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Rainfall Trend Detection in Northern Nigeria over the Period of 1970-2012

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Abstract
This study examined the trends in variability and spatial distribution of annual rainfall over northern Nigeria during the period 1970-2012 with a view to understand the pattern of rainfall trend (significance and magnitude), by applying various statistical tools on the data obtained from 11 weather stations. The non-parametric Mann–Kendall test was used to determine the statistical significance of trends while the magnitude of trends was derived from the Sen slope estimator of the linear trends using Kendall robust line fitting. Map of rainfall trends was generated by applying a geo-statistical interpolation technique to visualize the detected tendencies. The findings revealed that a significant positive increase of 2.16mm in rainfall was recorded in the entire northern Nigeria within the period of 1970 to 2012. It further indicated that majority of the stations revealed an upward trend, with Bauchi, Borno, Kebbi and Sokoto stations showing significant positive trends of 8.13mm, 4.30mm, 4.76mm and 4.42mm respectively. It is concluded that there is high variability in rainfall in the northern Nigeria which signifies a clear evidence of climate change in the region.
Keywords: Rainfall trend, Man-Kendall test, Northern Nigeria, Climate change

Introduction
To achieve sustainable development in water resources, agriculture, and ecosystem management, it is pertinent to understand the trends of rainfall as a hydrological variable. This is necessary for the economic development of any nation, especially with the threat of climate change and its disruptive influence on the hydrological and energy cycles of the atmosphere. The menace of climate change was exacerbated by the demand for water as a result of rise in population and economic growth. A growing field of research in the area of climate change in recent times is the analysis of rainfall trend (IPCC, 2007; Nicholson, 2013). Rainfall is an important element of climate which has a profound impact on the hydrological cycle. The influence of rainfall on the social and economic sectors of all nations provided the justification on why it is important to understand its behaviour. Detecting trends of rainfall over a period of time gives an important insight on the nature of the current climate and projection for the future climate trend of a particular geographical location.

In sub Saharan Africa, rainfall is an important determinant of social and economic development. Several studies used time series data from different parts of the globe to analyse trend of rainfall. Findings from the analysis of the studies showed that inter-annual rainfall variability was large over most of Africa; and in some regions multi-decadal variability was also substantial. In west Africa, a decline in annual rainfall has been observed since the end of the 1960s, with a decrease of 20% to 40% noted between 1931-1960 and 1968-1990 (Mitchell & Jones, 2005; Nicholson 2013; Nicholson et al., 2000). In the tropical rainforest zone, decline in the mean annual precipitation of around 4% in west Africa, 3% in north Congo and 2% in southern Congo for the period 1960 to 1998 was noted (Malhi & Wright, 2004). A 10% increase in annual rainfall along the Guinean coast during the last 30 years was however observed (Nicholson et al., 2000). In other regions, such as the southern Africa, no long-term trend was noted. However, increased inter-annual variability was observed in the post-1970 period, with higher rainfall anomalies and more intense and wide spread droughts reported (Fauchereau et al., 2003).

In Nigeria, a downward shift of 8.8% rainfall from the long-term mean of 1968 to 2008 was recorded in the north-western Nigeria (Ekpoh & Nsa 2011), also a consistent decrease in annual rainfall of 8 mm year^{-1} in the north-eastern part has been reported (Hess et al., 1995). Trends of rainfall was reported with a mixed impact depending on the location, some studies reported a decline in rainfall, while some studies observed an increase intensity of rainfall in the 20th century. Among the Sahelian studies there were a number of analyses involving some stations in Nigeria over different periods. Most of the analysis of rainfall trend in Nigeria covered different periods of time in the 20th century these include (Adefolalu, 1986, 1990; Alli, 2010; Bello, 1998; Hess et al., 1995; Odjugo, 2010; Oguntunde, Abiodun, Olukunle, & Olufayo, 2012; Tarhule & Woo, 1998). The general conclusion of these studies was that; a decline of rainfall in the dry season was observed over the years.
In recent years it was observed that there is anomaly in the trend of climate in northern Nigeria (NIMET, 2011). Despite effort by several studies to analyse the trend of rainfall in Nigeria, an extensive analysis over long period of time which covered a significant part of country is lacking. Analysis of rainfall trend that covered the entire

northern region is rarely found among the Nigerian studies. This issue coupled with lack of adequate literature on the trend of climate provided the main inspiration for the study. Therefore, the current study is an attempt to bridge these gaps, findings of the study will be beneficial in providing an understanding of the trends and magnitude of rainfall change in the area. The geographical location of the study area and its scope makes the analysis of the study unique. In view of these, the objective of this study is to contribute in understanding the pattern of rainfall trend (significance and magnitude) in Northern Nigeria from 1970 to 2012. The remaining part of the study is divided into four sections; next, is a brief highlight of the methodology of study in which a concise description of the study area was made; a summary of data for the study and statistical trend analysis followed; later results of the study were given and lastly, major conclusions of the study were presented.

Methodology

Study area

Northern Nigeria has a land area of 692,826 km^2; it is the largest geographical region in Nigeria. Nineteen out of the thirty six States of Nigeria are found in the northern region (NPC, 2010). Geographically the area is located between latitudes 7^0 and 14^0 North and longitudes 3^0 and 15^0 East. The climate of the area is marked by two distinct seasons, the short wet season that last from May to September and the prolonged dry season. Temperature is high all year round and the average annual rainfall is about 500 mm. The climate of the area is conducive for the production of several varieties of crops and animals and because of that the people are predominantly subsistence farmers. The vegetation of the area is sparse cut across three agro ecological zones; the guinea savannah is the most extensive, followed by the Sudan savannah and the Sahel. Population of the area was projected to be over 73 million (NPC, 2010).

Data and Statistical Trend Analysis

In order to observe the trend of rainfall, a time series data for rainfall in eleven stations in northern Nigeria were used for the analysis. Mean annual rainfall data for a period of 1970-2012 obtained from the Nigeria Meteorological Agency was used. Simple statistics such as mean, standard deviation, variance and data normality for the variables were computed to observe the characteristics of the data.

A common statistical tool for detecting trend of climatic and hydrological data is the trend analysis. Mann-Kendall test is one of these techniques used to detect a monotonic increase or decrease trend in the time series of climate such as temperature and rainfall (Bose et al., 2014; Juahir et al., 2010; Kendall, 1970). The test is non-parametric that is based on significant differences and not directly on the values of the random variables. The important strength of the test is that it is less prone to the effect of outliers. An important application of the Mann-Kendall test is the analyses of trends in time series data. It is also applied for dataset that suffers from uneven sampling and missing values. In using the Mann-Kendall test the assumption of normality for the random variables is not needed. In view of these attributes, Mann-Kendall test has been widely applied to detect trends in climatic studies. Additionally, ArcGIS© 10.2 software was employed to generate rainfall trend contour map showing the rainfall Sen Slope units. Areas with significant trends were superimposed on the contour map.

To apply the Mann-Kendall test in detecting climate trend, the null hypothesis H_0 that there is no trend and data are independently and randomly ordered is assumed; this is tested against the alternative hypothesis H_1 that there exists a trend in the time series. S which represents the Mann-Kendall test statistics is obtained using the following equation:

$$S = \sum_{k-1}^{n-1} \sum_{j=k=1}^{n} sgn\,(\mathrm{Xj} - \mathrm{Xk}) \quad (1)$$

Where x_j and x_k are the annual data values in year's j, k and n is the length of the data. S is assumed to be 0 if no trend. An S statistic with a high positive value shows an increasing trend whereas low negative value represents a decreasing trend in the time series as in equation below:

$$sgn(xj - xk) = \begin{cases} 1 \text{ if } xj - xk > 0 \\ 0 \text{ if } xj - xk = 0 \\ -1 \text{ if } xj - xk < 0 \end{cases} \quad (2)$$

To show the statistical significance of the trend, the probability of S and the sample size n needs to be determined. The variance of S is calculated as VAR(S)

$$\mathrm{VAR(S)} = \frac{1}{18} \left[n\,(n-1)(\,2n-5) - \sum_{p=1}^{9} tp\,(tp-1)(2tp+5\,) \right] \quad (3)$$

The calculated values of S and VAR(S) are required to obtain Z test statistic which is used to determine the level of significance it is obtained as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \ S > 0 \\ 0 & if \ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \ S < 0 \end{cases} \quad (4)$$

To test the statistical significance of Z value at 95% and 99% levels of significance the critical value of Z at 95% level which is $Z_{0.005}$ = 1.96 and the critical value of Z at 99% level which is $Z_{0.001}$ =2.58 are compared with the calculated values of Z. If Z is negative and the absolute value of Z calculated is greater than the critical value the trend is said to be significantly decreasing but if the value of Z calculated is positive and greater than the critical value the trend is said to be significantly increasing. If the absolute value of Z is less than the critical value it implies that there is no trend and the alternative hypothesis that there is trend is rejected. Significant value of Z implied that the trend is as a result of a definite cause and not due to chance alone. A significant trend at 99% level shows that the trend is highly significant.

The Sen Method of linear regression
Mann-Kendall statistic only shows the direction of the trend, to determine the magnitude of the trend a Sen Slope estimator also called the Kendall robust line fit is applied to calculate the degree of the trend. Sen Slope is applied for time series data where the trend is assumed to be linear. Sen Slope technique was named after Theil Sen who developed the estimator. It is a non-parametric test that is employed to provide an estimate of true slope of the Mann-Kendall trend. It shows the measure of the change in the trend per unit time, it is less vulnerable to single data and outlier effect. It is a vigorous technique that provides a more accurate estimate than linear regression for skewed and heteroscedastic data. Sen Slope estimator is given by:

$$Q = \frac{Xj}{j} - \frac{Xk}{k} \quad (5)$$

Where Q = Sen Slope estimator X_j and X_k are data values at time j and k (Kendall, 1970).

Results and Discussion
Descriptive statistics of the rainfall data for the states considered in the study are presented in Table 1. The overall average annual rainfall for all the stations was 993.68mm. Katsina, Borno and Sokoto recorded the least mean rainfall of 544.53, 565.84 and 635.40 respectively. The mean maximum rainfall was recorded mostly in the north central States of Nassarawa 1250.33, Niger 1211.19, Kwara 1173.07 and Kaduna 1180.78. The rainfall values considered in the analysis are for the period of 1970 - 2012.

Table 2: Descriptive statistics of rainfall values for States considered in the study

State	Observation	Minimum	Maximum	Mean	Std. deviation
Adamawa	43	326.00	1141.70	882.22	138.17
Bauchi	-	594.56	1621.10	1066.17	232.86
Borno	-	263.50	917.30	565.84	151.87
Kaduna	-	828.00	1476.00	1180.78	165.78
Katsina	-	262.00	972.00	544.53	155.18
Kebbi	-	584.00	1566.20	1004.29	182.43
Kwara	-	697.10	1595.50	1173.07	203.34
Nassarawa	-	814.70	1582.70	1250.33	131.07
Niger	-	823.40	1582.90	1211.19	169.76
Sokoto	-	373.20	1150.00	635.40	146.47
Zamfara	-	615.80	1507.10	903.38	191.50

The Mann–Kendall result in Table 2 showed the distribution of weather stations with positive and negative trends and their statistical significance. The result at regional level exhibited a positive trend in rainfall; a significant positive increase of 2.16mm in rainfall was recorded in the entire northern Nigeria within the period of 1970 to 2012. However, majority of the station revealed an upward trend, with Bauchi, Borno, Kebbi and Sokoto stations showing significant positive trends of 8.13mm, 4.30mm, 4.76mm and 4.42mm respectively. The results is consistent with the findings of (Abubakar & Adesola, 2012) who observed an upward trend for yearly total rainfall during the period of 1947 –1977. In contrast, a significant negative trend in rainfall was recorded in Kaduna station with a Sen Slope of -4.37mm, implying that a decrease of 4.37mm in rainfall was recorded between the study periods. The significant negative trend recorded in Kaduna were in agreement with the findings of (Abaje, I.B, S. Ishaya, 2010; Ishaku, 2010; Nicholson, 2013) who reported a significant negative trend in annual rainfall within the west African Sahel and the northern Nigeria.

Table 3: Result of mann-kendall test and sen slope estimator from 1970-2012

State	Unit	S	Q	Z	Trends	p-value	Significance
Adamawa	mm	3.00	0.01	0.02	↑	0.983	NS
Bauchi	-	253	8.13	2.63	↑	0.008	***
Borno	-	187	4.30	1.96	↑	0.052	**
Kaduna	-	− 189	−4.37	1.98	↓	0.049	**
Katsina	-	64	1.46	0.65	↑	0.510	NS
Kebbi	-	254	4.76	2.64	↑	0.008	***
Kwara	-	69	1.9	0.71	↑	0.477	NS
Nassarawa	-	−75	−1.20	0.79	↓	0.439	NS
Niger	-	97	2.17	1.00	↑	0.31	NS
Sokoto	-	219	4.42	2.29	↑	0.023	**
Zamfara	-	157	3.23	1.63	↑	0.103	NS
N. Nigeria	-	241	2.16	2.51	↑	0.012	**

Note: *** significant at 1%; **sig. at 5% level; NS means not significant

Several authors have pointed out that the circulation of rainfall over West Africa exhibits the most basic characteristics of a monsoon: a pronounced seasonal wind shift that is produced by thermodynamic contrasts between the land (i.e., the Sahara) and ocean (i.e., the equatorial Atlantic). South-westerly flow is established between the Atlantic cold tongue (cool water close to the equator between the boreal spring and summer) and the Saharan heat low, bringing moisture into the continent (Peyrillé & Redelsperger, 2007; Thorncroft & Peyrillé, 2011). The result also shows an extremely large variability in rainfall that is similar to what was previously reported by some authors (Nicholson, 2013; Nicholson & Kone, 2000).

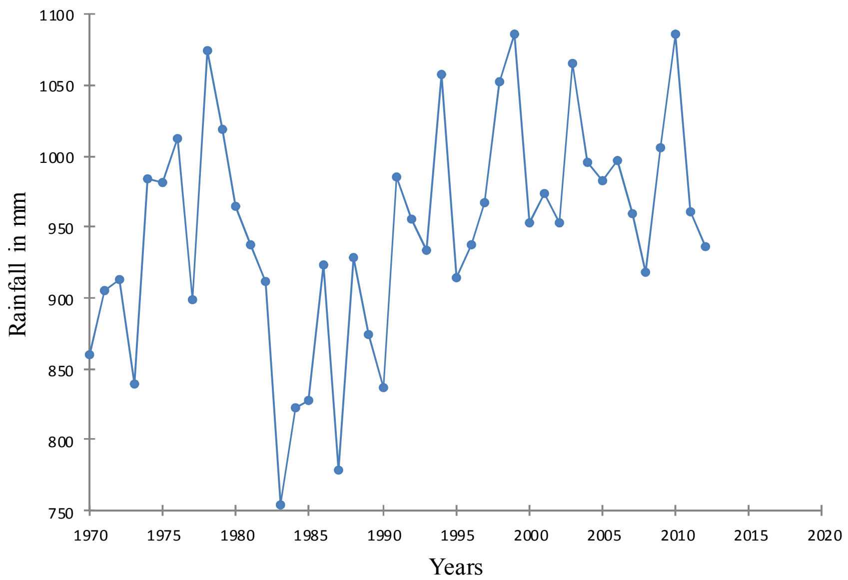

Figure 1: Trend of rainfall for northern Nigeria from 1970-2012

The spatial distribution of annual rainfall trends (mm per decade) is shown in Figure 2. Positive slopes represent an increase in rainfall over the period and negative slopes represent a decrease in rainfall. The rainfall trend contour map illustrates the spatial distribution of rainfall trends in the study period using ordinary kriging as interpolation technique (Del Río et al., 2011). The results revealed that the area with positive trends prevailed against the area with negative trends.

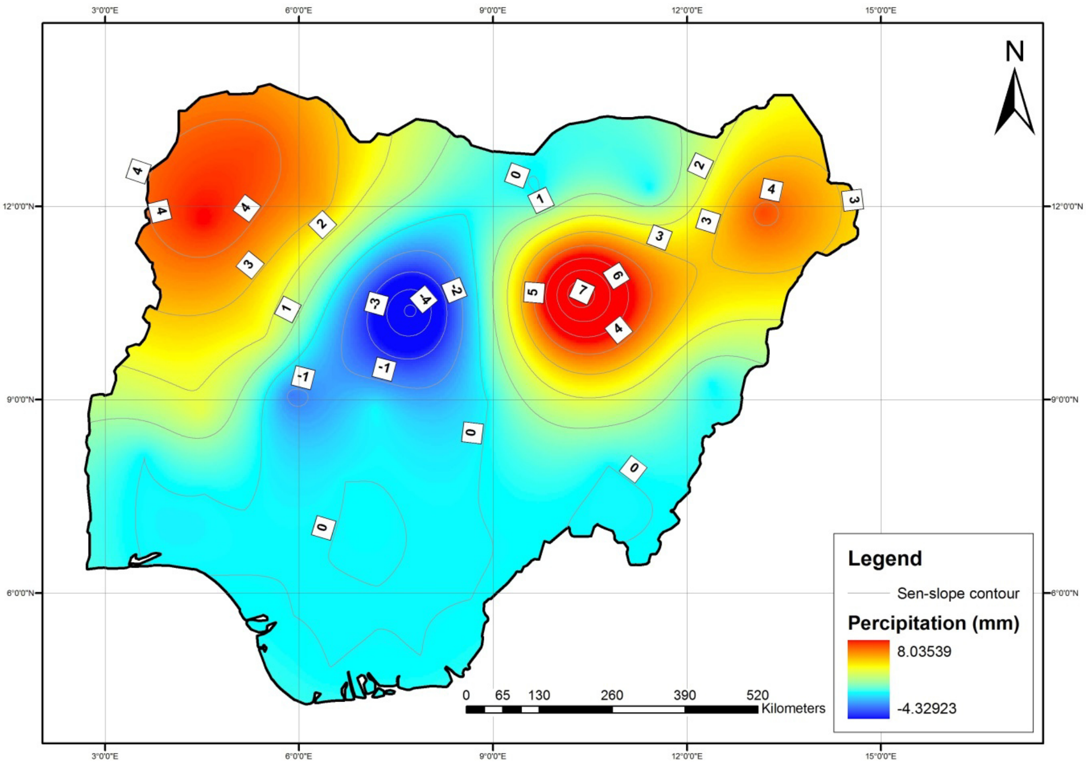

Figure 2 Spatial distributions of annual rainfall trends in northern Nigeria (1970-2012)

The positive Sen-slope values indicated a rising rainfall trends over the period of 42 years from (1970-2012) for the entire northern Nigeria with Bauchi, Borno, Kebbi and Sokoto stations showing significant positive trends of 8.13mm, 4.30mm, 4.76mm and 4.42mm respectively. In contrast, a significant negative trend in rainfall was recorded in Kaduna station with a Sen-slope of -4.37mm, implying that a decrease of 4.37mm in rainfall was recorded between the study periods. Findings of this study clearly pointed towards a significant increase in rainfall in northern Nigeria during the study period (1970-2012).

Conclusion

Mean rainfall data from 11 meteorological stations for a period of 42 years (1970-2012) were considered in this study to analyse the most recent rainfall trends in northern Nigeria and their spatial distribution using a range of statistical tools. The result revealed that a significant positive increase of 2.16mm in rainfall was recorded in the entire northern Nigeria within the study period. The findings from this study are in line with the global scenarios of more hotter and wetter regions in the world, and clearly explain the high surface run-off and its attendant environmental hazards such as flooding as recorded recently in most of the states in northern Nigeria. Additionally, the result could be a strong indication of climate change in the region, hence calls for a concerted effort by policy makers to address the issue through developing mitigation and adaptation options with the aim of reducing vulnerability of climate change impact. Finally, the current analysis was limited to one element of climate; future research should include other climatic elements and strive to cover more geographical area.

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