International Journal of Scientific & Engineering Research Volume 10, Issue 8, August-2019
ISSN 2229-5518

Evaluation of trends, cycles and effects of extreme rainfall events on hydraulic design over Nigeria

OWOSENI Oluwatosin John[1], OGUNTUNDE Philip Gbenro[1], YUSUF Habeeb Ajibola.[1*]

Abstract— Global warming effects have continued to drive considerable temporal and spatial shifts in variability and change of extreme events in Nigeria as related disasters are getting more frequent and severe. In this study, spatial and temporal variability of the frequency and intensity of extreme precipitation events in Nigeria (1975 – 2015) were examined using daily rainfall data set for 14 stations. Results showed a spatial pattern characterized by reducing frequency and intensity indicator values with increasing latitudes. The dominant trend discovered was the non-significant positive trend followed by significant positive trend which was observed in 46.6% and 24% of the assessed indices respectively. Bauchi (Sudan Savannah), Ilorin and Lokoja (Guinea Savannah) indicated significant increasing trend in at least 5 of the indices while Jos (Sudan Savannah) and Nguru (Sahel Savannah) showed decreasing trend in at least 3 of the assessed indices. Elevation when plotted against climatological mean of indices produced a relatively strong negative correlation (r > 0.5) and can averagely describe about 40% of the factors responsible for extreme rainfall in Nigeria.

Index Terms— extreme rainfall, Nigeria, rainfall, Spatial shift, temporal trend

◆

1 INTRODUCTION

PLANNING for weather-related emergencies due to global warming, design of hydraulic structures, flood plain development, water resources and reservoir management, pollution control, and insurance risk calculations, all rely on knowledge of the frequency and intensity of extreme events [1], [2], [3]. Disasters as a result of extreme rainfall events that occurred in Nigeria have been detailed out by [4], [5]. A Nigerian Meteorological Agency (NIMET) study by [6] reported an increase in storm frequency and high intensity rainfall nationwide. Babatolu *et al.* [7] used 70 years of daily rainfall from eight stations in Niger River Basin Development Authority Area in Nigeria and reported that more recent data records from 1980-2010 revealed a significant increasing trend in annual heavy rainfall amount and frequency in the area. Abaje *et al.* [5] also showed there was a change towards wetter conditions between 1979 and 2008 in the Sudano-Sahelian ecological zone of Nigeria. Change of extreme rainfall events in South Africa was examined by [8]. The study covered a period of 60 years (1931 – 1990) from 314 stations. The intensity of 5, 10, 20, 30 and 50-year recurrence interval was calculated for each station. The study was carried out using two time windows of 1931 – 1960 and 1961 – 1990. The trend analysis carried out showed that a significant increase in the intensity of high rainfall events was generally witnessed over the country. Kunkel *et al.* [9] also investigated trend of extreme rainfall events over the United States and Canada.

For the United States, 1295 rainfall stations with 66-year observation data (1931 – 1996) were analyzed while 63 rainfall stations with 43-year observation data (1951 – 1993) were analyzed for Canada. Extreme rainfall events were defined for durations of 1, 3 and 7 days. Precipitation thresholds were defined by recurrence intervals of 1 and 5 years. This was identified for each station. The subsequent trend analysis showed that significant increase in the number of 7-day, 1-year events over the study period in the United States, while a non-significant positive trend was identified over Canada. Zhai *et al.* [10] analyzed trend in frequency of daily precipitation extremes over China using 50 years (1951 – 2000) rainfall data from 530 stations. To assess trends, it was computed in the number of relative events defined as the days with daily precipitation amount greater than the 95th percentile of all rain days during the study period. Significant trends were found in the different regions and cities however negative and positive trends cancelled out each other across the country. Fu *et al.* [11] used 97 years' observation record from 191 rainfall stations to investigate temporal changes in the number of extreme rainfall events in Australia. From the data series, 1, 5 10 and 30 days' event duration were examined. The series identified was screened using recurrence interval of 1, 5 and 20 years. It was observed that more than half of the stations showed non-significant negative trend across the country. Klien Tank and Konnen [12] used seven indices of climate extremes for precipitation which are agreed internationally, they tested 151 rainfall stations across Europe. The results showed that an average of six out of the seven assessed indices significantly increase between 1946 and 1999 across Europe.

Most studies in Nigeria have concentrated effort in analyzing the trend of annual rainfall, with little research on extreme rainfall events, which are also mostly restricted to ecological

---

- *Owoseni O.J is currently pursuing a PhD. degree program in soil and water engineering in Federal University of Technology Akure, Nigeria, E-mail: owoseni.oluwatosin@gmail.com*
- *Oguntunde P.G is currently a professor of Agricultural & Environmental engineering in Federal University of Technology Akure, Nigeria*
- *Yusuf H.A is currently a lecturer in the department of Agricultural & Environmental engineering in Federal University of Technology Akure, Nigeria. E-mail: hayusuf@futa.edu.ng*

zones within the country. It has been suggested that tests for climate change should focus on changes in extreme events rather than on changes in climate mean [13]. This is further corroborated by [14] who found in a model-study that changes in moderately extreme precipitation may be more robustly detectable than changes in mean precipitation. Therefore, this study examines the time series of extreme rainfall events over Nigeria. The aims were to (I) detect possible temporal trend in frequency and intensity of extreme rainfall events in Nigeria for 1975 – 2015; and (II) determine daily maximum rainfall thresholds for 1, 5, and 25-year return periods.

2 STUDY AREA AND DATA SET

2.1 Description of study area

Nigeria is located in West Africa between latitudes 4º - 14ºN and longitudes 2º2′ - 14º30′E and has a total area of 923,768 km². The country's north-south extent is about 1,050 km and its maximum east-west extent is about 1,150 km. It is bordered in the east by Cameroon, the West by Benin Republic, the South by the Atlantic Ocean and in the North by Chad and Niger Republic. The far south is defined by its rain forest climate, characterized by heavy rainfall, while between the far south and far North is Savannah experiencing low rainfall, most especially in the Sahel Savannah zone. The agro-ecological zones of the country are classified by Nigeria Meteorological Agency (NIMET) into five, namely Swamp Rain Forest (SRF), Tropical Rain Forest (TRF), Guinea Savannah (GSH), Sudan Savannah (SuSH) and Sahel Savannah (SaSH). Fig. 1 shows a map of Nigeria and the location of stations from which data for this study were obtained. Mean annual rainfall reduces as one moves from the coastal region to the inlands

2.2 Data set

Part of the World Meteorological Organization (WMO) guidelines states that for statistical reasons, long term series over a 30-year period or more, is needed to obtain reasonable estimates of the intensity and frequency of rare events [15], [16] and to ignore bias trend. It is also desirable that the data should be high time resolution, at least daily data, to take into consideration the sub monthly nature of extremes. For the current study, 41 years (1975 – 2015) available data was considered as an ideal period to show the climatic trend of the study area. The data set for the 14 stations were obtained from the NIMET, Oshodi. The data were checked manually for missing rainfall records.

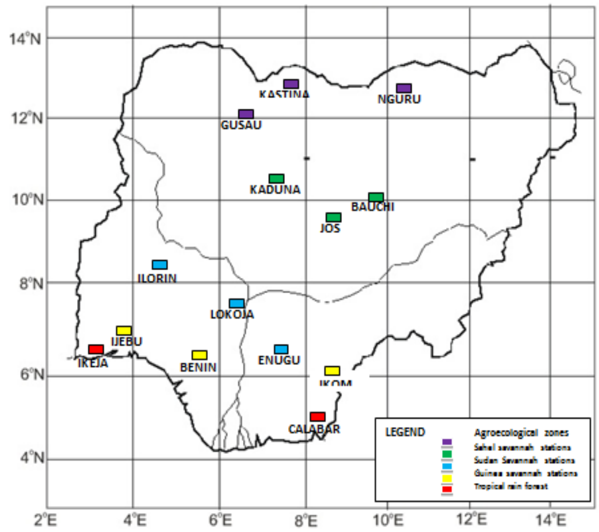


Fig. 1: Map of Nigeria showing the location of stations used in this study

3 ANALYSIS METHOD

3.1 Data homogeneity tests

For testing the homogeneity in this study, two tests were applied. This includes the Pettitt's and Buishand Range test. These tests are more sensitive to a shift in the middle of the series. Following [17], these tests are summarized as follows:

The Pettitt test is an adaptation of the rank-based Mann-Whitney test. It helps to identify the time at which a break occurs in a time series. This non-parametric test requires no assumption about data distribution. The ranks r_i, …, r_n of the Y_i, …, Y_n are used to calculate the statistics:

$$X_y = 2\sum r_i - y(n+1),\ \ y = 1, 2, 3, \dots, n \tag{1}$$

The break is identified occurring in year k when:

$$X_k = \max|X_y| \tag{2}$$

$1 \leq y \leq n$

The Buishand's range test can be used for data following any type of distribution. The test utilizes the adjusted partial sums or cumulative deviations S*, defined as:

$$S_0^* = 0 \tag{3}$$

$$S_y^* = \sum_{i=1}^{y}(Y_i - \bar{Y}),\ y = 1,2,3,\ \dots,\ n \tag{4}$$

For a homogeneous record, one may expect that the S_y^* fluctuate around zero since there is no sympathetic pattern in the deviations of the Y_i from their average value Y. If a break is present in year y, then S_y^* reaches a maximum or minimum value near the year y. The 'rescaled adjusted range', R, which is the gap between maximum and minimum of S_y^* scaled by the standard deviation of sample (s), is used to examine the significance of break.

$$R = \frac{(1 \leq Y \leq S_y^*\ (\max) - 1 \leq y \leq n S_y^*\ (\min\ \ )}{S} \tag{5}$$

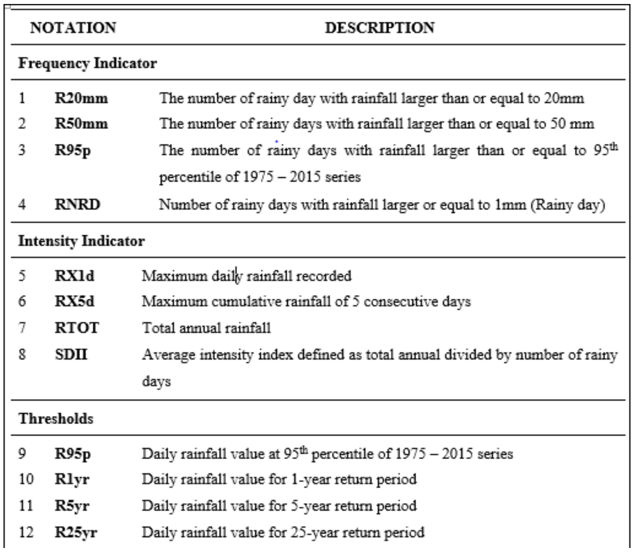
The homogeneity tests were applied on number of rainy days. Wijngaard *et al.* [17] proposed the number of rainy days in a year as more appropriate variable because its variability is lower than that of annual total rainfall but it still represents important characteristic variation at the daily scale. 1 mm was used to define a rainy day. The null hypothesis of the test is that data are homogeneous. The alternative hypothesis is that there is a date at which there is a change in the data. It was computed at significance level of 5%.

3.2 Threshold and extreme event indicators

For defining site specific thresholds, one-day duration events were examined and were screened using four precipitation thresholds which are expressed by 95th percentile of the daily rainfall distribution and daily maximum rainfall for 1, 5 and 25-year return periods. Similar method was adopted by [9], [11], [18]. The thresholds were determined by the ranked accumulated time series and recurrence intervals. Using 41 years daily rainfall record (1975 – 2015), threshold for the 95th percentile and 1-year recurrence interval was defined by sorting daily rainfall from the largest to smallest observation. The threshold for 1-year recurrence interval was defined as the 41st value in the series while rainfall value at the 95th percentile of the distribution represented the 95th percentile threshold. However, for 5 and 25-year return period, the threshold values were calculated using Gumbel's extreme value theory. It is a statistic that deals with extreme events which have low probability. It is also called extreme value theory type I and is unbounded.

Some extreme indices suggested by WMO were also calculated. These include R20mm, R50mm, R95p, RNRD, RX1d, RX5d, SDII and RTOT. These indices are presented in Table 2. Each index was calculated for each location and was expressed as annual series. RX5d was calculated using the accumulated precipitation time series method. For example, assuming x_1, x_2, . . . x_n represents the daily precipitation time series for a weather station, where 'n' is the number of days, the accumulated precipitation time series for RX5d would be x_{12345}, x_{23456}, . . . $x_{n-4,n-3,n-2,n-1,n}$. Similar method was used by [19] to determine rainfall for consecutive days.

TABLE 1
EXTREME INDICES AND THRESHOLDS IN THE STUDY



NOTATION		DESCRIPTION
Frequency Indicator		
1	**R20mm**	The number of rainy day with rainfall larger than or equal to 20mm
2	**R50mm**	The number of rainy days with rainfall larger than or equal to 50 mm
3	**R95p**	The number of rainy days with rainfall larger than or equal to 95th percentile of 1975 – 2015 series
4	**RNRD**	Number of rainy days with rainfall larger or equal to 1mm (Rainy day)
Intensity Indicator		
5	**RX1d**	Maximum daily rainfall recorded
6	**RX5d**	Maximum cumulative rainfall of 5 consecutive days
7	**RTOT**	Total annual rainfall
8	**SDII**	Average intensity index defined as total annual divided by number of rainy days
Thresholds		
9	**R95p**	Daily rainfall value at 95th percentile of 1975 – 2015 series
10	**R1yr**	Daily rainfall value for 1-year return period
11	**R5yr**	Daily rainfall value for 5-year return period
12	**R25yr**	Daily rainfall value for 25-year return period

3.3 Temporal Trend Analysis

The trend in the series was identified using the Mann-Kendall test. It has been applied by [1,20], etc. The Mann–Kendall test statistic S is given by [20] as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad (6)$$

Where n is the length of the time series x_i ……., x_n and sgn (.) is a sigh function, x_j and x_k are the values in years' j and k, respectively.

The test statistic Z is then given as:

if S>0
if S=0
if S<0

(7)

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma^2(S)}} \\ 0 \\ \frac{S+1}{\sqrt{\sigma^2(S)}} \end{cases} \qquad (8)$$

The Z statistic is then used to test the null hypothesis (H_0), that the extreme precipitation data are randomly ordered in time, against the alternative hypothesis (H_A), where there is an increasing or decreasing monotonic trend. For this study, the test statistics were tested at 0.1% (most significant), 1% (highly significant), 5% (more significant) and 10% (significant) significance levels. The slope of the trend was estimated using Theil-Sen slope estimator. The formula is given as:

$$b = median\left(\frac{x_j - x_i}{j-i}\right) \; for \; i = 1, \dots\dots\dots, n \; and \; i < j \qquad (9)$$

Where b is the estimate of the slope of the trend and x_i, x_j is the ith and j^{th} observation. It has been commonly used in identifying the slope of the trend in the hydrological data series [1].

Spatial point analysis was applied to explore spatial characteristic of extreme rainfall events. Similar application was used by [9], [11]. The variables are displayed on the map by points and marks which describe locations of the objects and provide additional information which further describes the variable through type, size or shape.

4 RESULTS AND DISCUSSION

4.1 Homogeneity Test Result

Significance level of 5% was selected for the Pettitt's and Buishand's test which was used to test the data homogeneity. In all the stations, the null hypothesis was accepted, that is, the data is homogeneous. As such, further analysis can be conducted using this data.

4.2 Site Specific Thresholds

There are four indices representing the characteristic of rainfall intensity at each specific location. This includes rainfall at 95th percentile (R95p) of the distribution, rainfall depth for 1-year return period (R1yr), rainfall depth for 5-year return period (R5yr) and rainfall depth for 25-year return period (R25yr). A box plot for all the thresholds is presented in Fig. 2. R95p varies from 38.8 mm to 64.2 mm. The minimum value was observed at Jos (Guinea savannah region) while the maximum value was observed at Calabar (Swamp rainforest region). Threshold values for 1-year return period (R1yr) varied from 49.7 mm up to 117.8 mm. The minimum value was observed at Nguru (SaSH) while the Maximum was observed also at Calabar. The ratio of maximum to minimum 1-year threshold in Nigeria is lesser than that in Australia (160 mm/2.5 mm [11]), China (200 mm/3.5 mm, [19]) and USA (100 mm/15 mm, [9]). This implies a relatively lesser spatial variation of extreme rainfall in Nigeria as compared with these countries. Threshold values for the 5-year return period range from 64.5 mm to 150.0 mm while for 25-year return period, the values range from 86.9 mm to 204.3 mm. The maximum and minimum values for both return periods were observed in the same location as 1-year return period. Calabar station recorded the highest value for all the thresholds while Nguru station recorded the least value for all thresholds except that for 95th percentile. The assessed stations showed an average of 49.5 mm, 76.5 mm, 105.3 mm and 140.1 mm for rainfall amount at 95th percentile, 1-year, 5-year and 25-year return period respectively. On the average, R5yr was about 2.1 and 1.38 times greater than R95p and R1yr respectively while R25yr was also about 2.83 and 1.83 times greater than R95p and R1yr respectively.

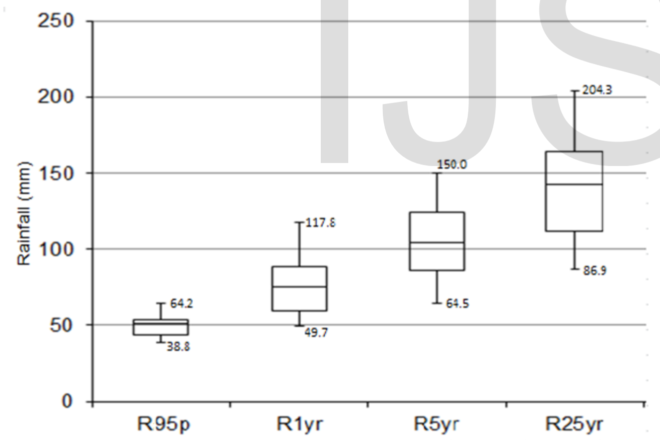


Figure 2: Box plot of thresholds for extreme rainfall of assessed stations across Nigeria. Each box encloses the middle of 50% of data in which the median value is displayed as a line within the box. The upper and lower ends of the box are upper and lower quartile (Q_3 and Q_1). The lines extending from the top and bottom of each box denote the minimum and maximum values based on quartile criteria (1.5 × Inter-Quartile Distance ($Q_3 - Q_1$)).

The spatial patterns for the thresholds analyzed, which are representatives of daily intensities, are similar and are displayed in Fig. 3, 4, 5 and 6. It is noticeable that in the rain forest region, the daily intensities for given recurrence interval are commonly high while it is generally low in the savannah region. It was also observed that areas with low altitudes had larger threshold values than those with smaller altitudes. Surprisingly, Bauchi exhibited high thresholds when compared to other stations analyzed in the savannah region. It was noticed that Ikeja, Benin, and Ijebu station has experienced at least two 25-year return period daily maximum rainfalls during the study period, both coming within the last two decades. Bauchi and Ilorin however had a daily maximum which far exceeded the 25 year return period daily maximum rainfall, all coming within the last five years of the study period. This shows increasing rate of very high intensity rainfall in recent years. Calabar, Katsina, and Lokoja however have not experienced the 25-year return period daily maximum within the study period.

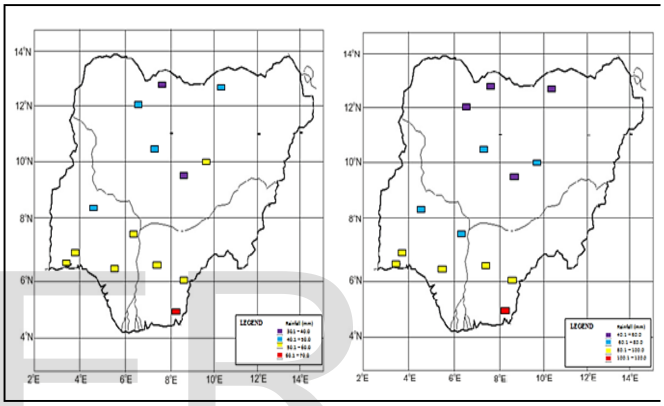


Fig. 3: Spatial distribution of thresholds based on 95th percentile (left)

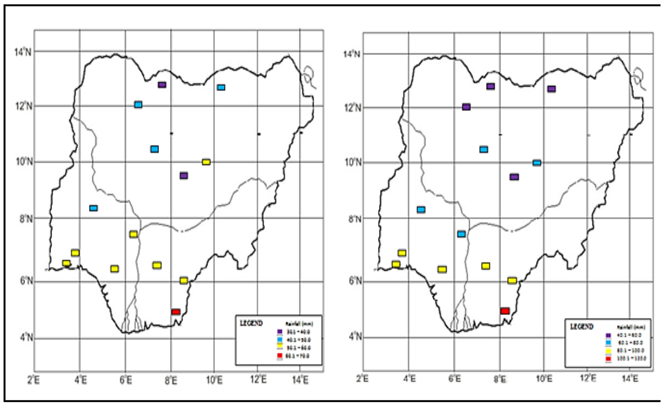


Fig. 4: Spatial distribution of thresholds based on 5-year (left) and 25-year (right) return periods in agro ecological zones of Nigeria and 1-year return period (right) in agro ecological zones of Nigeria

4.2.1 Comparison of The Site Specific Thresholds with Fixed Threshold

Nigeria Meteorological Agency (NIMET) in the Nigerian climate review (2012) and other flood studies have described rainfall of 100.0 mm and above as high impact (extreme) daily rainfall. This value has also been used as fixed threshold in China [10], Indonesia [25] and many more countries.

Comparing with the average of the site specific thresholds, it was observed that the fixed threshold being used by NIMET is probably related to an event with 5-year return period whose daily rainfall amount is about 105.3 mm in average over the study area. Thus, the fixed threshold of 100 mm is very much able to describe frequency of extreme events in terms of rarity. However, the use of a fixed threshold may be impractical for the study of extreme events in this study as there are large variations in rainfall pattern across the various agro ecological zones in the study area.

4.3 Climatological Mean of Annual Indices of Extreme Events

The frequency and intensity indices for each station were calculated based on annual block meaning that there is one value for each year and is presented in Table 2. For the 41-year period, each station has a maximum number of 41 values. To characterize spatial pattern of extreme indices, each annual index was averaged to obtain climatological mean of each index per station. The frequency and intensity indicators behavioral pattern is quite similar in respect of topographic and geographic feature. The pattern clearly indicates relatively higher values in the SRF region while low values are obtained in the SaSH region for all indices. This was also observed by [21] who reported Katsina (SaSH) and Calabar (SRF) as having the lowest and highest rainfall in the country respectively. The indices also showed reduction as one moves from the lower to the higher latitudes.

TABLE 2
CLIMATOLOGICAL MEAN OF FREQUENCY AND INTENSITY INDICATORS FOR EACH STATION

STATION	FREQUENCY INDICATORS (events per year)				INTENSITY INDICATORS (mm per year)			
	R20mm	R50mm	R95p	RNRD	RX1d	RX5d	RTOT	SDII
SWAMP RAIN FOREST								
CALABAR	48.7	13.4	7.8	159.5	128.3	230.6	2930.2	18.4
IKEJA	24.9	5.4	5	89.3	111.5	180.3	1465	16.4
TROPICAL RAIN FOREST								
BENIN	37.3	8	6.3	128.1	110.4	190.8	2163.9	16.9
IJEBU	27.3	5.8	5.2	102.8	98.6	153.7	1602.7	15.6
IKOM	39.2	8.9	7.1	141	104.7	183	2294.5	16.3
GUINEA SAVANNAH								
ENUGU	31	7	5	104	99	169.5	1782.1	17.1
ILORIN	21	3.6	4	81	87.2	126	1223.7	15.2
LOKOJA	22.1	4.2	3.7	73.85	80	124	1214.7	16.4
SUDAN SAVANNAH								
BAUCHI	20.2	3.8	3.3	65.7	80.5	140.6	1115.9	17
JOS	19.7	1.8	4.7	96.6	65.2	114.6	1242.6	12.9
KADUNA	21.2	2.6	4.3	84.4	71.2	133.2	1228.5	14.6
SAHEL SAVANNAH								
GUSAU	17	2	3.1	59.3	68.8	124.1	922.9	15.6
KATSINA	9.7	0.8	1.8	40.7	52.6	83.5	552.9	13.6
NGURU	7.4	0.95	1.4	30.2	52.4	86.4	425.2	14.1

4.4 Trend of frequency Indicators

The trend result for frequency of extreme events in Nigeria is presented in Table 3. The slopes have been converted and are in events per decade to clearly show the decadal magnitudes. The number of daily rainfall events exceeding 20 mm (R20mm) over all the zones showed an average Z of 1.48. Across the swamp rain forest zone, an upward trend was noticed which was significant at Ikeja station. In the Tropical rain forest zone, Benin showed an upward significant trend in R20mm while Ijebu and Ikom showed an upward and downward non-significant trend, respectively. The Guinea savannah zone shows a general upward significant trend except for Enugu station. In the Sudan savannah zone, Bauchi shows an upward significant trend, notably the highest in the country with an increase of approximately 3 events per decade. Jos and Kaduna shows a non-significant downward and upward trend respectively. The Sahel savannah zone generally shows non-significant trends with Katsina and Nguru showing positive trends while Gusau shows a downward trend in R20mm. The results of R50mm reveal that 6 stations have a significant upward increase in R50mm, with Bauchi having the highest Z value of 3.59 and significant at all significant levels applied. The Swamp rain forest zone had mixed trend results with Calabar and Ikeja having positive and negative trends respectively, though not significant. The tropical rain forest zone and the Guinea savannah zone show an overall upward trend in R50mm. This trend was significant at Ijebu station in the Tropical rain forest zone and at Ilorin and Lokoja in the Guinea savannah zone. Kaduna alongside Bauchi indicates a significant increase in amount of heavy rainfall in the Sudan Savannah. In the Sahel savannah zone, Katsina shows a significant increase in R50mm while Gusau and Nguru show a non-significant upward and downward trend respectively. The result of trend for number of rainfall exceeding 95th percentile of rainfall series (R95p), categorized as very heavy rainfall events showed three significantly increasing stations. Swamp rainforest zone shows a similar pattern with trend analysis of R50mm in Calabar and Ikeja. The tropical rain forest region shows an overall upward trend in R95p which was statistically significant at Ijebu. Same pattern was observed in the Guinea savannah zone and was statistically significant at Ilorin. Bauchi, like in other indices assessed earlier, shows the highest significant trend value. Jos and Kaduna however indicate a downward and upward trend respectively in the Sudan savannah zone. Nguru in the Sahel savannah zone shows no trend in the series while Gusau and Katsina show a statistically non-significant downward and upward trend in R95p. The number of rainy days (RNRD) was the last assessed frequency indicator. The Swamp rain forest region shows a general upward trend, which was significant at Ikeja station. In the tropical rain forest, only Ikom gives a non-significant downward trend in RNRD. Also in the Guinea savannah region, only Ilorin station shows a non-significant downward trend in Number of rainy days. Enugu shows a significant increase in number of rainy days with a magnitude of about 2 events per decade. Unlike other frequency factors earlier analyzed, Bauchi shows a non-significant downward trend in RNRD. Same trend was seen at Kaduna. Jos however shows a positive trend, but like other stations in the zone, this trend was not significant. The Sahel savannah zone shows a general non-significant increase in trend of RNRD.

TABLE 3
MANN-KENDALL AND SEN'S TESTS STATISTICS FOR FREQUENCY INDICATORS OVER DIFFERENT AGRO ECOLOGICAL ZONES OF NIGERIA

Stations	R20mm		R50mm		R95p		RNRD	
	Test Z	Slope	Test Z	Slope	Test Z	Slope	Test Z	Slope
SWAMP RAIN FOREST ZONE								
Calabar	1.48	1.540	0.07	0.000	0.76	0.000	0.72	1.090
Ikeja	2.10*	1.875	-0.44	0.000	-0.34	0.000	2.47*	3.846
TROPICAL RAIN FOREST ZONE								
Benin	2.06*	2.500	1.61	0.769	0.42	0.000	0.82	2.000
Ijebu	1.14	1.206	1.74+	0.513	1.76+	0.526	1.36	2.376
Ikom	-1.43	-0.074	0.61	0.000	0.67	0.000	-1.30	-1.890
GUINEA SAVANNAH ZONE								
Enugu	0.93	0.513	0.91	0.000	0.88	0.000	1.78+	1.962
Ilorin	2.12*	1.623	2.14*	0.488	1.96+	0.541	-0.70	-1.305
Lokoja	2.11	1.364	1.91+	0.500	1.47	0.132	0.80	1.165
SUDAN SAVANNAH ZONE								
Bauchi	4.32***	3.333	3.59***	1.538	3.39***	1.250	-0.73	-0.896
Jos	-0.03	0.000	-1.13	0.000	-0.91	0.000	0.43	0.354
Kaduna	0.05	0.000	1.69+	0.000	0.76	0.000	-0.98	-0.871
SAHEL SAVANNAH ZONE								
Gusau	-0.47	0.000	0.30	0.000	-0.16	0.000	0.17	0.000
Katsina	1.40	0.833	2.13*	0.000	0.46	0.000	1.37	1.286
Nguru	1.11	0.377	-0.11	0.000	0.00	0.000	1.24	0.656

***Trend is significant at α = 0.001. **Trend is significant at α = 0.01. *Trend is significant at α = 0.5. +Trend is significant at α = 0.1.

4.5 Trend of Intensity Indicators

The intensity indicators of extreme events assessed in this study includes maximum daily rainfall (RX1d), maximum cumulative rainfall amount of 5 consecutive rain days (RX5d), annual total rainfall (RTOT) and simple daily intensity index (SDII). Table 4 shows the result of trend analysis of intensity indicators assessed in this study. For RX1d, all stations in the rain forest region showed a non-significant upward trend with magnitude ranging from approximately 0.3 mm to 4.9 mm per decade of rainfall which were both found in the Swampy areas of the zone. The dominant trend in the savannah region is an upward trend. Lokoja and Bauchi stations in the savannah zone show significant increase in trend with Bauchi indicating over 10 mm increase in RX1d per decade over the study period. Nguru and Jos however show non-significant decreasing trends with Nguru having a decreasing magnitude of over 2 mm per decade. For index RX5d, the dominant trend across the agro ecological zones is non-significant upward trend. The swamp rain forest zone and Guinea savannah zones had an upward trend across their zones. The tropical rain forest region was dominated by reducing trend in RX5d except Ijebu which showed a magnitude of about 7.4 mm of increase per decade of maximum cumulative five-day consecutive rainfall. Ilorin and Bauchi stations were the only stations that showed significant increase in RX5d. Bauchi had highest magnitude of 14.2 mm per decade across the study location. It was observed all agro ecological zones have at least one station showing significant upward increase in annual total rainfall (RTOT) except Sahel savannah zone. The range of magnitude across the stations is between approximately 7.5 mm to 153.4 mm per decade. About 50% of stations experience significant increase in RTOT. Non-significant decreasing trends are observed at Ikom and Jos stations. Trend of average daily rainfall intensity (SDII) shows the dominant trend across all stations for this index is increasing trend. About 50% of all stations showed significant increase in SDII. These stations were concentrated within the tropical rainforest and Guinea savannah zones. Overall, both for the frequency and intensity indicators, the dominant trend was the non-significant positive trend. The frequency of R95p and R50mm was found to be on the increase averagely across the assessed stations. Similar observation was made by [6] who stated that high intensity rainfall is on the increase nationwide. Babatolu *et al.* [7] also reported an increasing trend in heavy rainfall events over the Niger Basin Development Authority Area, an area located within the Savannah region. BMKG [25] also observed an upward shift in rainfall across all climatic zones in the country. Furthermore, [5], [22], [23], [24] all stated an increasing wetter condition for areas in the Sudano-Sahel ecological zone. Only Ikom, Jos, Gusau and Nguru failed to show any significant trend. All other stations showed at least one significant trend in one of the indices.

TABLE 4
MANN-KENDALL AND SEN'S TESTS STATISTICS FOR INTENSITY INDICATORS OVER DIFFERENT AGRO ECOLOGICAL ZONES OF NIGERIA

Stations	RX1d		RX5d		RTOT		SDII	
	Test Z	Slope	Test Z	Slope	Test Z	Slope	Test Z	Slope
SWAMP RAIN FOREST ZONE								
Calabar	0.19	0.323	0.30	2.550	1.80+	98.220	1.89+	0.640
Ikeja	0.90	4.875	0.64	5.353	2.41*	89.125	1.49	0.426
TROPICAL RAIN FOREST ZONE								
Benin	0.79	3.818	-0.09	-1.131	1.93+	92.688	2.27*	0.693
Ijebu	1.19	3.905	1.34	7.381	2.26*	84.564	1.94+	0.530
Ikom	0.01	0.030	-0.09	-0.683	-0.40	-11.019	0.65	0.145
GUINEA SAVANNAH ZONE								
Enugu	0.04	0.183	0.09	1.000	2.47*	81.559	2.13*	0.427
Ilorin	1.53	5.401	1.75+	5.789	1.82+	51.470	2.45*	0.778
Lokoja	2.04*	4.667	1.43	5.729	1.91+	64.063	1.98*	0.571
SUDAN SAVANNAH ZONE								
Bauchi	3.30***	10.867	2.88**	14.200	3.66***	153.357	5.37***	2.425
Jos	-0.25	-0.489	-0.89	-2.613	-0.54	-7.492	-0.63	-0.087
Kaduna	1.29	2.517	1.34	5.575	1.03	29.508	1.21	0.338
SAHEL SAVANNAH ZONE								
Gusau	0.31	0.723	1.25	5.477	0.45	12.310	0.43	0.094
Katina	1.01	2.500	0.52	1.325	1.10	26.394	0.34	0.117
Nguru	-1.20	-2.254	-0.36	-1.551	0.83	13.375	0.09	0.024

***Trend is significant at α = 0.001. **Trend is significant at α = 0.01. *Trend is significant at α = 0.5. +Trend is significant at α = 0.1.

4.6 Spatial Distribution of Extreme Indices

Fig. 7 represents the spatial distribution of stations showing consistently significant trend. Bauchi station showed a very significant increase in every index except number of rainy days. Most of the indices assessed at this station were found to be significant at 0.1 %. The effect of extreme rainfall related disasters in this area could become very serious. Ilorin station also showed significant increase in six of the assessed eight indices including R20mm, R50mm and R95p. This leads to these areas potentially being at high risk of occurrence of extreme related disasters which may be more frequent in coming years. At Lokoja, significant positive trend was found for five indices which potentially lead to high risk of hydro-meteorological disaster. More so, the location is the confluence of two major rivers (River Niger and River Benue) in Nigeria. There is a high probability of rivers overflowing their banks and causing serious human and physical losses. These three areas have experienced some of the worst flooding in recent years.

Jos station was found to be consistently decreasing in all indices assessed except number of rainy days. If current trend is sustained in this location, drought may be probably expected in the coming years. Nguru also showed non-significant negative trends in RX1d, RX5d and R50mm. However, with increasing trends observed in moderate rainfall, number of rainy days and total annual rainfall, and if the negative trends detected at this station are temporary, then there could be hope of this area not sliding into drought or serious flooding. No station was found to be significantly reducing across all indices.

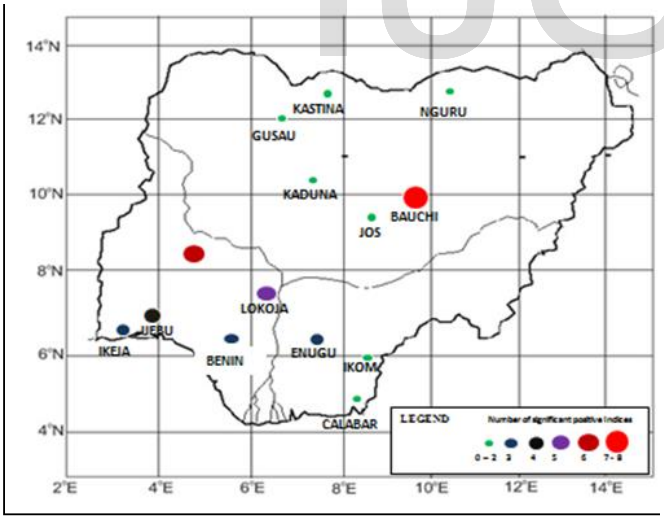


Fig. 5: Spatial distribution of stations showing consistently significant positive trend

4.7 Effect of Topography On Extreme Indices

The effect of topography was explored by plotting the climatological mean of different extreme indices against elevation of rain stations. Using a scattered plot, a relationship between these variables could be assessed. The elevation of the stations ranges from 38 to about 1290 meters (m). To obtain a clear pattern, the elevation has been converted using logarithmic transformation. This is to make the elevation range shorter than that of the original value.

Fig. 8, 9, 10 and 11 present the scatter plot of climatological mean of indices against elevation. Overall, elevation was found to significantly influence all index tested as their correlation coefficient exceeded 0.5. Also, influence of elevation was found to be weakest on R95p (30%) and RNRD (27%) and strongest on RX1d (57%) and SDII (48%). From the assessment, one can conclusively expect to observe more frequent and intense extreme rainfall at areas of high elevation and vice versa, as the values of the indices generally decreases with an increase in elevation.

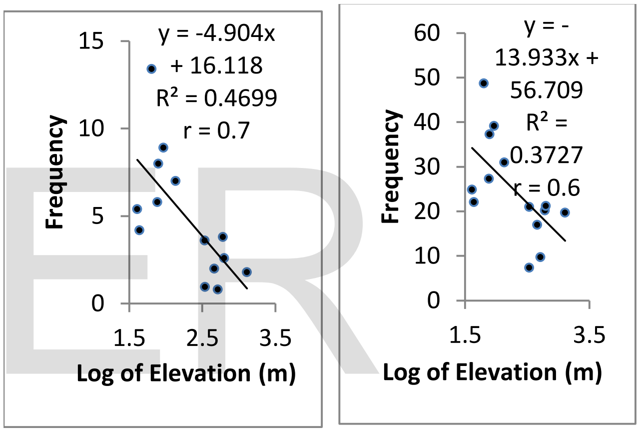


Fig. 6: The scatter plot index R50 mm (left) and R20 mm (right) against log of elevation

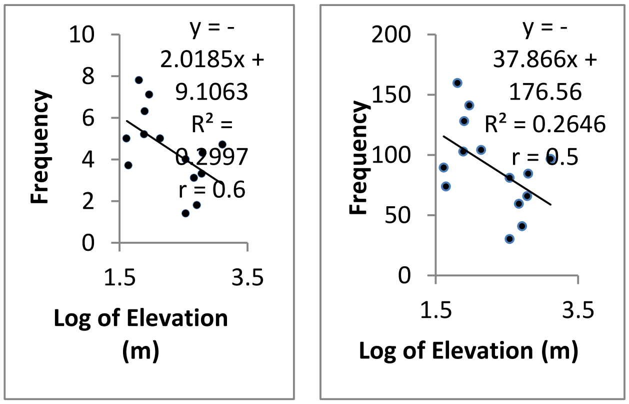


Fig. 7: The scatter plot index R95p (left) and RNRD (right) against log of elevation

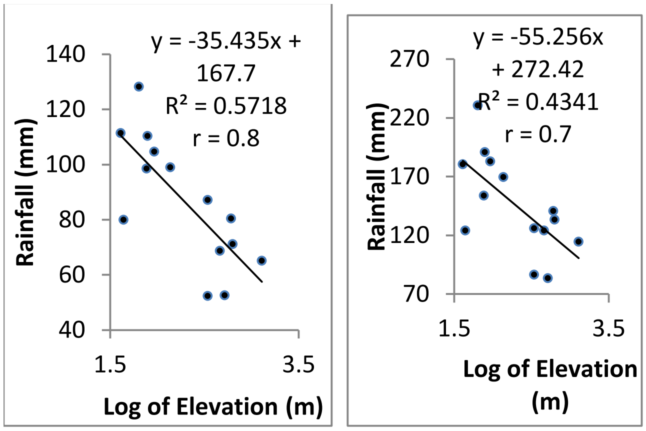


Fig. 8: The scatter plot index RX1d (left) and RX5d (right) against log of elevation

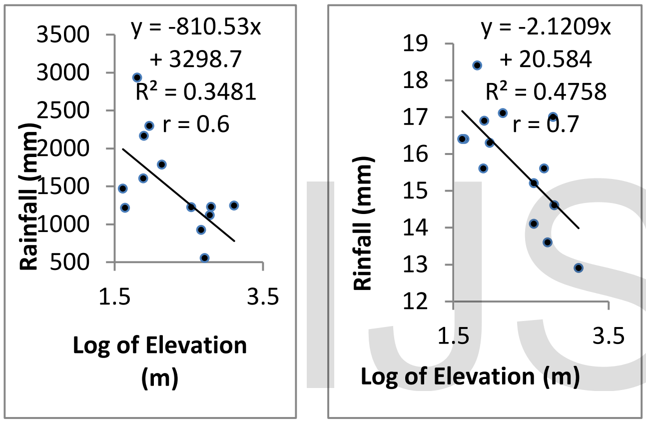


Fig. 9: The scatter plot index RTOT (left) and SDII (right) against log of elevation

5 SUMMARY AND CONCLUSION

Using daily rainfall data from fourteen stations for a period of forty-one years (1975 – 2015), the trend of extreme rainfall events over Nigeria have been assessed using some frequency and intensity indicators. Non-parametric statistical tests were used to evaluate the variation of these indices across the country. The results show that:

i. The spatial pattern of extreme rainfall events over Nigeria or both the frequency and intensity indicators is generally characterized by high values in areas along the coastline and reduces as one move inland towards the Northern parts of the country.

ii. Overall, the non-significant positive trend occurred in about 46.6% of assessed indicators and was the most widely noticed trend of extreme rainfall events across the country. However, Bauchi, Ilorin and Lokoja, all in the savannah climatological zone, showed consistently significant positive trend in at least five of the assessed indices and were tagged as high risk areas for more frequent floods in the future. Jos however consistently showed non-significant reducing trend in seven indices, thereby may be prone to drought in coming years.

iii. Elevation of stations has a relatively strong negative correlation with all the assessed indices with correlation coefficient ranging between 0.5 and 0.8 and can averagely describe about 40% of the indices variation.

iv. The impact may render existing hydraulic design criteria inaccurate and inappropriate while hydraulic structures in the country could become incapable and highly insufficient for the floods that may occur in the future. In general, effectiveness of hydraulic structures must be maintained at high level else their failure may begin to occur frequently, making extreme events more severe and disastrous in the coming years.

REFERENCES

[1] Oguntunde PG, Abiodun BJ, Lischeid G. 2011. Rainfall trends in Nigeria, 1901–2000. Journal of Hydrology. 411(3): 207–218.

[2] Hosking JRM, Wallis JR. 1997. Regional frequency analysis: an approach based on L- moments. Cambridge University Press, Cambridge, U.K.

[3] Cunderlik JM, Simonovic SP. 2007.Hydrologic Models for Inverse Climate Change Impact Modeling. 18th Canadian Hydrotechnical Conference: Challenges for Water Resources Engineering in a Changing World. Winnipeg, Manitoba, August 22 – 24, 2007.

[4] Olaniran OJ. 2002. An Inaugural Lecture on Rainfall Anomalies in Nigeria: The contemporary understanding. The 55th Inaugural Lecture Delivered at University of Ilorin.

[5] Abaje IB, Ati OF, Iguisi EO. 2012. Recent Trends and Fluctuations of Annual Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria: Risks and Opportunities. Journal of Sustainable Society. 1(2): 44-51

[6] Okoloye CU, Aisiokuebo NI, Ukeje JE, Anuforom AC, Nnodu ID, Francis SD. 2012. Rainfall variability and the recent climate extremes in Nigeria. NIMET study on Rainfall in year 2012. Unpublished.

[7] Babatolu JS, Akinnubi RT, Folagimi AT, Bukola OO. 2014.Variability and Trends of Daily Heavy Rainfall Events over Niger River Basin Development Authority Area in Nigeria. American Journal of Climate Change. 3: 1-7. http://dx.doi.org/10.4236/ajcc.2014.31001

[8] Mason SJ, Waylen PR, Mimmack GM, Rajaratnam B, Harrison M. 1999.Changes in Extreme Rainfall Events in South Africa. Journal of Climate Change. 41: 249 - 257

[9] Kunkel KE, Andsager K., Easterling DR. 1999.Long-term trends in extreme precipitation events over the conterminous United States and Canada. J. Climate 12: 2515–2527.

[10] Zhai PM, Zhang XB, Wan H, Pan XH. 2005. Trends in total precipitation and frequency of daily precipitation extremes over China. J. Clim. 18: 1096–1108.

[11] Fu GB, Viney NR, Charles SP, Liu JR. 2010. Long-term temporal variation of extreme rainfall events in Australia, 1910–2006. J. Hydrometeor. 11: 951–966. http://dx.doi.org/10.1175/2010JHM1204.1.

[12] Klien Tank AMG, Konnen GP. 2003.Trends in indices of daily temperature and precipitation extremes in Europe, 1946 – 1999.Journal of Climate. 16: 3665 – 3680.

[13] Von Storch H, Zwiers FW. 1988. Reoccurrence Analysis of Climate Sensitivity Experiments. Journal of Climate. 1: 157-171. http://dx.doi.org/10.1175/15200442(1988)001<0157 :RAOCSE>2.0.CO2

[14] Hegerl GC, Zwiers FW, Stott PA, Kharin VV. 2004. Detectability of anthropogenic changes in annual temperature and precipitation extremes. J

Clim 17: 3683–3700

[15] Longobardi Antonia, Villani Paolo. 2009.Trend Analysis of annual and seasonal rainfall time series in the Mediterranean area. International Journal of Climatology. DOI: 10.1002/joc.2001

[16] World Meteorological Organization (WMO). 2009. Guidelines on Ananlysis of Extremes in a changing climate in support of informed decisions for adaptation.WCDMP – No. 72. WMO – TD No. 1500.

[17] Wijngaard JB, Klien Tank AMG, Konnen G.P. 2003.Homogeniety of 20th century European Daily Temperature and Precipitation Series. International Journal of Climatology. 23: 679 – 692. DOI: 10.1002/joc.906

[18] Kunkel KE, Easterling DR, Redmond K, Hubbard K. 2003.Temporal variations of extreme precipitation events in the United States, 1895–2000.Geophys. Res. Lett. 30 (17), 1900. http://dx.doi.org/10.1029/2003GL018052.

[19] Guobin Fu, Jingjie Yu, Xiubo Yu, Rulin Ouyang, Yichi Zhang, Ping Wang, Wenbin Liu, Leilei Min. 2013. Temporal variation of extreme rainfall events in China, 1961–2009. Journal of Hydrology 487 (2013): 48–59. www.elsevier.com/locate/jhydrol

[20] Salmi T, Maatta A, Anttila P, Ruoho-Airola T, Amnell T. 2002.Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates – The Excel Template Application MAKESENS.Publication on Air Quality, no. 31. Finnish Meteorological Institute: Helsinki.

[21] Ewona IO., Osang JE, Udo SO. 2014. Trend analyses of rainfall patterns in Nigeria using regression parameters. International Journal of Technology Enhancements and Emerging Engineering Research. Vol. 2, issue 5 129 ISSN 2347-4289

[22] Ati OF, Iguisi EO, Afolayan JO. 2007. Are we experiencing drier conditions in the Sudano-Sahelian Zone of Nigeria. J. of Appl. Sci. Res. 3(12): 1746-1751.

[23] Ati OF, Stigter CJ, Iguisi EO, Afolayan J.O. 2009.Profile of rainfall change and variability in the northern Nigeria, 1953-2002. Research Journal of Environmental and Earth Sciences, 1(2), 58-63.

[24] Morakinyo TE, Ogungbenro SB. 2014. Rainfall distribution and change detection across climatic zones in Nigeria. Weather and Climate Extremes. Published by Elsevier. www.elsevier.com/locate/wace

[25] Badan Meteorologi Klimatologidan Geofisika (BMKG). 2010. The Condition of Weater and Climate Extreme, 2010 – 2011: a press release. Jarkarta. Published in Indonesian (bahasa Indonesia).J. Williams, "Narrow-Band Analyzer," PhD dissertation, Dept. of Electrical Eng., Harvard Univ., Cambridge, Mass., 1993. (Thesis or dissertation)