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Original Research Article

Flood Frequency Analysis of River Kaduna, Kaduna State, Nigeria, using Precipitation Concentration Index

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ABSTRACT

Flood frequency analyses of River Kaduna using the precipitation concentration index model, (PCI) was investigated. Rainfall data was collected for the duration 1962-2015 while stream discharge data at the Kaduna South gauging station was collected from 1967 to 2000. Precipitation concentration was classified based on the transformed annual precipitation departure (TAPD) and precipitation concentration index (PCI). Hydro-climatic data were analyzed for trends, fluctuations, exceedance probability, cumulative, lognormal and return periods for extreme values. Precipitation concentration index from 1962 to 2015 revealed that precipitation concentration was dominantly irregular and strongly irregular. The transformed annual precipitation departure showed that 16 years out of 54 years rainfall time series were wet years and these coincided with the flood events of 2003 and 2012. The PCI also showed that 19 years had strong irregularity of precipitation distribution meaning that for 19 years, precipitation concentrated in 4 months of each year, most of which coincided with years of drought in the Sudano-Sahel region of Nigeria. The calculated return periods for the 25 flood years revealed that the highest rainfall volume was recorded in the year 2013 with a return period of 55 years, while the lowest amount was in 1999 with a return period of 2.2 years. Due to the strong relationship observed in the regression analysis, it can be concluded that flood events coincided with periods of rainfall surpluses thus making PCI an effective model for flood prediction.

1. INTRODUCTION

In the tropics and subtropical region, severe flooding hazards of grave consequences resulting from heavy thunder storms, torrential monsoon downpours, hurricanes, cyclones and tidal wave surges in coastal and estuarine environments are a yearly occurrence (Sule *et al.*, 2016). On the whole, flood disasters are said to account for about a third of all natural catastrophes throughout the world (by number and economic losses) and are responsible for more than half of the facilities' damage (AGBM, 2008). In Nigeria, the effects of river flooding in recent years are well documented. For example, in 2010 flood killed about 1,555 people and displaced 258,000 people and destroyed properties worth millions of naira (Babatunde *et al*., 2011; Adejuwon and Aina 2014). It is reported that the 2012 flood had far higher casualties than any other in the history of the country (NEMA, 2012). The flood affected about 134,371 people, displaced 64,473, injured 202 and killed 148 and by the end of October, more than 7.7 million people had been affected by the floods, and more than 2.1 million were registered as internally displaced people (IDP). In all, about 363 people were reported dead and almost 600,000 houses were damaged or destroyed (NEMA, 2012). The impacts of riverine floods are even projected to increase in the future due to natural climate variability (Jain and Lall 2000; Enfield *et al*., 2001), and anthropogenic climate change driven by increasing greenhouse gas concentrations (Milly et al., 2008; Hirsch and Ryberg, 2012) and increased human development in flood-prone areas e.g., (Ntelekos *et al.,* 2010; Ceola, *et al*., 2014; Prosdocimi *et al.,* 2015). Floods fall into the category of hydrologic hazards and Sinnakordan *et* al., (2003) are of the opinion that a flood event can be regarded as a hazard if it has the potential of causing a threat to humans and their welfare.

As a result, the goal of flood hazard assessment is to understand the probability that a flood of a certain intensity will occur over an extended period of time. Hazard assessment thus aims to estimate this probability over periods of years to decades to support risk management activities (World Bank. 2015). Such assessment is key to flood risk management and infrastructure design. Unfortunately, one major challenge of sustainable water resources development, including flood control in most developing countries is stream data availability. Studies have shown that data on stream discharge for most basins in Nigeria for example are either lacking or grossly inadequate where they are available (Ayoade, 1988; Aper, 2006; Ezemonye and Emeribe, 2013). In some cases, while long and reliable data on rainfall and temperature are available for most basins, stream discharge data for these basins are very scarce, due to the general absence of functional gauging stations along our stream channels.

Thus, it becomes necessary to resort to alternative methods for assessing flood characteristics of ungauged or inadequately gauged basins. According to Sivapalan *et al*., (2003), and Viglione *et al*., (2007), the use of predictions in ungauged basins (PUB) over the last decade has also been useful. In this case, understanding precipitation variations on various time scales and their correlation has proven to be important for assessment of flood risks and for water resource management (Ezenwaji *et al.,* 2017). Precipitation extremes can, therefore be quantified by the frequency analysis of rainfall series and precipitation heterogeneity indexes (Kumbuyo *et al.,* 2014). Several indices of precipitation variations have been employed to evaluate precipitation concentration for providing information on its variability including precipitation concentration index (PCI), simple daily intensity index (SDII), precipitation concentration degree (PCD) and precipitation concentration period (PCP), modified fourier index (MFI), seasonality index etc (Oliver, 1980; De-Luis *et al.,* 2011, Kumbuyo *et al.,* 2014). Of these methods, the use of precipitation concentration index (PCI) has been mostly used for seasonal and annual rainfall distribution. This is because a higher precipitation concentration represented by greater percentages of the yearly total precipitation in a few rainy days, has the potential to cause flood and also drought phenomena (Ezenwaji *et al*., 2017; Sanguesa et al., 2018).

Kaduna State is not immune to climate change and variability as it is located in the Sudano-Savvanah climatic region which is characterized by sharp climatic variability. Over the years, there have been records of flooding with devastating impacts in the state. The flood of 2003 for example caused inundation of huge areas on the flood plain and as a result, cultivable lands and human dwellings were adversely affected and several thousands of people rendered homeless. It was estimated that about 30,000 houses were destroyed in 12 local government districts and at least 5,000 were left homeless and 2 people dead along the course of River Kaduna from its upper reaches, while more than 1,500 people in Kaduna Metropolis were affected (Sule *et al.,* 2016). In addition, the State also experienced a tremendous increase in floods as a result of heavy down fall of rain that occurred in 2005 which made the river Kaduna to over flow its bank. Properties worth millions of naira were destroyed, farmlands were washed away, lives were lost and even the Kaduna Bridge was submerged by the flood (Aggarwal and Jeb, 2008). Given the reoccurrence of riverine flood in Kaduna as well and in view of the expected impact of climate change, it has become very necessary to investigate precipitation variation and concentration in relation to flood probability.

2. MATERIALS AND METHODS

2.1. Study Area

This study is limited to Kaduna River upstream of the Shiroro Reservoir. The study area is geographically located between latitudes 9°52'38" N and 10°39'07" N and between longitudes 6°52'33" E and 8°28'50" E as shown in Figure 1.

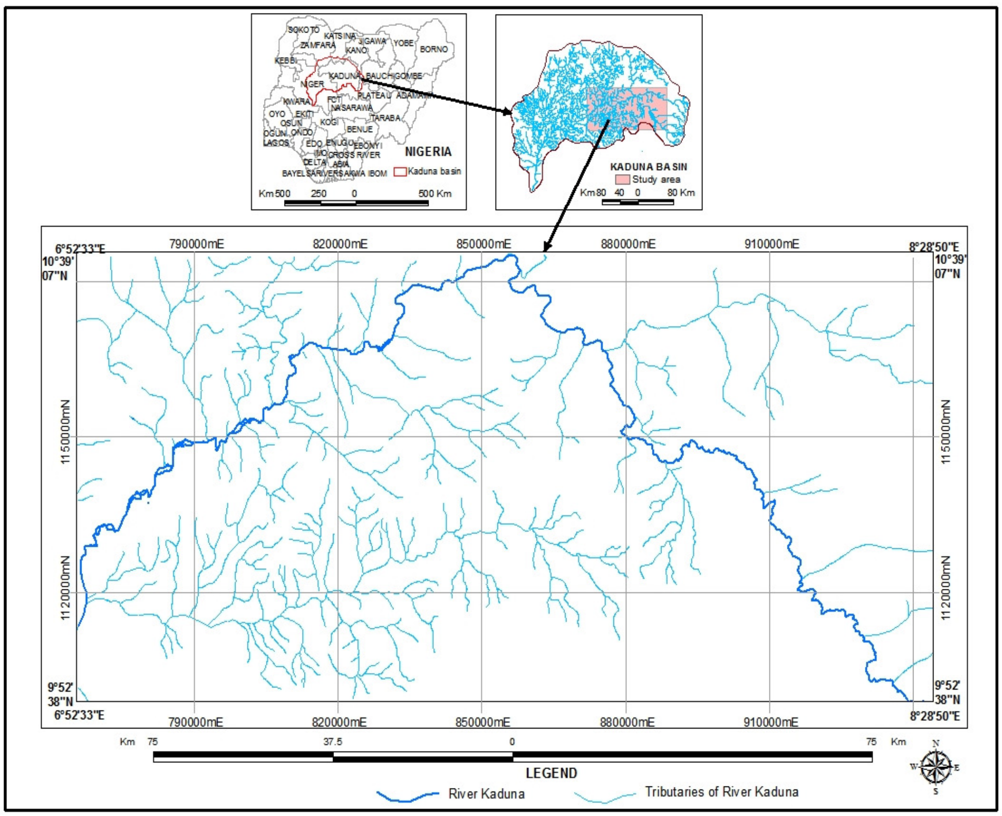

Figure 1: The Study area (Adopted from Ita, 1993)

The Kaduna River Basin lies between the 1000 mm and 1500 mm isohyets, which places the Basin within Nigeria's sub-humid zone with gradual decrease in annual rainfall amount from the southernmost of part of the basin towards the north. Rainfall last for a period of 5 months in the north to more than 8 months in the south. Mean monthly temperature reaches 28 °C in March and drops to 23.2 °C in December. The drainage network in the study area is predominantly tributaries to the Rivers Kaduna, prominent among these tributaries are; River Mariga, River Galma, River Magini, River Sarkin Pawa, River Esse, River Ngell, River Kajuru, River Romi and River Wuya. Downcutting by rivers is most active in the southern and western margins of the Basin, although gullying by ephemeral streams occurs in many small areas throughout, notably in the densely cultivated Zaria region.

2.2. Data Collection

Rainfall records from 1980-2010 were collected from the Department of Geography Ahmadu Bello University Zaria, Kaduna State, while records of 1962-1979, 2011-2015 were collected from the Department of Geography Federal University Dutsin-Ma, Kasina State. Stream discharge data for River Kaduna at the Kaduna South Gauging Station were collected from the Kaduna State Water Corporation covering the period from 1967 to 1969, 1971 to 1986 and 1988 to 2000.

2.2.1. Processing stream discharge data

Stream discharge data were available in different units; cubic feet per second (cfs) and cubic metres per second (m^3/s). There were also records in both discharge in (m^3/s) and gauge height in metres (m) as well as records in gauge height in metres (m) only. Discharge in (m^3/s) was adopted in the present study. Hence, the records in cfs were converted to m^3/s using the conversion factor: 1 cfs = 0.02832 m3/s. Owing to the relationship between gauge height and discharge some estimation of discharge was carried out by fitting the data that recorded both discharge and gauge heights into the following:

$$\text{Log}(Q) = \text{Log}(a) + b\text{Log}(H) \quad (1)$$

Where Q is discharge, H is gauge height and a, b are factors to be determined.

2.2.2. Validation of rainfall records

Statistical analysis of rainfall data from a single series should ideally possess elements of homogeneity such that properties or characteristics of the different portion of the data series do not exhibit gaps or jumps (there are no outliers). The rainfall data used for analyzing flood in this study was validated through chi-square which is given by:

$$x^2 = \sum \frac{(fo - fe)^2}{fe} \quad (2)$$

Where *fo* is observed frequency and *fe* is expected frequency.

2.3. Data Analysis

2.3.1. Analyzing rainfall data

Rainfall data was analyzed to show trends, fluctuations and occurrence of floods. Rainfall fluctuation was depicted by producing a hyetograph of the annual value and this was supported by the mean deviation and residual mass curve. Trends in the occurrence of floods were determined using statistical tools.

2.3.2. Rainfall distribution

Rainfall data that was used for flood analysis was tested for homogeneity using the chi-square statistical tool. Data for 54 years was inspected to find the largest and smallest values to enable the grouping of the data into classes. The values 1636.3 and 848.9 were noted for the largest and the smallest values respectively and nine classes were formed at 100 mm interval following statistical guidelines for class formation. The expected frequencies for the single series data was obtained by:

$$Fe = \frac{n}{m} \qquad (3)$$

Where Fe is expected frequency, n is the total number of observations and m the number of classes.

2.3.3. Time series analysis

The rainfall data acquired for this study was considered as a time series and was analyzed to show trends, fluctuations and occurrences of floods. To appreciate fluctuations, the annual total rainfall was plotted against each year. Trends in rainfall were constructed by establishing the truncation level (reference value) which is the mean annual precipitation (MAP) value. Further analysis depicting trends and fluctuations was carried out using the mean deviation technique. The mean deviation (or average deviation) is one of the measures of dispersion that indicates the departures of the individual rainfall values from the long-term mean. The departures of each year's record from mean annual precipitation were plotted as the amount of precipitation (mm) against the respective years. Years with precipitation exceeding MAP were to establish to indicate periods of rainfall surplus (flood years). When the amount of rainfall denoted by the product of an ordinate and time interval of a hyetograph is plotted against time by adding each new volume (amount) to the previous total, a cumulative mass curve is obtained. Such a curve provides a ready means of estimating water storage capacity. This technique as described by Kraus (1955) helped depict fluctuations in rainfall. In this study, by plotting the cumulative mean deviation against individual years, a residual mass curve was obtained, its characteristic feature assisting in the identification of the occurrence of floods.

2.3.4. Exceedance probability and return period of floods

To calculate exceedance probability, all rainfall values above the MAP were ranked m in descending order so that the largest value is m = 1 and the smallest value takes n, the n being the total number of observations. Exceedance probability was calculated using the expression:

$$P = \frac{m}{n} + 1 \qquad (4)$$

Where P is the exceedance probability, m is the rank number and n the total number of observations.

The return period of flood incidences was also calculated by the relation:

$$T = \frac{1}{P} \qquad (5)$$

Where T is return period and P is the exceedance probability.

After obtaining the exceedance probability, it was related to precipitation in a plot. To avoid jumps, trend or cycles in the exceedance probability plot, the cumulative lognormal distribution values rather than actual rainfall values were used and they were derived adopting the following steps:

a) Obtaining the log of annual precipitation values using the log-normal function in Excel.
b) Finding the mean and standard deviation of the log of annual precipitation using the Average and Stdev functions in excel.
c) The cumulative lognormal distribution was found for log annual precipitation values using the lognormal distribution function in excel. This function took as input, the log of annual precipitation values, the mean and standard deviation of the log of annual precipitation and returned the cumulative lognormal distribution functions.
d) The values obtained for the cumulative lognormal distribution replaced the actual calculated exceedance probability values to enable a smooth plot of the exceedance probabilities.
e) The cumulative lognormal distribution values were plotted against precipitation and exceedance probability was related to annual precipitation by the least square regression analysis.

2.3.5. Flood indexing using rainfall records

The PCI model was adopted for evaluating the concentration and variability of rainfall in time because it explores the possible relationships between PCI and annual rainfall total, and between PCI and rainy days as well as provides input to the evaluation of erosivity. Evaluation of the level of performance of PCI in providing information on long term total variability in the amount of rainfall received has been presented by (Michiels *et al.,* 1992; Apaydin *et al.*, 2006; De-Luis *et al.*, 2011). The indicators of rainfall concentration for annual and seasonal scales (wet seasons) are expressed as follows:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \text{ x } 100 \quad (6)$$

$$PCI_{wet} = \frac{\sum_{i=1}^{7} P_i^2}{\left(\sum_{i=1}^{7} P_i\right)^2} \text{ x } 58 \quad (7)$$

Where PCI_{annual} is annual precipitation concentration index, PCI_{wet} is seasonal (wet) precipitation concentration index and Pi is the monthly precipitation in month i.

Precipitation concentration index (PCI) classification by (Oliver, 1980) is shown on Table 1.

Table 1: Precipitation concentration index (PCI) classification (Oliver, 1980)

PCI Value	Distribution of precipitation
PCI ≤ 10	Uniform precipitation distribution (low precipitation concentration)
PCI>10 ≤ 15	Moderate precipitation distribution
PCI>16 ≤ 20	Irregular precipitation distribution
PCI >20	Strong irregularity of precipitation distribution

The number 100 in Equation 6 represents 12 months of the year signifying 100% and the numbers 58 for the seasonal PCI in Equation 7 represent the seven rainy months as a percentage of 12 months of the year. In this study, the wet season is considered to last for 7 months (from April to October). The long term variability in the amount of rainfall received was obtained using Equation (8) on an annual scale.

To define wet and dry years in the series a Transformed Annual Precipitation Departure (TAPD) z was used and is expressed as follows:

$$z = \frac{x-\mu}{\sigma} \quad (8)$$

Where x is the annual precipitation, μ is the annual mean precipitation, and σ is the standard deviation of the annual precipitation. The year is dry where z ≤ −0.5, and wet when z ≥ 0.5 (Pnevmatikos and Katsoulis, 2006).

2.3.6. Analysis of stream discharge data

Not all the rainfall recorded at a station contribute to streamflow (Brooks, 1985; Heggen *et al.*, 1996). Some of the water accounts for evapotranspiration and groundwater seepage. Based on this fact, the analysis of flood using rainfall data may not be reliable. Streamflow data for 30 years was also used to analyze flood in the present study. The streamflow data were analyzed to show frequency as well as the return period of flooding using Log-Pearson's Type III Distribution. This technique was carried following the steps as outlined:

a. Organizing the discharge data in a table in excel
b. Ranking the data from largest discharge to smallest discharge
c. Finding the log of each maximum or peak stream flow using the Excel formula {log (Q)}
d. Calculating the Average Maximum Q or Peak Q and the Average of the log (Q)
e. Finding the square of {(log Q - avg(logQ))}
f. Finding the cube of {(log Q - avg(logQ))}
g. Calculating the return period (Tr) for each discharge using the formula {(n+1)/m}. Where n = the number of values in the dataset and m = the rank.
h. Calculating the exceedance probability of each discharge using the formula {=1/Return Period or 1/Tr}.
i. Calculating the Sum for the {(logQ - avg(logQ))2} and the {(logQ - avg(logQ)) 3}
j. Calculate the variance, standard deviation, and skew coefficient as follows:
   Variance was calculated using Equation 9.

$$\frac{\sum_i^n \left(logQ - avg\ (logQ)\right)^{\wedge 2}}{n-1} \quad (9)$$

Standard deviation= $\sigma\ logQ = \sqrt{variance}$ (10)

Skew coefficient= $\frac{n \times \sum_i^n \left(logQ - avg\ (logQ)\right)^{\wedge 3}}{(n-1)(n-2)(\sigma\ logQ)^{\wedge 3}}$ (11)

k. Using frequency factor table and the skew coefficient to find the k values for the 2,5,10,25,50,100, and 200 recurrence interval.
l. Using the general equation, list the discharges associated with each recurrence interval as follows:
   General equation:

$$logQT_r = avg(logQ) + [K(T_r\,, C_s)] \times \sigma\ logQ \quad (12)$$

m. Calculating Discharge values using the log-Pearson analysis.
n. Plotting graph of discharge on return period.

3. RESULTS AND DISCUSSION

To analyze flood using rainfall data for the study period 1962 to 2015 the rainfall record was subjected to a homogeneity test by applying Chi-Square analysis based on the frequency, and the results are presented on Table 2.

Table 2: Observed and expected frequencies

Classes	Observed frequency	Expected frequency
800-900	3	6
900-1000	3	6
1000-1100	9	6
1100-1200	5	6
1200-1300	17	6
1300-1400	6	6
1400-1500	8	6
1500-1600	2	6
1600-1700	1	6

Chi Square was found by; $\chi^2 = (3\text{-}6)^2 + (3\text{-}6)^2 + (9\text{-}6)^2 + (5\text{-}6)^2 + (17\text{-}6)^2 + (6\text{-}6)^2 + (8\text{-}6)^2 + (2\text{-}6)^2 + (1\text{-}6)^2/6 = 9 +9 +9+1+121+0+4+16+25 = 198/6 = 33$

Degree of freedom (df) = m-1 = 8.

The calculated value of 33 is greater than the table value at both 0.01 (20.9) and 0.05 (15.1) confidence levels. Therefore, the rainfall data is normally distributed and considered suitable for use in the analysis of flooding without any adjustments. Values of Chi square critical values were determined from chi square statistic tables (Anyadike, 2009).

Long-term mean annual precipitation (MAP) is presented in Figure 2. The hyetograph reveals fluctuations as evidenced in the alternating bars as well as an indication that some values exceeded the MAP while others fell below it. Floods occur when precipitation exceeds a given threshold. The 1233.58 mm green line in Figure 2 represents the truncation level for defining surpluses and deficits of rainfall from the series. Then the difference between the MAP and individual annual rainfall volumes (the mean deviation) was used to determine deviations from the mean (Figure 3). Table 3 indicates that 25 years of the 54 years rainfall series were rainfall surpluses years and these years were considered as flood years. To obtain an idea of the water storage capacity of the study area, a mass curve was created and it could be seen to display dates of climatic phase change as shown in Figure 4. The statistics in Table 3 show the years of flood occurrence corresponding to dates of climatic phase change as depicted in the mass curve in Figure 4.

Table 3 showed that 25 years of the 54 years precipitation distribution used in the study were above MAP, implying floods of varying magnitudes during the study period. The plot in Figure 5 shows the relationship between exceedance probability and annual precipitation defined by a linear relationship. The calculated return periods for the 25 flood years in Table 4 shows that the highest rainfall volume was recorded in the year 2013 with a return period of 55 years, while the lowest amount was in 1999 with a return period of 2.2 years. Due to the strong relationship observed in the regression analysis, it can be asserted that flood events coincided with periods of rainfall surpluses. This result is similar to that of study by Santos and Fragoso (2016), who estimated the precipitation thresholds for triggering floods in the Corgo Basin, Portugal.

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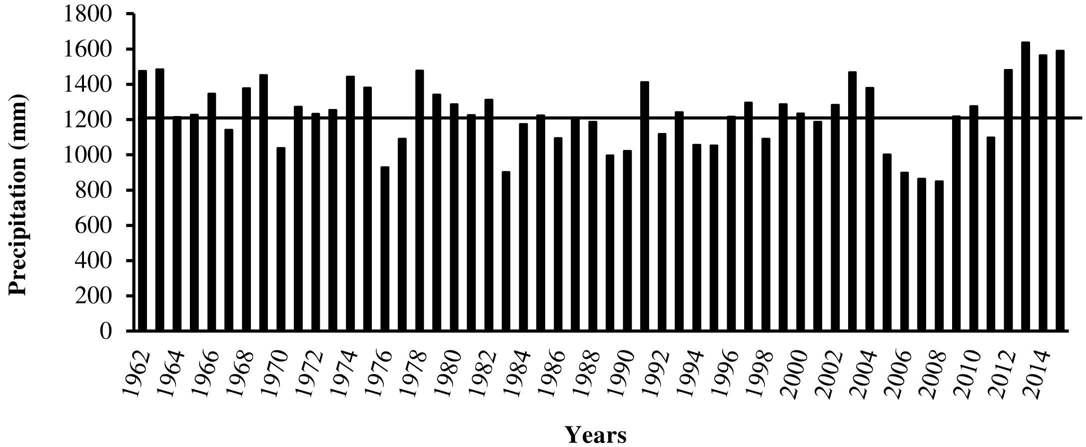

Figure 2: Annual precipitation and flood incidences (horizontal line symbolizes mean annual precipitation)

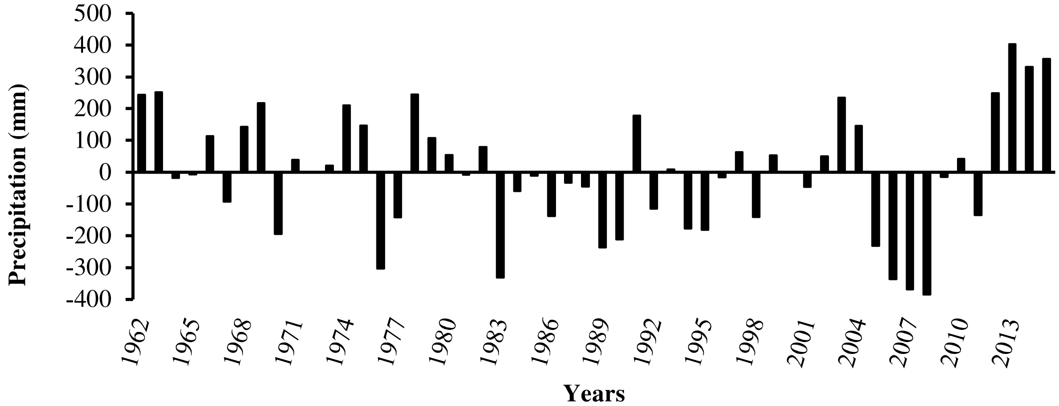

Figure 3: Rainfall departure from mean annual precipitation (MAP)

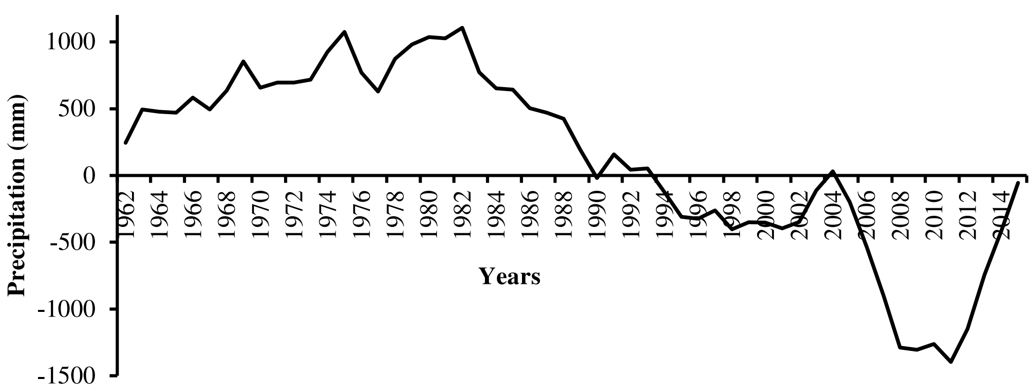

Figure 4: Residual mass-curve of precipitation

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Table 3: Years with preciptation above MAP (Floods)

Years	Rainfall	Mean deviation
1962	1476.8	243.22
1963	1485.4	251.82
1966	1346.9	113.32
1968	1376.89	143.31
1969	1451.61	218.03
1971	1272.7	39.12
1973	1254.6	21.02
1974	1444.3	210.72
1975	1380.3	146.72
1978	1478	244.42
1979	1341.4	107.82
1980	1287.2	53.62
1982	1312.8	79.22
1991	1411.4	177.82
1993	1242.5	8.92
1997	1297.1	63.52
1999	1286.3	52.72
2002	1284	50.42
2003	1468.3	234.72
2004	1379.4	145.82
2010	1276.3	42.72
2012	1482.3	248.72
2013	1636.3	402.72
2014	1565	331.42
2015	1590.4	356.82

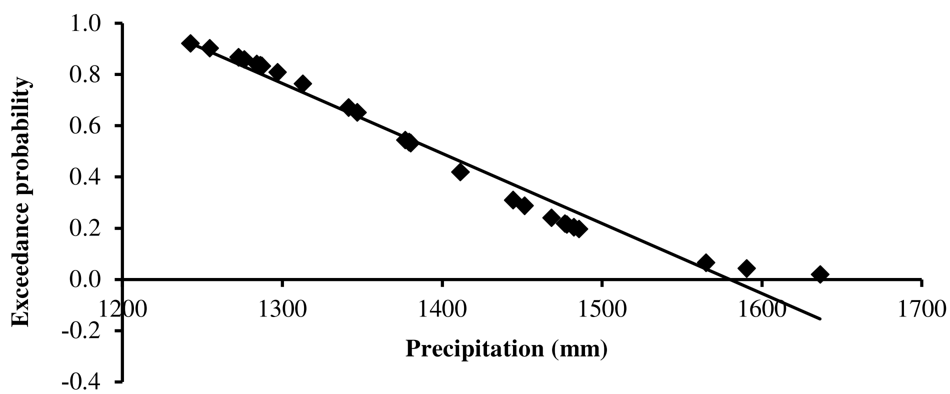

Figure 5: Plot of exceedance probability on annual precipitation

Floods occur when precipitation exceeds a given threshold. The 1233.58 mm green line in Figure 2 represents the truncation level for defining surpluses and deficits of rainfall from the series. Figure 3 shows the departure from the mean annual precipitation (MAP). However, analysis using transformed annual precipitation departure (TAPD) showed that not all the 25 years that recorded surpluses were wet as presented in Table 3 (years with precipitation above MAP (floods).

Table 4: Precipitation, log precipitation, rank, exceedance probability, cumulative lognormal and return period values for flood years

Years	Precipitation	Log precipitation	Rank	Exceedance probability	Cumulative Log normal	Return period (years)
2013	1636.3	7.40	1	0.02	0.98	55
2015	1590.4	7.4	2	0.04	0.96	27.5
2014	1565	7.4	3	0.06	0.94	18.3
1963	1485.4	7.3	4	0.07	0.80	13.8
2012	1482.3	7.3	5	0.09	0.79	11
1978	1478	7.3	6	0.12	0.79	9.2
1962	1476.8	7.3	7	0.13	0.78	7.9
2003	1468.3	7.3	8	0.15	0.76	6.9
1969	1451.61	7.3	9	0.16	0.71	6.1
1974	1444.3	7.3	10	0.18	0.69	5.5
1991	1411.4	7.3	11	0.2	0.58	5
1975	1380.3	7.2	12	0.22	0.47	4.6
2004	1379.4	7.2	13	0.24	0.47	4.2
1968	1376.89	7.2	14	0.26	0.46	3.9
1966	1346.9	7.2	15	0.27	0.35	3.7
1979	1341.4	7.2	16	0.29	0.33	3.4
1982	1312.8	7.2	17	0.31	0.24	3.2
1997	1297.1	7.2	18	0.33	0.19	3.1
1980	1287.2	7.2	19	0.35	0.17	2.9
1999	1286.3	7.2	20	0.36	0.16	2.8
2002	1284	7.2	21	0.38	0.16	2.6
2010	1276.3	7.2	22	0.4	0.14	2.5
1971	1272.7	7.2	23	0.42	0.13	2.4
1973	1254.6	7.1	24	0.44	0.09	2.3
1993	1242.5	7.1	25	0.46	0.08	2.2
	mean	7.2				
Standard deviation		0.08				

Table 5 from indicates 16 wet years, 16 dry years and 22 years that did not fit into the wet or dry classes and in this study, those years are referred to as normal. Table 6 illustrates the annual precipitation concentration index (PCI) values. Comparing these values with precipitation concentration index classification in Table 1, it can be seen that on the whole annual precipitation distribution in the study area, assumed mostly an irregular pattern (35 years of PCI less ≤ 20) with the remaining 19 years exhibiting strong irregular annual precipitation distribution (>20). Similarly, seasonal PCI in Table 7 reveals 8 years of uniform precipitation distribution and 46 years of moderate precipitation distribution. According to De-Luis *et al.* (2011) PCI value between 16 and 20 indicates that the total precipitation was concentrated in half of the period (1year) which translates to 6 months, while PCI values greater than 20 means that the total precipitation concentration occurred in one-third of the period which also translates to 4 months within 1 year. The 8 years of seasonal Uniform Precipitation Distribution implies that nearly the same amount of rainfall occurred in each month of the wet season a situation that poses little threat to flooding and erosion. Rainfall variability characterized by irregularities that have resulted in a high concentration such as those observed in annual and seasonal PCI cause flooding and erosion. The results obtained from this study are similar to other studies carried out in Nigeria such as (Ezenwaji *et al.,* 2017) who analyzed precipitation concentration for Awka urban arsea, Nigeria and (Adegun *et al*., 2012) who estimated annual and seasonal precipitation concentration in Owerri and Enugu, Nigeria.

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Table 5: Values of annual precipitation departure for wet and dry years

Year	Wet	Year	Dry	Year	Normal
1962	1.28517834	1970	-1.031387054	1964	-0.0974373
1963	1.33062087	1976	-1.605178336	1965	-0.0343989
1966	0.59878468	1977	-0.752338177	1967	-0.4867635
1968	0.75725231	1983	-1.74996037	1971	0.2067107
1969	1.15207398	1986	-0.728560106	1972	-0.0078203
1974	1.11344782	1989	-1.251677675	1973	0.11107001
1975	0.77527081	1990	-1.117992074	1980	0.28332893
1978	1.29151915	1992	-0.606499339	1981	-0.041638
1979	0.56972259	1994	-0.940977543	1982	0.41859974
1991	0.9396037	1995	-0.961585205	1984	-0.3190489
2003	1.2402642	1998	-0.751281374	1985	-0.0553765
2004	0.77051519	2005	-1.227371202	1987	-0.1769089
2012	1.31424042	2006	-1.774795244	1988	-0.240317
2013	2.12797886	2007	-1.947582563	1993	0.04713342
2014	1.75122853	2008	-2.032655218	1996	-0.0865522
2015	1.88544254	2011	-0.714293263	1997	0.33564069
				1999	0.27857332
				2000	-0.0041215
				2001	-0.2482431
				2002	0.26642008
				2009	-0.0828534
				2010	0.22573316

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Table 6: annual precipitation concentration index

Year	$\sum_{i=1}^{12} P_i^2$	$(\sum_{i=1}^{12} xP_i)^2$	$\frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2}$(PCI)
1962	355405.96	2180938	16.29601212
1963	368336.8	2206413	16.69391783
1964	290472.5174	1476565	19.67217659
1965	308668.6827	1505701	20.50000145
1966	390598.1306	1814140	21.53076469
1967	221076.771	1302931	16.96765083
1968	315333.4425	1895826	16.6330365
1969	370240.1389	2107172	17.57047885
1970	248395.1249	1078254	23.03679586
1971	306876.73	1619765	18.94575294
1972	306363.45	1518070	20.18110939
1973	324779.72	1574021	20.63375819
1974	434791.97	2086002	20.84331021
1975	334934.71	1905228	17.57976967
1976	147044.5	864528	17.00864439
1977	195625.94	1190717	16.42924958
1978	333216.3	2184484	15.25377618
1979	329412.3	1799354	18.30725401
1980	356178.88	1656884	21.49691315
1981	296089.01	1502340	19.70851561
1982	334201.36	1723444	19.39148536
1983	165189.5	814325.8	20.28543221
1984	231435.68	1376398	16.81458703
1985	285185.75	1495974	19.06355487
1986	264147.69	1200558	22.00206755
1987	276319.83	1440240	19.18567934
1988	340073.27	1411582	24.09164781
1989	167421.91	993410.9	16.85323884
1990	229936.24	1044484	22.01433818
1991	458352.74	1992050	23.00909863
1992	269978.22	1251713	21.56869227
1993	329709.05	1543806	21.35689307
1994	200255.19	1114080	17.97493403
1995	243483.16	1105863	22.01748832
1996	294246.18	1481576	19.8603522
1997	297584.01	1682468	17.68734606
1998	220894.5	1191154	18.54458008
1999	332867.19	1654568	20.11807628
2000	293313.54	1519796	19.29953565
2001	279415.38	1408020	19.84456665
2002	303632.7	1648656	18.41698329
2003	393619.85	2155905	18.2577558
2004	394667.96	1902744	20.74203809
2005	181236.51	1002602	18.07662124
2006	148023.71	805865.3	18.36829453
2007	146535.12	748225	19.58436567
2008	137592.25	720631.2	19.093296
2009	330970.27	1483280	22.31339858
2010	309661.95	1628942	19.01000827
2011	224433.14	1206483	18.60226973
2012	410283.63	2197213	18.67290863
2013	497797.99	2677478	18.59204997
2014	488974.32	2449225	19.9644508
2015	582428.24	2529372	23.02659329

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Table 7: Seasonal (Wet) precipitation concentration index

Year	$\sum_{i=1}^{12} P_i^2$	$(\sum_{i=1}^{12} xP_i)^2$	$\frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2}$(PCI)
1962	354444.47	2088314.01	9.844199273
1963	368255.8	2179756.96	9.798723799
1964	290199.94	1436713.88	11.71534335
1965	308591.02	1475326.04	12.13174481
1966	390598.13	1814139.61	12.48784352
1967	221048.36	1290791.38	9.932515224
1968	314998.92	1845793.96	9.898145548
1969	370109.49	2074118.43	10.34962629
1970	247939.73	1034390.7	13.9023913
1971	306871.44	1613916.16	11.02817108
1972	306259.41	1493039.61	11.89723679
1973	324063.9	1460230.56	12.87173869
1974	434161.96	2014128.64	12.50237605
1975	334922.46	1895578.24	10.24779789
1976	146444.25	819568.09	10.3637106
1977	195625.94	1190717.44	9.528964756
1978	332503.41	2106271.69	9.156082699
1979	327630.97	1686102.25	11.27013279
1980	356174.88	1651739.04	12.50690487
1981	296089.01	1502340.49	11.43093905
1982	334200.36	1720819.24	11.26418187
1983	165189.5	814325.76	11.76555068
1984	231427.27	1369602.09	9.800497355
1985	280215.5	1328486.76	12.23384341
1986	264094.4	1184614.56	12.93034521
1987	275437.74	1369836.16	11.66226253
1988	339934.02	1383446.44	14.25149004
1989	167421.91	993410.89	9.77487853
1990	229936.24	1044484	12.76831614
1991	458339.78	1981900.84	13.41323779
1992	269971.24	1243671.04	12.59041291
1993	329708.8	1542564	12.39696402
1994	200255.19	1114080.25	10.42546174
1995	243473.55	1099352.25	12.84526038
1996	294246.18	1481575.84	11.51900428
1997	295878.32	1577033.64	10.88178598
1998	220894.5	1191153.96	10.75585645
1999	332737.23	1625370.01	11.87345603
2000	293313.54	1519795.84	11.19373068
2001	279415.38	1408019.56	11.50984866
2002	303632.69	1648399.21	10.68351399
2003	393619.85	2155904.89	10.58949836
2004	393291.55	1801769.29	12.66028344
2005	181236.51	1002601.69	10.48444032
2006	148023.71	805865.29	10.65361083
2007	146535.12	748225	11.35893209
2008	137592.25	720631.21	11.07411168
2009	330970.27	1483280.41	12.94177118
2010	309659.39	1624860.09	11.05340991
2011	224431.45	1203628.41	10.81481958
2012	410283.63	2197213.29	10.830287
2013	495493.99	2522696.89	11.39203506
2014	488929.43	2428298.89	11.67809575
2015	581358.95	2426429.29	13.89647712

Analysis of discharge records for River Kaduna at Kaduna South has also shown high discharge values in the earlier years of the study without accompanying flood events. The ranking of annual maximum discharge from highest to lowest values, calculated log (Q), log(Q)-Avg(log(Q))^2, log(Q)-Avg(log(Q))^3, return period and exceedance probability are shown in Table 8 and Flood frequency for RIVER Kaduna at Kaduna South using Log Pearson Type III Analysis using average daily discharge values is shown in Figure 6.

Since the calculated skew coefficient of -1.3760 is not a discrete number, and it occurs between two given skew coefficients in the Frequency Table then the appropriate k-value was extrapolated between the two numbers K(-1.3) and K(-1.4). In this study, the k-value was found by taking the mean of the two Frequency Table values. The skew coefficient obtained and their associated discharges for the flood recurrent interval; 2, 5, 10, 25, 50, 100 and 200 years are shown in Table 9 and the plot of the associated discharge on the return period is shown in Figure 6. The plot can be used to predict floods for given return periods.

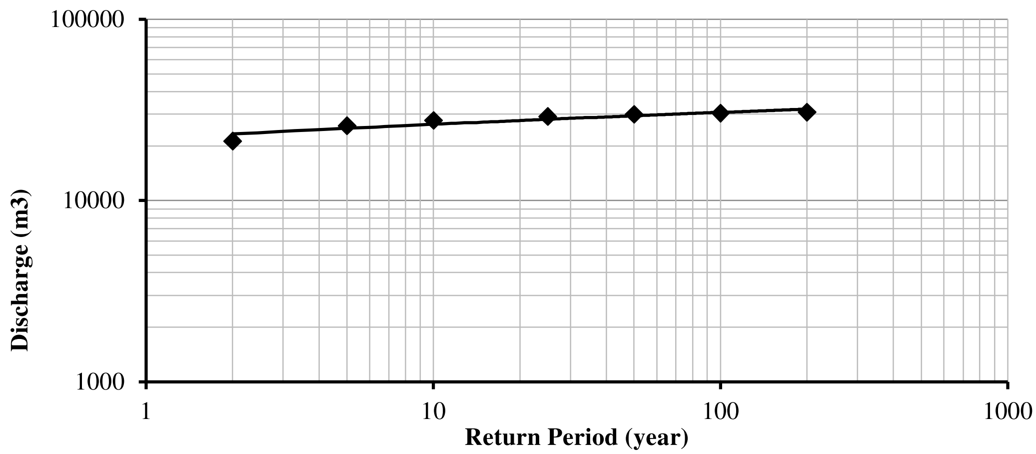

Figure 6: Flood frequency for River Kaduna at Kaduna South using log Pearson Type III analysis using average daily discharge values (1967-2000)

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Table 8 Ranking of annual maximum discharge values for River Kaduna at Kaduna South

Rank	Years	Q	log(Q)	log(Q) -Avg(log(Q))^2	log(Q) - Avg(log(Q))^3	Tr = n+1/m	1/Tr (EP)
1	1975/76	29827.53	4.475	0.03115	0.00550	31.00	0.0323
2	1974/75	29007.61	4.463	0.02706	0.00445	15.50	0.0645
3	1993	28242	4.451	0.02326	0.00355	10.33	0.0968
4	1998	27667.5	4.442	0.02059	0.00295	7.75	0.1290
5	1999	26860.74	4.429	0.01704	0.00223	6.20	0.1613
6	1992	26447	4.422	0.01525	0.00188	5.17	0.1935
7	2000	24836.29	4.395	0.00931	0.00090	4.43	0.2258
8	1967/68	24384.43	4.387	0.00783	0.00069	3.88	0.2581
9	1994	23980	4.38	0.00666	0.00054	3.44	0.2903
10	1972/73	23950.14	4.379	0.00648	0.00052	3.10	0.3226
11	1971/72	23934.1	4.379	0.00648	0.00052	2.82	0.3548
12	1991	23773	4.376	0.00601	0.00047	2.58	0.3871
13	1981	23659	4.374	0.00570	0.00043	2.38	0.4194
14	1973/74	22761.12	4.357	0.00342	0.00020	2.21	0.4516
15	1979	20480	4.311	0.00016	0.00000	2.07	0.4839
16	1968/69	20189.89	4.305	0.00004	0.00000	1.94	0.5161
17	1997	20006	4.301	0.00001	0.00000	1.82	0.5484
18	1996	19398.1	4.288	0.00011	0.00000	1.72	0.5806
19	1990	19374	4.287	0.00013	0.00000	1.63	0.6129
20	1995	17354	4.239	0.00354	-0.00021	1.55	0.6452
21	1988	17306	4.238	0.00366	-0.00022	1.48	0.6774
22	1980	17035	4.231	0.00456	-0.00031	1.41	0.7097
23	1989	16523	4.218	0.00648	-0.00052	1.35	0.7419
24	1986	16477	4.217	0.00664	-0.00054	1.29	0.7742
25	1985	15330	4.186	0.01266	-0.00142	1.24	0.8065
26	1977/78	15021.9	4.177	0.01476	-0.00179	1.19	0.8387
27	1982	14849	4.172	0.01600	-0.00202	1.15	0.8710
28	1976/77	14737.11	4.168	0.01703	-0.00222	1.11	0.9032
29	1983	11723	4.069	0.05267	-0.01209	1.07	0.9355
30	1984	6895.27	3.839	0.21114	-0.09702	1.03	0.9677
						Variance	0.0185
		Mean	Mean	Sum	Sum	Std	0.1359
		20734.32	4.2985	0.53584	-0.09354	Skew coeff	-1.3760

Table 9: Discharges associated with recurrent interval

Tr	K (-1.3)	K (-1.4)	K (-1.3760)	Q(m^3)
2	0.21	0.225	0.218	21312
5	0.838	0.832	0.835	25852
10	1.064	1.041	1.053	27678
25	1.24	1.198	1.219	29154
50	1.324	1.27	1.297	29875
100	1.383	1.318	1.351	30384
200	1.424	1.351	1.388	30738

4. CONCLUSION

The study examined the annual patterns of rainfall over River Kaduna and effects on flood probability using the Precipitation Concentration Index. The study found that annual precipitation concentration index shows that 35 of the 54 years were characterized by irregular precipitation distribution which implies that for 35 years precipitation concentrated in 6 months of each year. The PCI also shows that 19 years had strong irregularity of precipitation distribution meaning that for 19 years, precipitation concentrated in 4 months of each year, most of which coincided with years of drought. Due to the strong relationship observed in the regression analysis, it can be asserted that flood events coincided with periods of rainfall surpluses. Information derived from this study can be used by government agencies in developing flood protection infrastructures in Kaduna riverine community to improve the economic inhabitant. Finally, such information can also be used for flood risk analysis and flood hazard management in the study area.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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