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Full Length Research Paper

Evaluation of rainfall trends in Nigeria for 30 years (1978-2007)

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The issue of climate change appears to be on the fore burner and it cannot be ascertained to occur without evidence. Rainfall is one of the climatic factors that can indicate climate change. In this work, the non-parametric Mann-Kendall test is used to test for significant trend in rainfall in Nigeria through randomly selected locations in the six geopolitical zones within a 30 years period (1978-2007). The selected locations are; Maiduguri (13°10',11°50') in the North East, Kaduna (7°27',10°31') in the North West, Lokoja (6°45',7°43') in the North Central, Ibadan (3°53',7°22') in the South West, Enugu (7°30',6°27') in the South East and Calabar (8°28',4°57') in the South South. During the 30 years period, the yearly average rainfalls (mm) were 580.5, 1187.5, 1228.7, 1317.2, 1753.8 and 2925.6, respectively. While the rest of the locations had no significant trend yet Maiduguri showed an increasing trend at a rate of 9.88 mm/year, where formally the trend there from the period 1961-1990 was decreasing. This change could either be a problem or blessing to dwellers in that location and there is need for continuous monitoring.

Key words: Mann-Kendall test, rainfall, significant trend, six geopolitical zones in Nigeria.

INTRODUCTION

Climate change seems to be the foremost global challenge facing humans at the moment, even though it seems that not all places on the globe are affected. World leaders, union leaders, pressure groups and others who have shown concern have been meeting to find a lasting solution to the 'acclaimed' dilemma. The scientific community has not been left out as causes and solutions are being proffered and it is expected to linger on for a long time. One of the indicators of climate change is rainfall (Adger et al., 2003; Frich et al., 2002; Novotny and Stefan, 2007).

Rainfall is a climate parameter that affects the way and manner man lives. It affects every facet of the ecological system, flora and fauna inclusive. Hence, the study of rainfall is important and cannot be over emphasized (Obot and Onyeukwu, 2010). Aside the beneficial aspect of rainfall, it can also be destructive in nature; natural disasters like floods and landslides are caused by rain (Ratnayake and Herath, 2005). Globally, lots of studies have been carried out on rainfall. A few of them is discussed briefly; Jayawardene et al. (2005) observed different trends across Sri Lanka using 100 years data. Some parts recorded decreasing trend, some increasing trend while some locations showed no coherent trend. They also showed that the trend characteristics vary with the duration of the data analyzed. Smadi and Zghol (2006) examined the trend analysis of rainfall over Jordan picking 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 days and the total amount of rainfall after the mid 1950s. While in Turkey, Partal and Kahya (2006) examined the trend within a 64 year period (1929-1993) of rainfall for 96 stations. The overall result indicated that the trend in precipitation is downward, nonetheless, there are few stations that showed increasing trend.

Statistical tools commonly used to detect significant

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trends in climatic and hydrological time series is either or both of the non-parametric test such as Mann-Kendall or Spearman's rank correlation and the parametric test such as student's t-test. The non-parametric test is considered better because it is a function of the ranks of observation and it displays much insensitivity to outliers unlike the parametric counterpart. Beside some of the works already mentioned above that is (Jayawardene et al., 2005; Smadi and Zghol, 2006; Partal and Kalya, 2006), others that have used the traditional Mann Kendall non-parametric rank correlation in some instances to test for trend in countries include; Italy (Cislaghi et al., 2005), Japan (Xu et al., 2003), Iran (Modarres and Silva, 2007), Bulgaria (Bocheva et al., 2009), Botswana (Batisani and Yarnal, 2009), Portugal (Loureiro and Coutinho, 1995), Spain (Munoz-Diaz and Rodrigo, 2006), Argentina (Pasquini et al., 2006) and Australia (Raiber et al., 2009).

Nigeria is a country with diverse ethnic groups practicing different cultures, and having variations in farming and religion beliefs. The country can primarily be divided into two major geographical zones namely the North and South, though that has historical underlying (Tamuno, 1978). Furthermore, both the North and South are segmented into three regions each, making a total of six geopolitical zones. These six geopolitical zones in the country are; North East, North West, North Central, South West, South East and South South. Policies, resource allocations, sites of infrastructures and even political and other appointments are mostly considered by zoning in Nigeria. The purpose of this work is to find out the characterized trend of total amount of rainfall across Nigeria as it affects some selected locations in the six geopolitical zones within a 30 year period (1978-2007). The outcome could help to inject inputs for proper planning in the country.

METHODS

Six locations across Nigeria each falling within the six geopolitical zones, are randomly chosen for this study. These include; Kaduna (7°27',10°31') in the North West, in the North East there is Maiduguri (13°10',11°50'), Lokoja (6°45',7°43') in the North Central region, Ibadan (3°53',7°22') in the South West, Enugu(7°30',6°27') in the South East region and Calabar (8°28',4°57') in the South South region of the country. Rainfall data spanning a period of 30 years (1978-2007) were supplied by the Nigerian Meteorological Services NIMET Lagos, Nigeria. The obtained data were in daily values from which the yearly totals were calculated.

To avoid the serial effect of time series on the null hypothesis, the lag1 serial correlation coefficient is tested to access the serial dependence. The lag1 type 1error rejects a null hypothesis when actually it is true due to serial correlation effect. In situations where the lag1 correlation coefficient, r is up to 0.30, then the series is 'prewhitened' using the format; $Y_t = X_t - r_1 X_{t-1}$.. In this work, the method used in the evaluation of the trend in rainfall is the Mann- Kendall rank correlation described below.

Mann-Kendall rank correlation

Given a data set of n size, whereby n is not less than 10, for a mean of zero and a standard deviation of 1, and assuming that the time series is independent, then the Mann-Kendall statistic *S* is described as;

$$sign(x_j - x_i) = 1 \quad if\ x_j - x_i > 0$$
$$= 0 \quad if\ x_j - x_i = 0$$
$$= -1 \quad if\ x_j - x_i < 0$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i)$$

Here, x_i and x_j are sequential data for the i[th] and j[th] terms.

$$VAR(S) = \frac{n(n-1)(2n+5)}{18}$$

For situation where ties occur, then *VAR(S)* is extended to the form;

$$VAR(S) = \left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] / 18$$

Where *q* is the number of tied groups and t_p the number of data values in the p^{th} group.

$$Z = \frac{S-1}{\sqrt{VAR(S)}} \quad if\ S > 0$$
$$= 0 \quad if\ S = 0$$
$$= \frac{S+1}{\sqrt{VAR(S)}} \quad if\ S < 0$$

The null hypothesis Ho for a two sided test is rejected when $|Z| \geq Z_{\alpha/2}$ at α level of significance. If *Z* is positive, then the trend is increasing and if *Z* is negative then the trend is decreasing.

The probability density *pdf* for a normal distribution with a mean of 0 and standard deviation of 1 is given by; $f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}}$..

The value of *pdf* should be equal to 1.000 or relatively very close to 1.000 to have a high chance of a significant change occurring. The function NORMSDIST ([*Z*]) is used to evaluate the probability density on Microsoft Excel. And for the critical $Z_{\alpha/2}$, the function NORMINV(1-(alpha/2), mean, standard deviation) is used for evaluation from Microsoft Excel, whereby the mean is zero and the standard deviation is unity. Alpha (α), the level of significant is taken here to be 0.05. Otherwise the critical value can be obtained from the standard normal cumulative distribution tables. For cases where there the data are prewhitened, the original data were still used for the evaluation of other results like mean and standard deviation, except only for the Z.

The Mann-Kendall method does not give the rate of change, so to estimate the slope of an existing trend that is the change in rainfall (mm) per year, the nonparametric Sen's method given below is used. This method can be used in cases where the trend can be assumed to be linear.

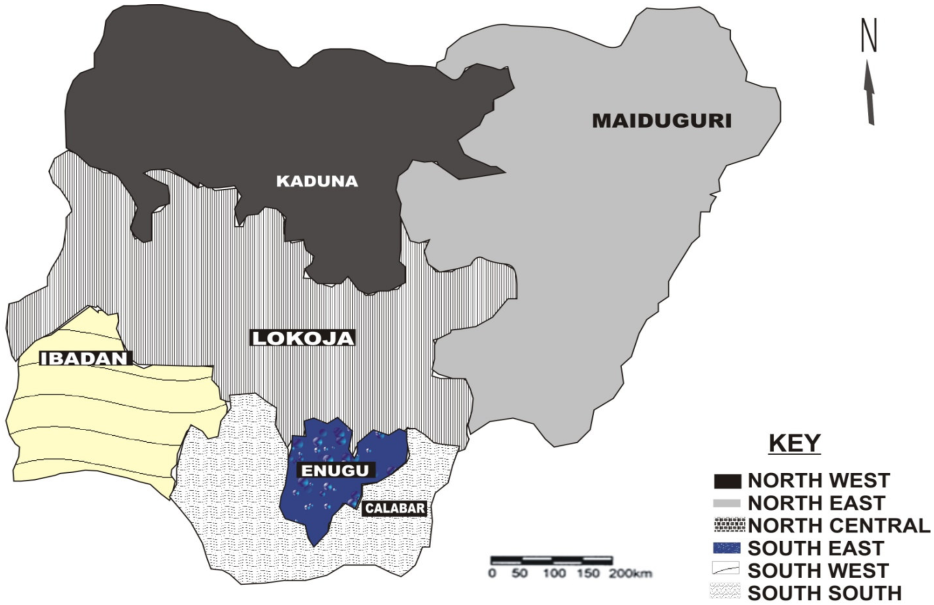

Figure 1. Map of the six Geopolitical Zones in Nigeria.

Table 1. Statistical results of the total amount of rainfall (mm) for a 30 year (1978-2007) period in selected locations of the six geopolitical zones in Nigeria.

Location	r	Z	Min	Max	Sum	Mean	Std	pfd	CV	Slope
Maiduguri	0.51*	*2.28*[a]	263.5	925.7	17415.8	580.5	164.1	0.99	0.28	9.46
Kaduna	0.26	-1.43	865.0	1476.0	35657.7	1187.5	166.5	0.92	0.14	-4.88
Lokoja	0.27	1.36	834.6	1767.4	36860.4	1228.7	236.3	0.91	0.19	7.17
Ibadan	0.09	-0.46	760.2	1966.4	39516.8	1317.2	282.1	0.68	0.21	-2.83
Enugu	0.22	1.32	913.1	2262.4	52613.4	1753.8	283.0	0.91	0.16	7.07
Calabar	0.18	0.87	2347.0	3825.5	88067.1	2925.6	381.7	0.86	0.13	7.87

* prewhitened, [a] significant at α = 0.05.

$$\beta = median\left[\frac{x_j - x_i}{j-i}\right] \text{ for all } i < j$$

Where xi and xj are data points measured at i and j respectively. At first, the whole 30 year (1978-2007) period is considered and tested for trend, and then the data are further segmented into two 20 year periods of (1978-1997) and (1988–2007) to verify inter decades trend and for better assessment and conclusion.

RESULTS AND DISCUSSION

The results are presented in the manner that the locations are arranged in order of decreasing altitude across the map of Nigeria (Figure 1), that is from the North down to South. For the whole 30 years that is, the period of 1988–2007(Table 1), the mean values of the total amount of rainfall for the six locations namely Maiduguri, Kaduna, Lokoja, Enugu and Calabar are 580.5, 1187.5, 1228.7, 1317.2, 1753.8 and 2925.6 mm, respectively. Correlation coefficient r for the period under review was greater than 0.30 at Maiduguri only (r = 0.51), therefore prewhitening was applied. The co-efficient of variation, CV which depicts the ratio of standard deviation to mean ranges from 0.13 to 0.28; indicating that there is not much variation in the total amount of rainfall between the locations. CV captures the variance nature of the parameter under review and it is quite desirable that CV be almost 0.00. It could be likening to the root mean square error, RMSE and whenever the value of CV is up to 1.00 then such a result indicates high variance of the desperation. When CV is less than 1.00, it implies low variance of the desperation. For the *Z* value to be quite meaningful so that a definite conclusion is drawn that is whether Ho be rejected or not, it is desired that probability function *pdf* be equal to or very close to 1.00. Since the *pdf* is directly proportional to the absolute value of Z, then the *pdf* can tell how close a significant trend should have occurred even when the trend was not

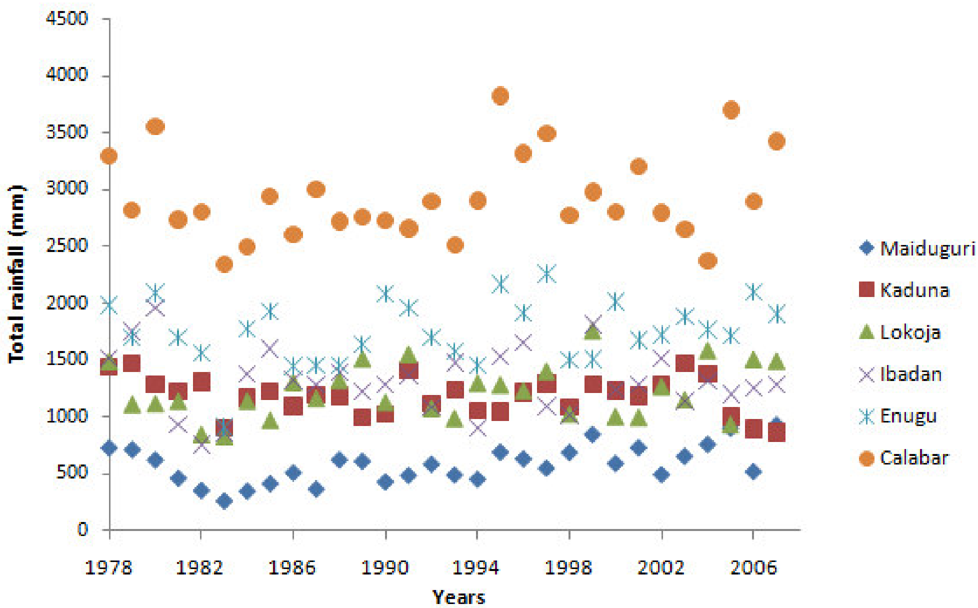

Figure 2. Annual rainfall distribution across the six locations.

significant. In the 30 year period, the *pdf* values ranges from 0.68 to 0.99 and the trend was significant only when *pdf* was 0.99. The sum of rainfall (mm) over the 30 year period is increasing as one is moving from the North down South, even to the Coastal region. That pattern is also the same for maximum, mean and standard deviation values. Invariably, there is much rainfall down South compared to the North (Figure 2).

Nigeria is bounded at the extreme South by the Atlantic Ocean. Calabar being a Costal city, no surprisingly among the locations under review has the highest amount of rainfall records; it has the highest values in minimum, maximum, mean and sum columns, respectively. Maiduguri, which is located in the North-East region, has the least amounts of rainfall; its minimum value is the least and its maximum value is the lowest in the max column. The location that shows a strange result with respect to its geographical site is Ibadan. The minimum rainfall in Ibadan is 760.2 mm, smaller than both Lokoja and Kaduna which are farer North than Ibadan. The minimum rainfall in Lokoja and Kaduna are 834.6 and 865.0 mm respective. Lokoja likewise displays the anomaly with respect to Kaduna.

The Mann-Kendall Z for the six locations are 2.28, -1.43, 1.36, -0.46, 1.32, 0.87, respectively. Despite the fact that Calabar has the highest total rainfall, yet it has not shown any significant trend in the 30 year period. Maiduguri that is at the far Northern region incidentally has the lowest total rainfall and falls within the arid zone in Africa (Hess et al., 1995; Hess, 1998; Gadzama, 2009), yet its Z value (2.28) is greater than the critical $Z_{\alpha/2}$ value which is 1.96 at 95% confidence level. Hence, the hypothesis Ho that no change occurred is rejected. Maiduguri is the only location that has shown a significant trend and it is an increasing trend. And this location has the highest slope value standing at 9.46.

An earlier study by Hess et al. (1995) which used a data set of 1961-1990, saw Maiduguri and other areas in the North East as having declining rainfall. In contrast this work reveals that the declining trend has given way to an increasing trend. The result obtained here is somewhat in consonance with the findings of Ati et al. (2008). In their work which looks at 87 years (1916-2002) rainfall at Kano, it was concluded that despite the fact that the total rainfall was decreasing in the 1960s, but in recent times (specifically in the 1990 decade) the rainfall has been increasing in Kano. The increasing trend found in Kano is contradicting previous predictions that were based on older studies. Kano is in the North West while Maiduguri is in North East, though the two locations are in the Northern geographical zone in Nigeria and are both situated in the arid zone of West Africa (Gadzama, 2009). However, it should be noted that the increasing trend found in Kano did not show fort when the same decade was considered in this work but it is observed as the 2000 decade comes in (Tables 2 and 3). And that it is reported that the Mann-Kendall as well as the Spearman non-parametric tests from SPSS software package did not reveal the trend in Kano but was shown by the parametric student t-test. In this work the increasing trend is seen using the 'better' non-parametric Mann-Kendall test. Hess et al. (1995) also used the t-test. As earlier stated, the non-parametric test e.g. Mann-Kendall is acclaimed more suitable than the parametric test e.g. student's t-test for detecting monotonic trend for hydrological time series (Yue and Wang, 2002).

Table 2. 1st subset (which is a 20 year period of 1978-1997) statistical results for the total rainfall amount for the six locations in the six geopolitical zones in Nigeria.

Location	r	Z	Min	Max	Sum	Mean	std	pfd	CV	Slope
Maiduguri	0.07	0.49	263.4	726.1	10321.9	516.1	131.7	0.69	0.26	1.64
Kaduna	0.33*	-1.10	902.4	1476.0	23934.9	1196.3	151.0	0.88	0.13	-8.40
Lokoja	0.29	1.27	834.6	1560.7	24065.1	1203.3	205.1	0.90	0.17	9.95
Ibadan	0.12	-0.42	760.2	1966.4	26422.3	1321.1	314.4	0.66	0.24	-6.38
Enugu	0.23	0.91	913.1	2262.4	34806.3	1740.3	320.7	0.82	0.18	12.71
Calabar	0.23	0.88	2347.0	3825.5	58450.4	2922.5	387.9	0.81	0.13	15.58

* Prewhitened.

Table 3. 2nd subset (which is a 20 year period of 1988- 2007) statistical results for the yearly total rainfall amount for the six locations in the six geopolitical zones in Nigeria.

Location	r	Z	Min	Max	Sum	Mean	std	pfd	CV	Slope
Maiduguri	0.55*	2.34[a]	429.0	925.7	12640.1	632.0	143.2	0.99	0.23	13.33
Kaduna	0.07	0.32	865.0	1468.3	23293.7	1164.7	166.8	0.63	0.14	-1.88
Lokoja	0.03	-0.20	939.4	1767.6	25672.5	1283.6	238.4	0.58	0.19	1.21
Ibadan	0.02	0.10	905.9	1814.9	26127.3	1306.4	218.0	0.54	0.17	-0.57
Enugu	0.19	1.04	1455.9	2262.4	36046.3	1802.3	245.7	0.85	0.14	7.81
Calabar	0.24	1.20	2371.8	3825.5	59445.1	2972.3	394.9	0.88	0.13	16.28

* Prewhitened, [a] significant at $\alpha = 0.05$.

In an attempt to trace inherent consistency and to alight hidden characteristics that could have been swallowed up or existing variations in data length, the 30 year data were subdivided into two intra decades of 20 years whereby some years appear in both subsets. In the 1st 20 year period (1978-1999) from Table 2, there is no significant trend in any part of the country. Of note is the prevalent situation in the minimum rainfall column whereby a location down South and closer to the Atlantic Ocean would have a lower value compared to a location up North and closer to the arid and semi-arid zone. That of Kaduna is higher than those of Lokoja and Ibadan and in turn that of Lokoja is higher that of Ibadan.

However, in the 2nd sub-division of 20 year period (1988-2007), the characteristic behavior of the total amount of rainfall is very erratic as can be seen in Table 3. In this period, there is the positive significant trend which was also detected in 30 year period of Table 1. Obviously, it is this period (1988-2007) that accounts for the trend which was not seen in the period (1978-1999). Aside that there is an uncoordinated pattern between the Mann-Kendall test and the Sen's slope witnessed in three locations namely Kaduna, Lokoja and Ibadan. The values of both parameters are very low and they exhibit contradicting signs in the three locations. For instance while Z is positive, the slope is negative for Kaduna, ditto for Lokoja and Ibadan. This could imply that a change is about to begin or has begun, on the other hand it is probably the effect of equal increasing and decreasing series cancelling out each other.

For the third time, the inconsistency existing in the minimum rainfall column is observed; Ibadan minimum's rainfall is 905.9 mm, lower than that of Lokoja which is 939.4 mm. However, in this particular case the minimum rainfall in Lokoja is higher than that of Kaduna, different from the other two instances. It is quite certain that the minimum rainfall in the Mangrove e.g. Calabar is higher than that around the arid region e.g. Kaduna. It should also be noted that the location with the highest or lowest slope does not necessarily translate to significant trend. In Table 3, Calabar has a slope of 16.28 mm/year yet there is no significant trend while Maiduguri has a lower slope of 13.33 mm/year with an increasing significant trend, whereas in Table 1, the highest slope had the significant increasing trend. The phenomenon whereby a location down South over a period of time will experience an unusual drier year than any in the North could probably be linked to the dynamics of the West Africa monsoon. Although the West Africa monsoon system is yet not fully understood since it a function of many interwoven dynamic components, however, occurrence of abrupt change in rainfall has been observed (Le Barbe et al., 2002; Sultan and Janicot, 2000; Melani et al., 2010). Aside the fact that this work has pointed out that a location close to but not in the arid or semiarid region can witnesses a drier year than one in any of the regions over a period of time, it has also shown that there is an increasing trend in the total amount of rainfall in Maiduguri in North East of Nigeria. Thus, the climate in a certain location in Nigeria is changing. Similar climate change with respect to increasing trend in rainfall has also been observed in India. Rupa Kumar et al. (2006) reported an increasing trend in both the West Coast and Central India. And Goswami et al. (2006) observed an increasing trend in the frequency and magnitude of extreme rain events and warns over expected rainfall hazards in Central India. Certainly, the same warning should be extended here to the case of Maiduguri and its environs. The limitations of this works are that a few places are considered in the whole country, the period of 30 years may be regarded as short duration and the monthly and seasonal trends within the period were not evaluated.

Conclusion

The total amount of rainfall across Nigeria in selected locations in each of the six geopolitical zones within a 30 years period (1978-2007) from the Mann Kendall test reveals an increasing trend in only one out of the six locations. Maiduguri (North East) where formally the trend was decreasing (Hess et al., 1995) is now witnessing an increasing trend of 9.46 mm of rainfall per year. This trend was non-existing in a sub 20 year period of (1978-1997) but came out when another sub period of (1988-2007) was examined. The latter period seems to be a period of ‘change’ showing erratic pattern in four out of the six zones when compared to the former period. It appears that the minimum rainfall witnessed in a location does not necessarily have to do with the geographical or cardinal placement of that location. The outcome of this detected significantly increasing trend could lead to either rainfall disasters like erosion and flooding or rainfall blessings like increased water level and availability, bomber harvest for farmers, and an end to deforestation and other aridity hazards hitherto witnessed in this location. Besides, there is need for continuous studies to know the further extent of the change which just occurred and so that relevant planning could be put in place. From the foregoing, there rises the question of how arid is the arid zone in Nigeria or West Africa at present. Also continuous monitoring would help to detect any possible change that may occur in the future in any other location. Finally, the cusum test should be applied to longer data range to find out how many changes have occurred in all of the North East zone of Nigeria and to see if there is any cycle in it.

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