An Analysis of Rainfall Characteristics for Flood Risk Assessment in the Delimi River Catchment, Jos Plateau State

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Abstract: ***Rainfall characteristics are analyzed for a forty-year record (1977-2016) in the Delimi Catchment. Results showedan average rainfallamount of 1353.21mm/yr. Significant rainfall months are March to October (8 months), with peaks in July thentrailed closely in June. July 2012 had the highest depth rainfall with 680.1mm and July 2002 recorded the least with 132.5mm. A count of daily rainfall ≥24.00mm showed June, July, August, and September with high counts;with July having the highest records of 171 occurrences. Standard Precipitation Index (SPI) analysis and the Probability of Exceedance (Px) analysis carried out revealeda steady but upward trend in SPI values from 1977 to 2016meaning an increase in wetness over the years (-1.83 in 1977 to a + 1.69 in 2016). And Px calculations from three methods (Hazen, Welbul, and California)showed that eight different years 1978, 1981, 1991, 1994, 1996, 2012, 2014, and 2015 had less than 20% probability(having weather conditions called humid). With a corresponding return period (recurrence interval) Tx of between 5 to 40 years.This indicates years of excess or extreme rainfall and probable floods. Thereby allowing for a better understanding of the influences of rainfall characteristics on catchment runoffs and flooding's.***

Keywords: Rainfall amount, antecedent weather condition, Standard Precipitation Index (SPI) analysis, Delimi Catchment

1. Background to the Study

The Delimi River is one of the head-water of the Delimi-Bunga river system, a sub-system of the Chad drainage basin. The river network takes its source some 10km south-east of Jos town, flows through Joscity, then north-eastwards through theBauchi plains into the Jama'are - KomaduguYobe river system. Evidence of rapid urbanization of the Delimi basin abounds, especially within the geographical entity called Jos town. According to the United Nations, in its report on the State of African Cities (2014), Jos city was included amongst the top 14 cities with high population dynamics in Nigeria for 2011; having an average annual growth rate of 4.81%. Similarly, the top 10 Agglomerations in West Africarevealed Jos city as the seventh on the list with a population of 101,862 persons in 1950, 404,112 persons in 1980, and 766,821 by the year 2000 (Moriconi-Ebrard et al, 2008). According to Zevenbergen et al. (2008), an unwanted side effect of rapid urbanization is the increased susceptibility towards flooding as a result of the concentration of people and assets in flood-prone areas. They further asserted that climate change may cause floods to occur more frequently and severely.

Climate change causes frequent, severe weather, and climate events that threaten sustainable development globally. Its fallouts especially in variable rainfall patterns have resulted in increased frequency of extreme events (Olanrewaju, Ekiotuasinghan and Godwin 2017). Floods are closely related to rainfall.Therefore, is a need for accurate estimation and characterization of rainfall; and an investigation on long-term trends for different temporal scales. The amount of rainfall falling within a catchment is a key factor in determining the volume of water that flows and inundates riparian lands. According to FAO (1991), runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of a rainfall event, i.e., intensity, duration, and distribution. Others are the amount, and frequency or return period.

Hydrologists, water resource personals and catchment managers, and in particular flood risk managers are often concerned with rainfall characteristics because they are of great importance to the development, monitoring, and management of any catchment of which the Delimi river basin is one. In fact, according to Sharma et al (2016),there are three main characteristics of rainfall that are at the fore of flood determinants, namely the amount, frequency, and intensity, the values of which vary from place to place, day to day, month to month, and also year to year.

Rainfall is perhaps the most important climatic element globally and in particular, Sub-Saharan Africa. Man, and other living things depend on rainfall for their daily growth. According to Huho (2017), rainfall accounts for about 60% of agriculture (rain-fed)in the region. It is on this rainfed agriculture that many livelihood sources depend and households get their staple food production.

Rain is liquid precipitation, that is water falling from the sky. Raindrops fall to Earth when clouds become saturated or filled, with water droplets (NGS, 2011). Studies have presented three main types of rainfall (Iwena, 2012, Ayoade 2004). These are:

1) Convectional Rainfall: This occurs commonly in the tropics and temperate regions during summer. When the earth's surface is heated by the sun (isolation), evaporation occurs, and heated moisture-laden air rises

in convectional currents upward, towards the atmosphere to form cumulonimbus clouds and subsequently torrential rainswhich are accompanied by lightning and thunder.

2) Orographic or Relief Rainfall: Orographic rainfall is associated with mountainous regions. Air is forced to rise above a mountain/relief barrier, usually on the windward slope side of mountains. Rising air expands and becomes cooler and relative humidity rises and the air becomes saturated. Water vapour condenses, clouds form,and rainfall on the windward slope and little or no rainfall on the leeward side as air descends.
3) Cyclonic or Frontal Rainfall: Cyclonic rainfall is caused by the meeting of two air masses, which are different in terms of origin and characteristics. Warm, light, moisture-laden air rises above cold and dense air. The ascent of the warm air over cold air lowers the temperature of the warm air, cooling takes place and condensation occurs. Clouds form, further condensation leads to precipitation.

According to CHARIM (2015), two types of rainfall data are generally needed when dealing with natural hazards, longer time series with daily data that can be used for a frequency magnitude analysis, while detailed intensity data are needed for flood modeling and engineering (hydraulic) design purposes. Statistical analysis of data or the statistical behavior of any hydrological series can be described based on certain parameters, general mean, variance, standard deviation, coefficient of variation, and coefficient of skewness and or its homogeneity. These parameters can be used to describe the variability of rainfall in any catchment and are also useful for forecasting floods. From afar mention, this paper aims to characterize rainfall in terms of variability and trends in the Delimi river catchment for 40 years (1977-2016). The data and results contained herein can be used to predict future precipitation, employed for rainfall-runoff models and in the forecast of floods. In addition, it provides updated information about the current weather and climate situations in the River basin.

For this paper, rainfall characteristics are definedby the indices of Amounts, Frequency (Return Period), and Seasonal Distribution. These are further explained.

- **Rainfall Amount:** is the sum of all the rain showers which occurred during a specified period and measured in millimeters (FAO 1991). Rainfall amount is important to the overall hydrologic cycle and replenishment of the soil water in a catchment.
- **Rainfall Frequency (Return Period):** Refers to how often rainfall occurs at a particular amount or intensity and duration. For example, rainfall return periods are referred to as 100 year-1-hour rainfall or 100 year-24-hour rainfall to define the probability that a given amount will fall within a given period.
- **Rainfall Seasonal Distribution:**This refers to the time of year when various rainfall amounts occur. The seasonal distribution determines when surface runoff or deep percolation are most likely to occur or if irrigation is needed.

2. Materials and Methods

2.1. The Study Area

The Delimi River originates from the rocky terrains of the Jos Plateau and traverses through five other Nigerian states (Jigawa, Kano, Yobe, Borno, and Bauchi) where it has acquired different names such as Hadejia, Jama'are, Kamadugu, and Yobe River before finally emptying into Lake Chad (Figure 1). The river network takes its source some 10km south-east of Jos town, flows through Jos city, then north-eastwards through the Bauchi plains into the Jama'are - KomaduguYobe river system. Its major tributary is the Tilden Fulani, which rises from the Shere Hills, and flows through the Neil's Valley before joining the Delimi at about 20km beyond the northern Plateau edge in the southern margin of the Zala and Bauchi Plains.

The study area lies between latitudes 9^o 52′N and 10^o 00′N and longitudes 8^o49′E and 9^o00′E. The spatial coverage of the basin area of study is about 163.00 km^2. The source of the river is at a height of about 1, 310 meters and the basin length is about 31.15km.

Paper ID: SR211011181244 DOI: 10.21275/SR211011181244

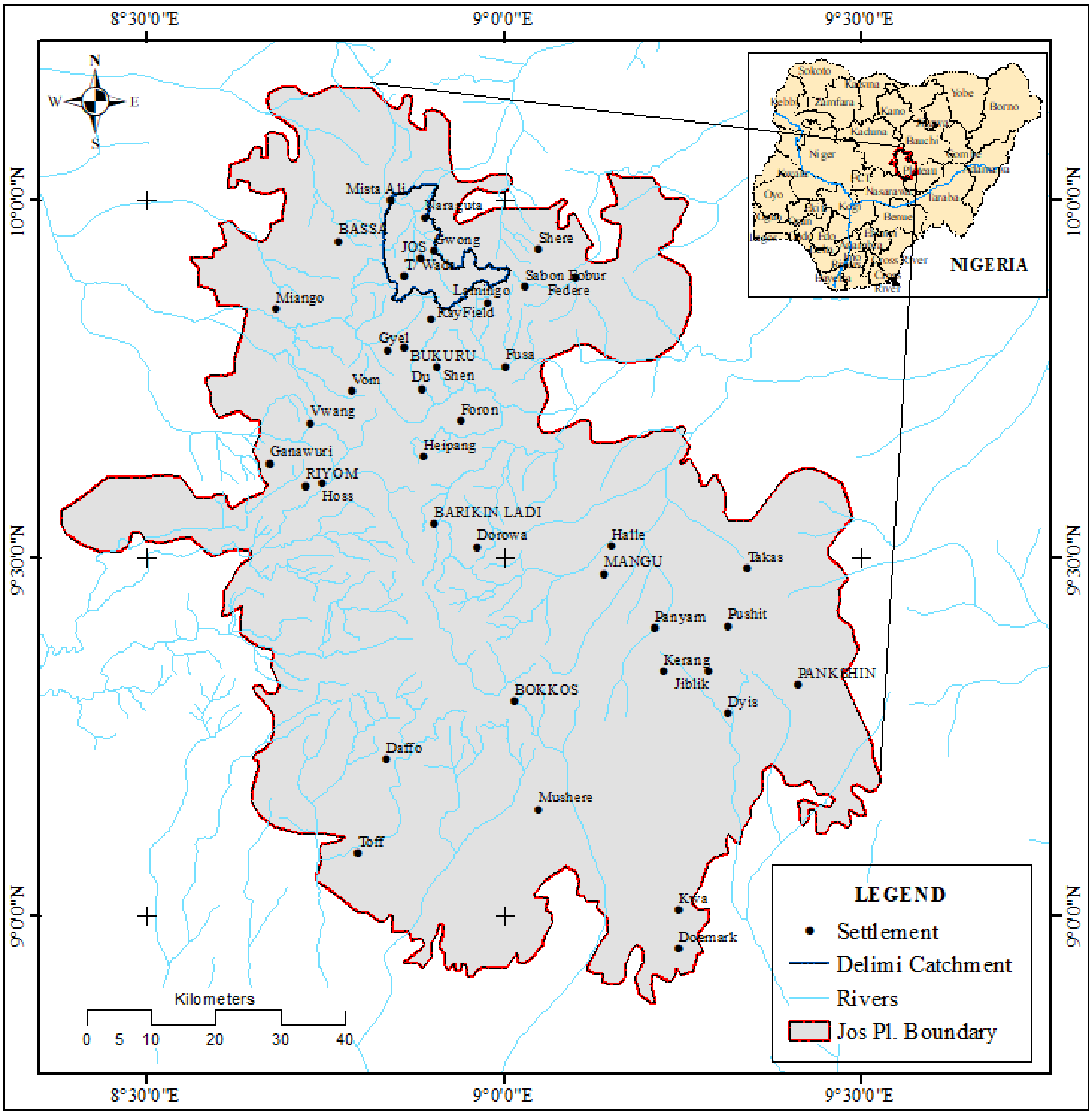

Figure 1: The Jos Plateau and Delimi River Catchment

The climatic conditions of the Delimi basin are influenced by relief, latitude, and winds. On the account of these factors, the basin generally experiences a modified climatic condition of lower temperatures and higher rainfalls compared to other places on equivalent latitudes. Climatically, this area experiences the Koppen A_w climate, that is, Tropical rainy climate (wet and dry). It lies within the northern Guinea savannah ecological zone of Nigeria.In the basin, temperatures are generally low having an annual mean of about 23.7^{o}c (table 1); monthly temperature is highest in March and April, these are usually the hottest months of the year with average daily air temperatures reaching over 31^{o}c.

2.2. Data

Climatic data were collected from the University of Josweather observatory established in 1976; located at Latitude 09° 57'N, Longitude 08°53'E, and altitude 1,159m AMSL. Data from this station was used based on temporal availability and the fact that the station provides the most available in-situ collectionfor the catchment. The data set include monthly temperature and daily rainfall for 40 years (1977 – 2016) but no records of rainfall duration. Table 1 presents a summarized account of the major elements (Temperature and rainfall) for the study period. Table two summarizes the activity, specific actions, and data requirements for this work.

Table 1: Mean Rainfall and Temperature in Jos (1977-2016)

	J	F	M	A	M	J	J	A	S	O	N	D	Sum	Aver
Temp ^{o}C	21.7	23.4	25.7	26.6	25.1	23.8	22.5	22.2	22.8	23.3	22.9	21.7	284.2	23.7
Rainfall (mm)	0.03	0.82	32.11	69.83	147.51	218.31	290.17	310.44	172.79	51.65	0.25	1.84	1285.5	106.0

Source: University of Jos Weather Observatory.

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Table 2: Specific Action, Data Requirement, and Results

Activity	Specific actions	Data required	Result
To analyze rainfall characteristics for the Delimi Catchment	• Test for homogeneity Calculate: • Average rainfall • Frequency of number of heavy daily rainfall • Antecedent weather condition • Magnitude and frequency analysis of extreme rainfall • Return period (tx) analysis	40 years daily rainfall	Description of Rainfall Characteristics

2.3. Statistical Analysis

The data assembled were subjected to the following statistical analysis to assist in characterizing rainfall data. These are:

a) Test for Homogeneity of Rainfall Time Series Data

According to Ahmed et. al (2018), long-term homogeneous precipitation data are essential for the assessment of hydro-climatic conditions of a region. In practice, however various non-climatic factors such as relocation of recording station, changes in instrumentation, changes in the surroundings, malfunctioning or inaccuracy of instrumental, and changes in observation or calculation procedures cause inhomogeneity in observed data and result in unrealistic trends, jumps, and shifts in time series of recorded rainfall data. Many methods are available to assess homogeneity, usually, a combination of methods is employed. For this work, the Pettitt's test (Pettitt, 1979)and the Buishand Test (Buishand, 1982) were employed to test for homogeneity of assembled rainfall data.

1) Pettitt's test: Pettitt's test (Pettitt, 1979), a nonparametric test adapted from the rank-based Mann-Whitney test that allows identifying the point at which the shift occurs in a time series. The break is detected near the year *m* when the estimated value (X_E) exceeds the critical value:

$$X_E = max_{1 \le d \ge n} |X_d| \quad (1)$$

Where

$X_d$is the Mann-Whitney statistic and can be calculated as $X_d = 2\sum_{i=1}^{d} r_i - d(n+1)$, d = 1, 2, 3, 4…*n*, *n* is the number of years, and r_i*is* the rank of the i^{th}observation.

The critical value of Pettitt's statistics is at a 95% confidence level for numbers of data points.Omar et al. (2017) gave a brief description of the methodology.

2) Buishand Test: This test is based on the adjusted partial sums or cumulative deviations from the mean (Buishand, 1982). The null hypothesis is the same as the Pettitt test. The adjusted partial sum is calculated as:

$$S_o^* = 0;\ S_k^* = \sum_{i=1}^{k}(X_i - \overline{X}), K = 1, 2, \ldots\ldots\ldots N \quad (2)$$

Where

$\overline{X}$ is the mean of time series observations (X_1, X_2, ……X_N) and

K is the number of the observation at which a breakpoint is occurring.

Rescaled adjusted partial sums are determined as follows:

$$S_k^{**} = \frac{S_K^*}{D_x}, k = 1,2 \ldots\ldots, N \quad (3)$$

$$D_x = \sqrt{\frac{\sum_{i=1}^{N}(x_1 - \overline{x})^2}{N}} \quad (4)$$

The statistic Q is used for testing homogeneity:

$$Q = max_{0 \le k \le N}|S_k^{**}| \quad (5)$$

The null hypothesis is accepted, when the value of $Q/\sqrt{N}$ is less than the critical values given by Buishand (1982).

- **Average rainfall for the study catchment:** Daily rainfall data assembled for the 40year period (1977-2016) was summarized using the summation and average function in Microsoft Excel application and summary presented as bar graphs according to months.
- **Frequency of Heavy Rainfall in The Study Catchment:**The 'countifs' function in Microsoft Excel was employed to count daily rainfall values equal to or greater than 25.00mm from 1977 to 2016. Counts are presented as graphs according to year and months.
- **Computation of Standard Precipitation Index (SPI):** The SPI (McKee et al, 1993, 1995) also known as the standard rainfall anomaly index is a powerful, flexible index that is simple to calculate. It is a normalized index representing the probability of occurrence of an observed rainfall amount when compared with the rainfall climatology at a certain geographical location over a long-term reference period. Precipitation is the only required input parameter. Also, it is just as effective in analyzing wet periods/cycles as it is in analyzing dry periods/cycles. The formula is presented by Equation6:

$$Xj = ((rij-ri))/\delta i \quad (6)$$

Where

Xj = the normalized departure

rij = the annual rainfall for the station in year j

ri = the long term means for the station ij

δi = standard deviation of the station with annual rainfall.

The SPI classification system in Table3, defines rainfall deficit or surplus situations. The SPI Generator application as developed by the National Drought Mitigation Centre – UNL was employed to calculate SPI values for the catchment. The SPI calculated in this program is based on representing the historical precipitation record with a gamma distribution. Positive SPI values represent wet conditions; the higher the SPI, the more unusually wet a period is. Negative SPI values on the contrary represent dry conditions; and gives a converse of wet conditions.

Table 3: Standard Precipitation Index (SPI) Values

Range	Description
2.0+	Extremely Wet
1.5 to l.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 to less	Extremely Dry

Source: McKee et al (1993)

b) Frequency Analysis of Extreme Rainfall

Frequency analysis involves the estimation of rainfall depths for selected probabilities or return periods as required for management and planning purposes. The analysis involves collecting historical data over a sufficient number of years and subsequently estimating the Probability of Exceedance (Px), Return period (T_X), and an Estimate of extreme rainfall.

1) **Probability of Exceedance (Px):**

The probability of exceedance/Occurrence refers to the probability of the occurrence of a rainfall depth greater than some given value rainfall depths (Xp). The probability of exceedance (Px) is expressed as a fraction (on a scale ranging from zero to one) or as a percentage chance with a scale ranging from 0 to 100 percent. It is the probability that has been determined as assigned to each of the rainfall depths. If the data are ranked in descending order, the highest value first and the lowest value last, the probability is an estimate of the probability that the corresponding rainfall depth will be exceeded. When data are ranked from the lowest to the highest value, probability refers to the probability of non-exceedance. According to RAES and Leuven (2004), the probabilities of exceedance can be estimated by any one of the several methods listed to include Hazen (1930), Weibull (1939), Sevruk, and Geiger (1981), and the Gringorten methods (WMO 1983) amongst others. The first three methods are adopted for this work and are presented in Table 4.

Table 4: Methods for Estimating Probabilities of Exceedance

Method	Estimate of probability of exceedance or non-exceedance (%)
California (California State Department, 1923)	$\frac{r}{n}$ 100
Hazen (Hazen,1930)	$\frac{r-0.5}{n}$ 100
Weibull (Weibull, 1939)	$\frac{n+1}{r}$ 100
P_x = probability of exceedance/Occurrence r = the rank number n = number of observations	

Adopted from RAES and Leuven (2004)

2) **Computation of Return Period (TX)**

The return period (also called the recurrence interval) T_X is the period expressed in number of years in which the annual observation is expected to return. It is the reciprocal value of the probability (P_x) when expressed as a fraction (Equation 12) or as presented in table 5.

$$T_x = \frac{1}{P_x} * 100 \qquad (12)$$

Table 5: Methods for Estimating Return Period (T_X) In Years

Method	Return Period (T_x) In Years
California (California State Department, 1923)	$\frac{n}{r}$
Hazen (Hazen, 1930)	$\frac{n}{r-0.5}$
Weibull (Weibul, 1939)	$\frac{n+1}{r}$

Adopted from RAES and Leuven (2004)

3) **Estimates of Extreme Rainfall**

Extreme Rainfall/Peak Runoff frequency analysis is a form of risk analysis used to extrapolate the return periods of rainfall beyond records. It is based on recorded past events which can supply useful predictions of future probabilities and risks. To estimate peak flow in 2, 5, 10, 20, 50, and 100 years return periods. The Log-Pearson Type III distribution as recommended for flood frequency analysis, according to the U.S. Water Advisory Committee on Water Data (1982) was adopted for this work. It is a statistical technique for fitting frequency distribution data to predict the return period for rainfall depths which can invariably be employed to model runoffs for the study catchment.

3. Results and Discussion

3.1. Rainfall Data Homogeneity Test

Homogeneity analysis carried out on the annual precipitation data for the Delimi Catchment employed two tests namely Pettitt's and Buishand's test. The tests were carried out at a 0.05 level of significance. The two tests showed our data sets to be homogeneous, as the computed p-value is greater than that of the significance level alpha at 0.05, therefore, we cannot reject the null hypothesis H_0. But accept it.

Table 6: Data for Homogeneity Test

Variable	Observations	Obs. With Missing Data	Obs. Without Missing Data	Minimum	Maximum	Mean	Std. Deviation
Rainfall Depth	40	0	40	1019.1	1731.7	1353.21	193.395

Summary statistics:

Pettitt's test		Buishand's test			
K	96	Q	4.385	R	7.641
t	1988	t	1988		
p-value (Two-tailed)	0.861	p-value (Two-tailed)	0.861	p-value (Two-tailed)	< 0.0001
alpha	0.05	alpha	0.05	alpha	0.05

Test interpretation:

H_0: Data are homogeneous

H_a: There is a date at which there is a change in the data

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H_0.

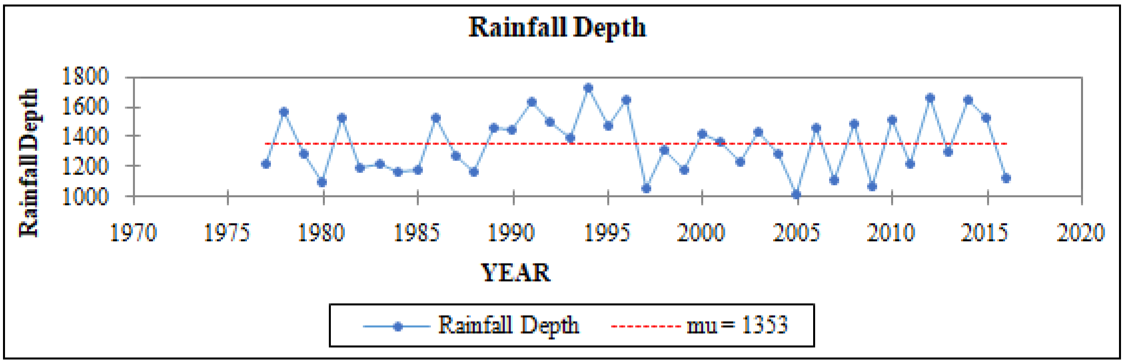

Figure 2: Rainfall Trend

3.2. Rainfall Amount and Distribution

Assembled rainfall data for the period was summarized by averaging on monthly basis and for the period of study. The result in figure 3andtable 6,showsa forty-year average rainfall amount of 1353.21 mm for the catchment. The significant rainfall months were identified to be from March to October (8 months), and traces of rainfall are noticed from November to April (4 months). The rainfall pattern gradually peaks from March to July and dips from August to October.July 2012 had the highest depth rainfall with 680.1mm and July 2002 recorded the least with 132.5mm. In addition, Figure 2 reveal's a rainfall trend that is a rise and fall in yearly rainfall amounts. Table 7 shows the first five highest rainfall years to be1994 (1731.7 mm), 2012 (1659.3mm), 2014 (1650.8mm), 1996 (1648.4 mm), and 1991 (1633.25). Figures 3 and 4 corroborate the single maxima rainfall characterization for the climatic zone thatthe study area is situated. However, the catchment gainsadvantages of excess rainfalls over its adjourning areas due to its relief. These excesses of rainfall amounts, coupled with the nature of soils, rocky terrains and anthropogenic influences could lead to excess runoffs and subsequent floods in the area.

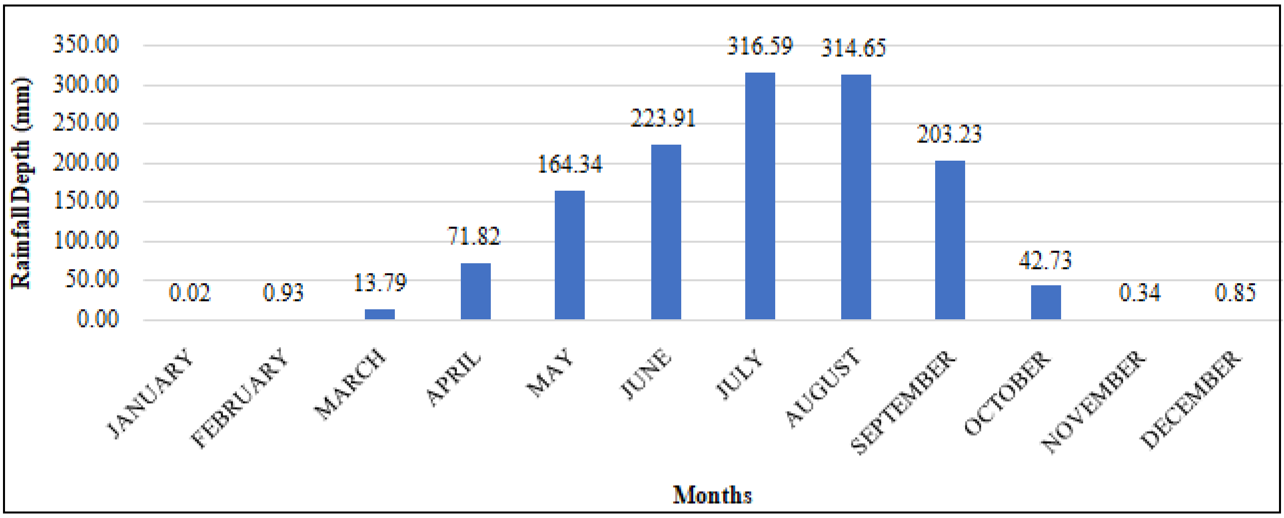

Figure 3: Average Rainfall Distribution for the Study Catchment (1977-2016)
Source: Researcher's Analysis (2018)

Table 7: Summary of Rainfall data according to months and year

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	0	0	0.8	1.7	183	161.8	371.8	248.9	202.6	42.5	0	0	1213.10
1978	0	0	15.8	147	173.6	226	334	386.1	193.7	93.7	0	0	1569.90
1979	0	0	10.2	95.9	126.6	207.6	337.5	337.6	156.5	10.7	4.4	0	1287.00
1980	0	0.6	30	10.6	209.1	161.3	280	285.6	66.4	51.2	0	0	1094.80
1981	0	0	0	80.8	242.3	203.9	295.3	363.1	294.4	49	0	0	1528.80
1982	0	3.8	1.5	90.2	169.3	192	303.7	292.4	130	11.8	0	0	1194.70
1983	0	0	10.3	0.2	168.6	232.9	307.2	332.3	160.3	0	0	0	1211.80
1984	0	0	41	105.2	153.5	187.5	276.2	230.9	144.4	31.9	0	0	1170.60
1985	0	0	65.2	1	138.1	108.9	353.4	299.5	203.4	4.4	0	0	1173.90
1986	0	3.1	0	109.3	166.1	239.7	438	275.05	252.4	38.2	0	0	1521.85
1987	0	0	53.2	10.8	29.6	205.4	273.7	467.4	99.3	127.4	0	0	1266.80
1988	0	0.9	17.8	70.6	156.7	225.77	225.95	231.05	229.8	9.4	0	0	1167.97
1989	0	0	2.1	156.1	177	243.2	232.6	403.3	196.1	47.3	0	0	1457.70
1990	0	0	0	32.3	327.7	205.4	304.6	283.11	238.3	59.9	0	0	1451.31

1991	0	0	39.6	49.4	217	333.9	490.25	359	123.6	20.5	0	0	1633.25
1992	0	0	44.5	91.9	202.8	215.7	389.1	307.3	214.2	33.4	4.1	0	1503.00
1993	0	0	0	108.3	147.5	304.75	264.8	352	194.4	18.9	0	0	1390.65
1994	0	0	0	97.2	196.4	305.1	413.8	239.5	320.2	159.5	0	0	1731.70
1995	0	0	0	92.2	165.8	284.2	231.7	467.7	207.8	19.5	0	0	1468.90
1996	0	0	1.1	18.2	270.2	280.7	371.1	473.8	189.7	43.6	0	0	1648.40
1997	0.9	0	30	124.8	204.9	187.55	208	114.5	92.8	92.8	4.4	0	1060.65
1998	0	0	0	58.4	172.8	162.1	276.5	352	210.9	80.7	0	0	1313.40
1999	0	0	45.6	17.5	94.9	251	292.6	135.8	239.3	103.7	0	0	1180.40
2000	0	0	9.6	48.18	113.1	211.4	411	410	204.1	17.3	0	0	1424.68
2001	0	0	0	137	178.5	310.2	273	432.3	30.4	0	0	0	1361.40
2002	0	0	16.7	119.1	80.9	271.5	132.5	309.2	230.8	65.6	0	0	1226.30
2003	0	0	0	41.4	143.1	205.1	306.8	481.2	242.6	13.4	0.8	0	1434.40
2004	0	0	22.9	65.3	180.7	221.1	368.8	235.8	191	4.4	0	0	1290.00
2005	0	6.9	0	67	76.9	239.9	192.2	229.3	150.7	56.2	0	0	1019.10
2006	0	0	0	44.1	208.3	197.6	260.4	405.7	291.7	55.7	0	0	1463.50
2007	0	0	2.1	81.3	92	251.2	276.8	269.2	133.5	0.2	0	0	1106.30
2008	0	0	8.5	38.2	92.5	258.6	513.5	368.1	172.4	1	0	33.9	1486.70
2009	0	0	0	65.4	149.3	131.9	133.2	346.9	247.9	0	0	0	1074.60
2010	0	0	62	58.7	92.7	206.6	307.5	289.4	317.5	185.6	0	0	1520.00
2011	0	0	0.1	124.5	122	172.6	324.5	228	240.6	2.8	0	0	1215.10
2012	0	0	0	28.4	223	239	680.1	219.3	235.3	34.2	0	0	1659.30
2013	0	0	0	163	124.8	170	228.1	349.9	236.6	26.6	0	0	1299.00
2014	0	1.8	2.1	172.5	331.6	312.5	281.2	188.4	304.4	56.3	0	0	1650.80
2015	0	20	6.9	3.4	141.8	192.9	380.3	383	360.6	39.7	0	0	1528.60
2016	0	0	12.1	45.9	129	238	322	202.4	178.6	0	0	0	1128.00
Sum	0.9	37.1	551.7	2872.98	6573.7	8956.47	12663.7	12586.01	8129.2	1709	13.7	33.9	54128.36
Aver	0.02	0.93	13.79	71.82	164.34	223.91	316.59	314.65	203.23	42.73	0.34	0.85	1353.21

Table 7: Return Period for Ranked Annual Rainfall Estimated with Various Methods

S/ N.	Year	Rainfall Depth	Rank Number (r)	Probability (P)	Return Period (Tx = 1/Px) *100		
					Hazen	Welbul	Califonia
1	1994	1731.7	1	0.03	80.00	41.00	40.00
2	2012	1659.3	2	0.05	26.67	20.50	20.00
3	2014	1650.8	3	0.08	16.00	13.67	13.33
4	1996	1648.4	4	0.10	11.43	10.25	10.00
5	1991	1633.25	5	0.13	8.89	8.20	8.00
6	1978	1569.9	6	0.15	7.27	6.83	6.67
7	1981	1528.8	7	0.18	6.15	5.86	5.71
8	2015	1528.6	8	0.20	5.33	5.13	5.00
9	1986	1521.85	9	0.23	4.71	4.56	4.44
10	2010	1520	10	0.25	4.21	4.10	4.00
11	1992	1503	11	0.28	3.81	3.73	3.64
12	2008	1486.7	12	0.30	3.48	3.42	3.33
13	1995	1468.9	13	0.33	3.20	3.15	3.08
14	2006	1463.5	14	0.35	2.96	2.93	2.86
15	1989	1457.7	15	0.38	2.76	2.73	2.67
16	1990	1451.31	16	0.40	2.58	2.56	2.50
17	2003	1434.4	17	0.43	2.42	2.41	2.35
18	2000	1424.68	18	0.45	2.29	2.28	2.22
19	1993	1390.65	19	0.48	2.16	2.16	2.11
20	2001	1361.4	20	0.50	2.05	2.05	2.00
21	1998	1313.4	21	0.53	1.95	1.95	1.90
22	2013	1299	22	0.55	1.86	1.86	1.82
23	2004	1290	23	0.58	1.78	1.78	1.74
24	1979	1287	24	0.60	1.70	1.71	1.67
25	1987	1266.8	25	0.63	1.63	1.64	1.60
26	2002	1226.3	26	0.65	1.57	1.58	1.54
27	2011	1215.1	27	0.68	1.51	1.52	1.48
28	1977	1213.1	28	0.70	1.45	1.46	1.43
29	1983	1211.8	29	0.73	1.40	1.41	1.38
30	1982	1194.7	30	0.75	1.36	1.37	1.33
31	1999	1180.4	31	0.78	1.31	1.32	1.29
32	1985	1173.9	32	0.80	1.27	1.28	1.25
33	1984	1170.6	33	0.83	1.23	1.24	1.21
34	1988	1167.97	34	0.85	1.19	1.21	1.18
35	2016	1128	35	0.88	1.16	1.17	1.14
36	2007	1106.3	36	0.90	1.13	1.14	1.11
37	1980	1094.8	37	0.93	1.10	1.11	1.08
38	2009	1074.6	38	0.95	1.07	1.08	1.05
39	1997	1060.65	39	0.98	1.04	1.05	1.03
40	2005	1019.1	40	1.00	1.01	1.03	1.00

Researcher's Analysis (2018)

3.3. Frequency of Number of Heavy Rainfall Days

According to Ologunorisa(2006), the need to analyze the frequency of the number of heavy daily rainfall is important for understanding flood generating mechanisms. Daily rainfall equal to or greater than 24.00mm from 1977 to 2016 was analyzed and results are shown in figure 4. This revealed that the frequency of heavy daily rainfall is highest in June, July, August, and September. July's highest record was 171 occurrences followed immediately by August with 164 occurrences then June and September with 108 and 102 counts respectively. This gives ample indication of months that are possible flood months. It also gives a good description of the antecedent weather condition in the catchment. Frequent heavy rainfalls predispose a catchment to flood especially when other causative factors are in place.

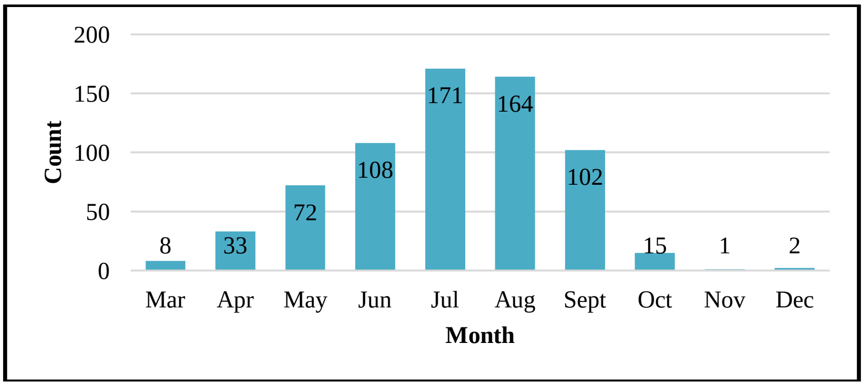

Figure 4: Frequency of Heavy Daily Rainfall (≥ 24mm) (1977 – 2016)

3.4. Distribution of Rainfall Excess

The distribution patterns for rainfall excess over individual monthly means show a 40 to 50% excess occurrence. For example, in June; the average rainfall value through the studyperiod was 223.91mm.19 year of the 40 years studied (1991, 2014, 2001, 1994, 1993, 1995, 1996, 2002, 2008, 2007, 1999, 1989, 2005, 1986, 2012, 2016, 1983, 1978, 1988) had rainfall values in excess of June average. In July, 16 years (2012, 2008, 1991, 1986, 1994, 2000, 1992, 2015, 1977, 1996, 2004, 1985, 1979, 1978, 2011, and 2016) had values greater than the July meanof 316.59mm.Similarly, across the months of August, 19 years (2003, 1996, 1995, 1987, 2001, 2000, 2006, 1989, 1978, 2015, 2008, 1981, 1991, 1993, 1998, 2013, 2009, 1979, and 1983) had rainfall in excess of august314.65mm average. And finally, September had a total of 21 years with rainfall excess of its 203.23mm average. These are displayed in figure 5.

Additionally, the monthly distribution of rainfall depth for peak rainy months June to September as displayed in Figure 4, revealed the highest rainfall values in June to be 333.9mm in 1991 and the least values for the same month to be 108.9 in 1985. July values show an all high of 680.1mm of rainfall for 2012 and the least rainfall of 132.5 in 2002; August highest value was 481.2mm in 2003 and least of 114.5mm in 1997 finally, September rains had the highest in 2015 with 360.6mm of rain and an all-time low of 30.4mm in 2001. This rainfall distribution pattern may be the first prove to support the assertion that the first 10 rainfall excess years (1994, 2012, 2014, 1996, 1991, 1978, 1981, 2015, 1986, and 2010) may be grave flood years.

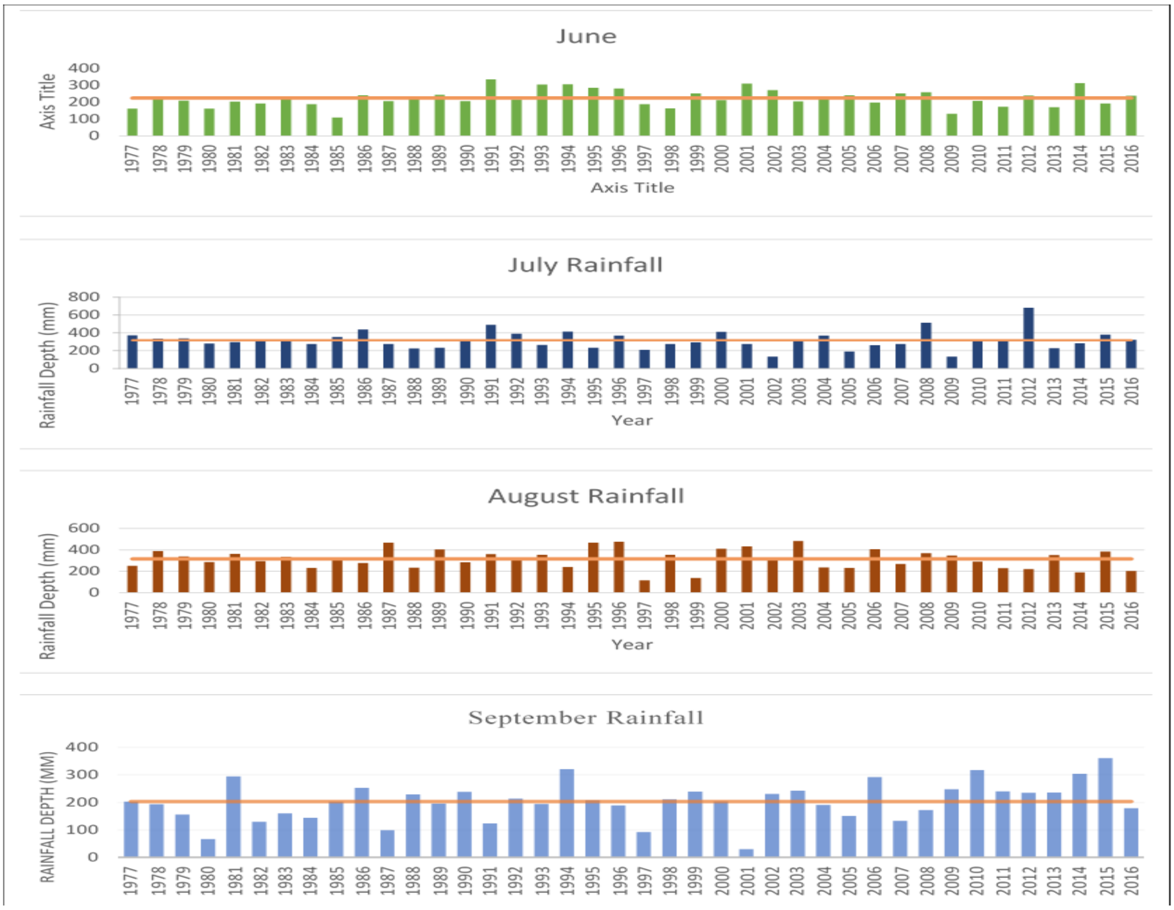

Figure 5: Rainfall Depths Distribution by Year for floodable Month

Researcher's Analysis (2018)

3.5. Magnitude and Frequency Analysis of Extreme Rainfall

The monthly peak rainfall for floodable months June – September (Figure 4) for the study years were employed in basin extreme rainfall magnitude and frequency analysis. Ologunorisa (2006), maintained that major attention should be given to the estimation of magnitude/frequency relationships of rainfall to floods since floods within the tropics are primarily due to intense and prolonged rainfall. From these relationships, the corresponding runoffs can be calculated by various methods.Thus, the need to estimate the Standard Precipitation Index (SPI), Probability of Exceedance (Px), and Extreme Rainfall Return Period (Tx).

3.6. Results of Standard Precipitation Index (SPI)

A 12-month SPI which is a comparison of the precipitation for 12 consecutive months with the same 12 consecutive months during all the previous years of available data, was adopted. The SPI results showeda steady but upward trend in precipitation patternsfrom 1977 to 2016.This indicates an increase in wetness over the years, from a -1.83 SPI in 1977 to 1.69 SPI in 2016. It is worthy of note that Positive SPI values represent wet conditions; the higher the SPI, the more unusually wet a period is. On the contrary, negative SPI values represent dry conditions, and the lower the SPI, the more unusually dry a period is. Further analysis of the SPI values to generate a frequency table of SPI for the study area(Table 8) revealed a 22.55 cumulative percentage frequency of Very Wet and Moderately Wet SPI values. SPIs of long-time scales are said to be tied to stream flows, reservoir levels, and even groundwater level recharge (NDR 2018). The implication of this is that certain processes such as the rate at which shallow wells, small ponds, and smaller rivers become drier or wetter have longer time scales, typically several months (for example, 6 to 9 months). Some other processes have much longer time scales, such as the rate at which major reservoirs, or aquifers, or large natural bodies of water rise and fall, and the time scale of these variations are on the order of several years.

Table 8: Monthly Rainfall SPI Frequency Distribution for a 12month Series (1977-2016)

SPI Description	Range	Frequency	Percentage	Cumulative %
Very Wet	1.5 to 1.99	36	7.52	7.52
Moderately Wet	1.0 to 1.49	72	15.03	22.55
Nearly Normal	-0.99 to 0.99	192	40.08	62.63
No Data	99	11	2.30	64.93
Moderately Dry	-1.00 to -1.49	96	20.04	84.97
Severely Dry	-1.5 to -1.99	72	15.03	100.00
Grand Total		479	100.00	

Researcher's Analysis (2018)

3.7. Results of Probability of Exceedance (Px)

The result of the Probability of Exceedance (Px) calculated from three methods (Hazen, Welbul, and California methods) are presented in table 9. The yearly rainfall data for the forty years wereranked in descending order (the highest value first and the lowest value last). This gives the probability that the corresponding rainfall depth will be exceeded. According to RAES and Leuven (2004) and FAO (Smith, 1992), the Probability of Exceedance (Px) can be used to determine dry, normal, and humid weather conditions based on the following rules.

- The weather condition in a period is called ***dry*** if the rainfall received during that period will be exceeded 4 out of 5 years, i.e., having a probability of exceedance of 80%;
- The rainfall in a period is ***normal*** if the rainfall received during that period will be exceeded in 1 out of 2 years. The probability of exceedance is equal to 50%;
- The weather condition in a period is called ***humid*** if the rainfall received during that period is exceeded 1 out of 5 years, i.e., having a probability of exceedance of 20%.

From calculations of the probability of exceedance, eight different years - 1978, 1981, 1991, 1994, 1996, 2012, 2014, and 2015 had less than 20% probability (i.e. 1 in every 5years will receive rainfall that exceed the 2015 value). These eight years are considered as having weather conditions called humid which is indicative of excess rainfalls and probable flood years. A graph of annual rainfall versus its probability of exceedance (estimated with the three formulas) on a normal probability paper is displayed in Figure6. Since the data in the probability plot fall in a reasonable alignment, it may be assumed that the annual total rainfall in the Delimi catchment is normally distributed.

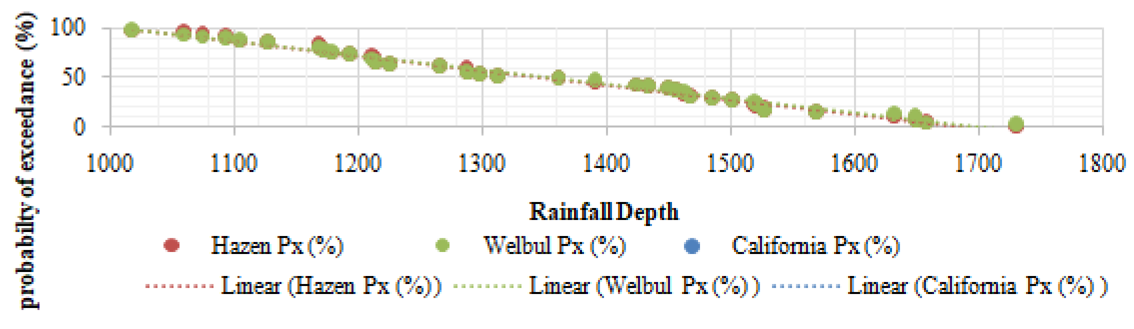

Figure 6: Probability Plot of the Total Annual Rainfall for the Delimi River Catchment

Researcher's Analysis (2018)

Table 9: The Estimate of the Probabilities of Exceedance of Ranked Annual Rainfall

S/N.	Year	Rainfall Depth	Rank Number (r)	Probability of Exceedance Px (%)		
				Hazen	Welbul	California
1	1994	1731.7	1	1.25	2.44	2.50
2	2012	1659.3	2	3.75	4.88	5.00
3	2014	1650.8	3	6.25	7.32	7.50
4	1996	1648.4	4	8.75	9.76	10.00
5	1991	1633.25	5	11.25	12.20	12.50
6	1978	1569.9	6	13.75	14.63	15.00
7	1981	1528.8	7	16.25	17.07	17.50
8	2015	1528.6	8	18.75	19.51	20.00
9	1986	1521.85	9	21.25	21.95	22.50
10	2010	1520	10	23.75	24.39	25.00
11	1992	1503	11	26.25	26.83	27.50
12	2008	1486.7	12	28.75	29.27	30.00
13	1995	1468.9	13	31.25	31.71	32.50
14	2006	1463.5	14	33.75	34.15	35.00
15	1989	1457.7	15	36.25	36.59	37.50
16	1990	1451.31	16	38.75	39.02	40.00
17	2003	1434.4	17	41.25	41.46	42.50
18	2000	1424.68	18	43.75	43.90	45.00
19	1993	1390.65	19	46.25	46.34	47.50
20	2001	1361.4	20	48.75	48.78	50.00
21	1998	1313.4	21	51.25	51.22	52.50
22	2013	1299	22	53.75	53.66	55.00
23	2004	1290	23	56.25	56.10	57.50
24	1979	1287	24	58.75	58.54	60.00
25	1987	1266.8	25	61.25	60.98	62.50
26	2002	1226.3	26	63.75	63.41	65.00
27	2011	1215.1	27	66.25	65.85	67.50
28	1977	1213.1	28	68.75	68.29	70.00
29	1983	1211.8	29	71.25	70.73	72.50
30	1982	1194.7	30	73.75	73.17	75.00
31	1999	1180.4	31	76.25	75.61	77.50
32	1985	1173.9	32	78.75	78.05	80.00
33	1984	1170.6	33	81.25	80.49	82.50
34	1988	1167.97	34	83.75	82.93	85.00
35	2016	1128	35	86.25	85.37	87.50
36	2007	1106.3	36	88.75	87.80	90.00
37	1980	1094.8	37	91.25	90.24	92.50
38	2009	1074.6	38	93.75	92.68	95.00
39	1997	1060.65	39	96.25	95.12	97.50
40	2005	1019.1	40	98.75	97.56	100.00
	SUM	54,128.36				
	AVE	1353.209				

Researcher's Analysis (2018)

3.8. Results of Return Period (Tx) analysis

The return period (also called the recurrence interval) Tx, is the period expressed in the number of years in which each observation is expected to return. Table10 presents the return period for ranked annual rainfall estimated using the Hazen, Welbul, and Califonia methods. The Welbul and Califonia method gave similar Tx of between 5years to 40 years for rainfall values for years 1978, 1981, 1991, 1994, 1996, 2012, 2014, and 2015 with corresponding depths of 1528.6, 1528.8, 1569.9, 1633.25, 1648.4, 1650.8, 1659.3 and 1731.7mm respectively. These years, therefore, present the years of extreme rainfall depth for the catchment and possible years of floods.

4. Conclusion

An understanding of the characterization and distribution of rainfall in the DelimiBasin is of importance to provide descriptiveand quantitative information for planning and management of agriculture, existing water resources, and floods in the catchment. The average rainfall amount for the study period in the catchment is 1353.21 mm. Rainfall months were identified to be from March to October (8 months), with four months having the highest amounts and the highest frequency of daily heavy rainfall (June, July, August, and September in this order). And magnitude frequency analysis revealed that rainfall excess years to 1994, 2012, 2014, 1996, 1991, 1978, 1981, 2015, 1986, and 2010. This rainfall excess years distribution patterns may be the first prove to support the assertionthat excess rainfall years are probable grave flood years.

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