" signifies an upward trend, while a negative "t" value signifies a downward trend. A significance level α is also utilized. If "t" is greater than "t_(α,v)" where "α" depicts the significance level, then the trend is considered as statistically significant.

Student's t (parametric) test

For trend analysis the parametric analysis test considers the linear regression of the random variable Y on time X. The regression coefficient β (the Pearson correlation coefficient) is the interpolated regression line slope coefficient computed from the data. "t" for trend analysis is as given in Equation 11.

$$t = \frac{\beta\sqrt{n-2}}{(1-\beta^2)^{0.5}} \quad (11)$$

$$\beta = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \quad (12)$$

The statistic follows the Student's t distribution with n − 2 degrees of freedom. Where n is the sample size. A positive value of "t" signifies an upward trend, while a negative "t" value signifies a downward trend. If "t" is greater than "tα" where α depicts the significance level, then the trend is considered as statistically significant (Longobardi and Villani, 2009; Asikoglu and Ciftlik, 2015).

Comparison of rainfall magnitudes and flood dates

A comparison of flood dates and their corresponding rainfall magnitudes was done, by comparing the available flood dates with the rainfall magnitudes on such dates as indicated in Table 2.

RESULTS AND DISCUSSION

Homogeneity Tests

The result of the metadata inspection presented in Figure 1 shows some remarkable changing points (the areas encircled in Figure 1). The first period was years' 1965 to 1966, and the second was 1977. These periods were noted to have defective records, probably due to poor working conditions of the rain gauges; hence they were screened out for any further analyses in this work. The result of the student's t test for stability of means, shows that the observed t value (0.24) is less than the critical t value i.e. $t_{\alpha,v}$ (2.009), hence the means are stable and the data is homogeneous.

Rainfall Variability

Going by the SPI classification in Table 1, Figure 2 shows that 1955 and 1993 had the occurrence of wet extremes, while 1958 and 2003 were the driest years. Also, 1998 and 1999 were very wet, while 1967, 1988 and 2005 were very dry years. 1963, 1969 and 2012 were moderately wet years, while the years 1982, 1983, 1985, 2004 and 2015 were moderately dry. The remaining years; about 70% of the study period, were near normal. With respect to monthly variations, Figure 3 shows that September was very wet, August, moderately wet, while January, February, November, and December were moderately dry. The remaining months were near normal. In terms of seasons, Figure 3 shows that the wet period was the months of May to October, and the dry period, November to April. The dry season contributed 10.66% while the wet season contributed 89.24% to the annual mean rainfall of the study period.

Table 2: Dates of flood occurrence and corresponding extreme rainfalls

Flood occurrence date	**Rainfall magnitudes**	
	Dates	**Magnitude**
29-Aug-96	29-Aug-96	86.3
25-Jun-99	25-Jun-99	119.3
3-Aug-00	3-Aug-00	149.3
11-Sep-02	11-Sep-02	101.1
August, 2008	30-Aug-08	60.8
	31-Aug-08	71.5
October, 2011	5-Oct-11	89.7
August-September 2012	13-Jul-12	87.3
	30-Jul-12	56.0
	16-Aug-12	98.4
	16-Sep-12	90.4
September-October, 2014	28-Sep-14	180.0
	29-Sep-14	62.3
August, 2015	11-Aug-15	174.1

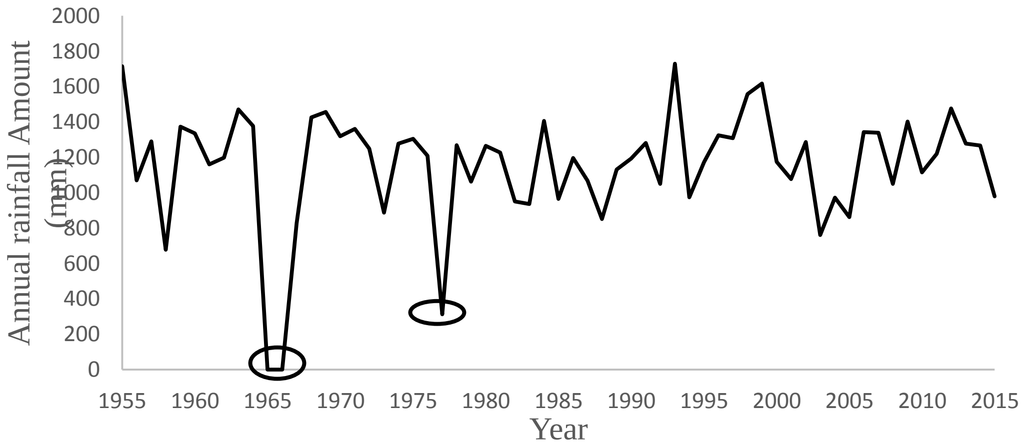

Figure 1: Time series plot of annual rainfall against year

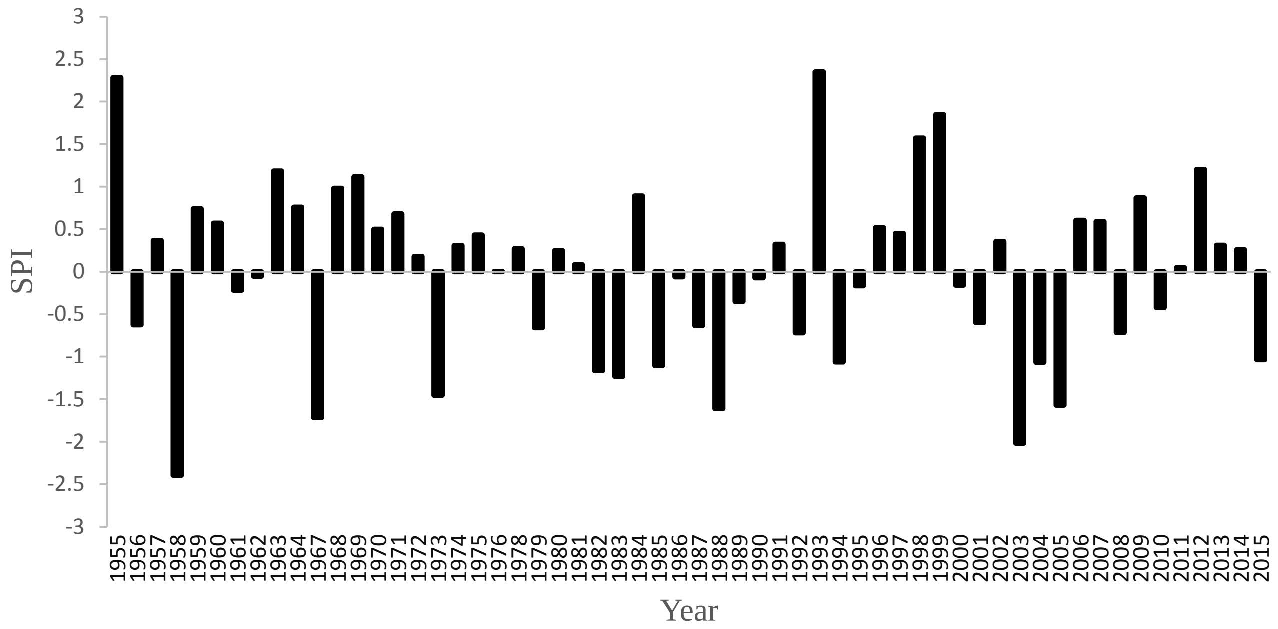

Figure 2: Plot of yearly SPI

Rainfall Trends

The summary result of trend analysis presented in Figure 4, shows that the three tests gave similar results for most periods except for the months of January, February, November, and December, and the years 1967-1976 and 2008-2015. The trend summary in Table 2 was arrived at by comparing the three tests and classifying the period based on the two most prevalent trend conditions of the three tests. For instance, for January, the Mann-Kendall and Student's t tests shows positive statistically insignificant, while the Spearman's rank correlation shows positive statistically significant, the two most prevalent trend status is positive statistically insignificant trend, thus it was concluded that the trend is positive statistically insignificant.

From this analysis, it has been noted that increasing rainfall trends exists in January, February, August, October, November and December (statistically insignificant). While there was a statistical significant decrease in rainfall trend for March and a statistical insignificant decrease for the months of April, May, June, July and September. The seasonal trend for both dry and wet season had a statistically insignificant decreasing trend. On the short term, there was a positive increasing rainfall trend in the years 1955-1964 and 1988-1997, while 1967-1976, 1978-1987, 1998-2007 and 2008-2015 had a decreasing statistically insignificant trend. The long term total annual trend was a decreasing statistically insignificant trend, while the annual extreme rainfall for both annual maxima and cumulative extremes had increasing statistically insignificant trends.

Table 3: Trend analysis summary

Period	**Trend summary**
January	Positive (statistically insignificant)
February	Positive (statistically insignificant)
March	Negative (statistically significant)
April	Negative (statistically insignificant)
May	Negative (statistically insignificant)
June	Negative (statistically insignificant)
July	Negative (statistically insignificant)
August	Positive (statistically insignificant)
September	Negative (statistically insignificant)
October	Positive (statistically insignificant)
November	Positive (statistically insignificant)
December	Positive (statistically insignificant)
Total Annual	Negative (statistically insignificant)

Extreme Annual	Positive (statistically insignificant)
Wet	Negative (statistically insignificant)
Dry	Negative (statistically insignificant)
1955-1964	Positive (statistically insignificant)
1967-1976	Negative (statistically insignificant)
1978-1987	Negative (statistically insignificant)
1988-1997	Positive (statistically insignificant)
1998-2007	Negative (statistically insignificant)
2008-2015	Negative (statistically insignificant)

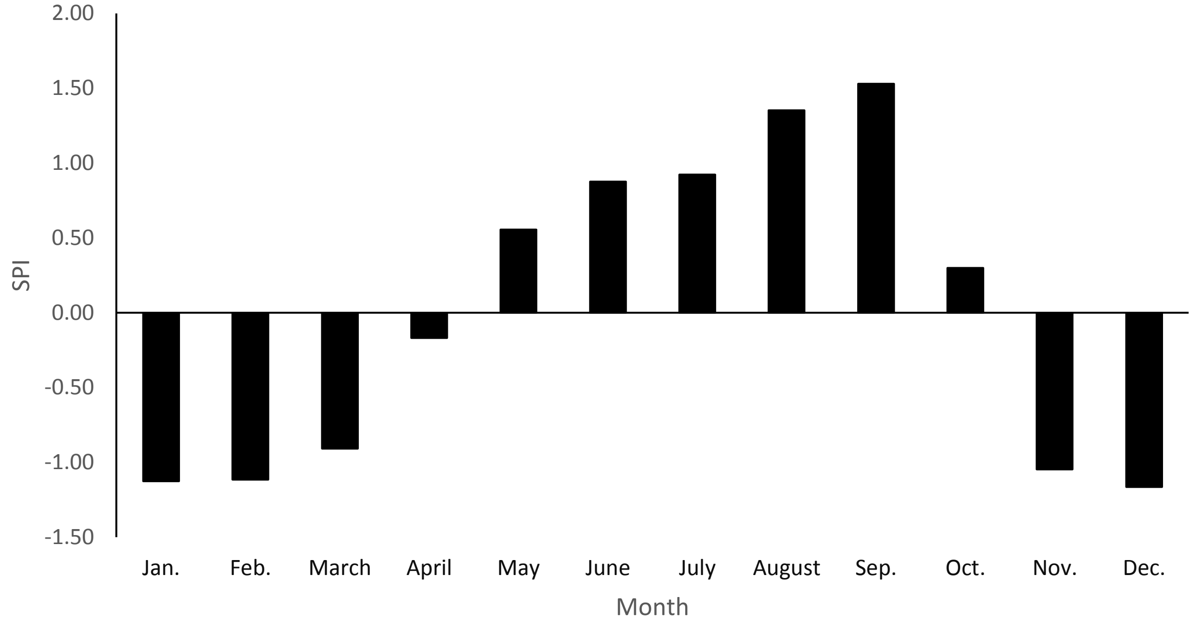

Figure 3: Plot of monthly SPI

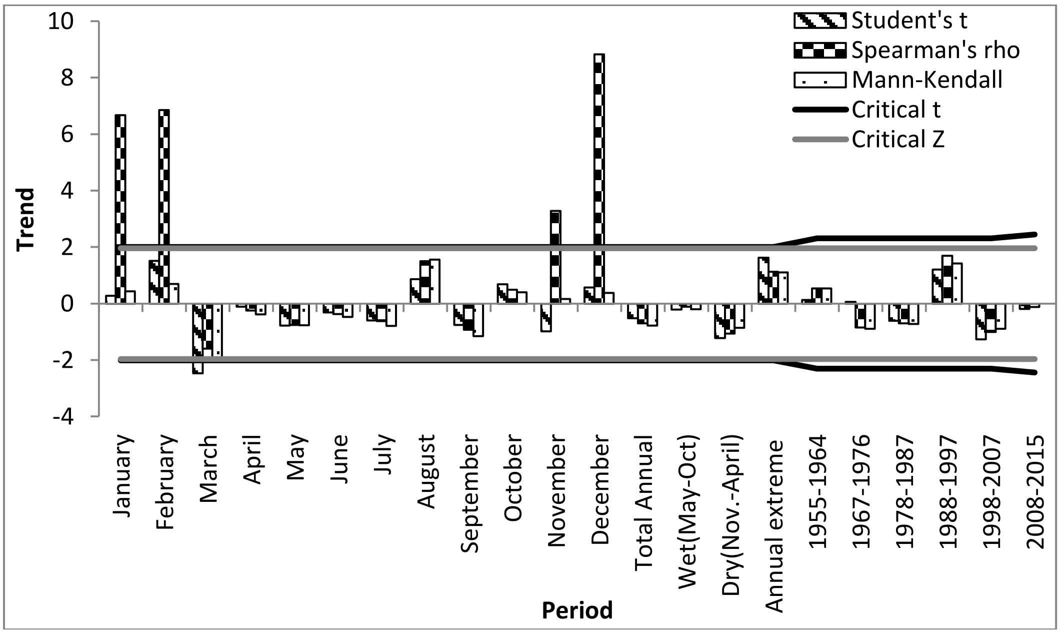

Figure 4: Trend analysis summary result

Flood Occurrence

Analysis of rainfall magnitudes and available records of floods showed that flood events corresponded to extreme rainfall events on the series. For instance, the flood events of 29 August, 1996; June 25, 1999; August 3, 2000; and September 11, 2002 among others; corresponds to extreme rainfall magnitudes as depicted in Table 3. This implies major floods were mostly associated with extreme rainfalls. The total annual and extreme rainfall trends showed negative and positive trends respectively, an indication that Makurdi is getting drier in terms of annual total rainfalls, but the occurrence of extreme rainfall (flood causing rainfall) magnitude is increasing. This finding also agrees with Ologunorisa and Tersoo (2006). As a matter of fact, the two peak extremes recorded throughout the study period (180 mm and 174 mm), were in the last two years of observation i.e. 2014 and 2015 respectively. This implies that the total rainfall is not necessarily the cause of floods in Makurdi, but the fractions that occurs as extremes.

CONCLUSIONS

Analyses of rainfall data for Makurdi town for the purpose of detecting variability, trends, and its implications on flood occurrence was undertaken in this study. The variability analysis indicated that 1955 and 1993 were the wettest years, while 1958 and 2003 were the driest years within the study period. In terms of monthly variations; September was the wettest, closely followed by August, while December was the driest month.

Trend analyses, showed that there was a negative (decreasing) statistically insignificant trend for the total annual rainfall data from 1955 to 2015, but a positive (increasing) statistically insignificant trend for the extreme rainfall, based on annual trend. Observations from the trend analysis shows that, Makurdi is getting drier in terms of annual rainfall totals, but receiving unprecedented extreme rainfalls in recent years.

Extreme rainfall events corresponded to flood occurrence, indicating that there is a relationship between extreme rainfall and flood. Thus, the annual rainfall total is not necessarily an important cause of increased flood frequency, but the fraction of it that comes as extremes especially in months of water surplus when the ground is saturated. Effective mitigation measures should be put in place for likely floods that may arise owing to the anticipated extreme rainfall magnitudes in the coming years in Makurdi.

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