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ASSESSMENT OF TEMPORAL VARIATION OF RAINFALL IN ADAMAWA CATCHMENT FOR PRELIMINARY FLOOD VULNERABILITY INVESTIGATION

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ABSTRACT

Heavy rainfall induced by current climate changes is one of the causes of the flooding. This study investigates the temporal variation of rainfall in Adamawa catchment. Rainfall data were acquired and analyzed based on Harshfield method to compute the Probable Maximum Precipitation (PMP). Furthermore, Gumbel analysis was employed to determine probability of occurrence of precipitation and generation of frequency curve; and the design flood for different recurrence interval were predicted. Rainfall Intensity Duration Frequency (RIDF) revealed that rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. *Regression model developed for each return period showed that the correlation coefficient for each equation is above 0.82 which indicates a strong relationship in RIDF equations. PMP results revealed 353.596 mm with a flood frequency factor of 2.9129. The 1% flood observed is 343.45mm. Isohyets showing the spatial pattern of rainfall were produced. It revealed that, the east and west regions of the catchment experienced the highest rainfall. The spatial variability of rainfall show that mean annual rainfall is low at the central part. The monthly rainfall pattern in the region show that a total of 62% of the annual rainfall falls between July and September. The highest and lowest average monthly rainfall is 188.1mm in August and 6.4mm in March respectively. Monthly rainfall in most of the months is less than 200mm. The monthly pattern show that rainfall only rose above 1600mm in July. The study conclude that the pattern of rainfall in the catchment varies in spatial and temporal dimension due to modification of rainfall events resulting from changing climate.*

Key words: Adamawa catchment, flood frequency, Isohyets, Rainfall, RIDF

1.0 Introduction

Rainfall when in excess in an area leads to flooding, which usually exposes the people to different risk. Excessive rainfall coupled with climate change are significance contribution to flood and inundation. Kolawole *et al*. (2011) opined that floods destroy produce and caused massive loss of lives and properties thereby posing the risk of hunger to those engaged in farming activities. Flooding has been on the increase in many region of the world since 1997 in Bangladesh, china (1998), Ecuador (1997) Mozambique (1997), USA (1993) Poland

(2000), Czech Republic (2001), and Nigeria (2012) among others (Drogue *et al.*, 2004). In the past decade, thousands of people were displaced from flooding across Africa (Huq *et al.*, 2007). Huq *et al.* (2007) reported cases of heavy rains in East Africa in 2002 that brought floods and mudslides, and forced tens of thousands to leave their homes in Rwanda, Kenya, Burundi, Tanzania, and Uganda. In Nigeria, the occurrence of flooding is becoming more alarming particularly in the Upper Benue region (Nwilo *et al*., 2012). According to Nwilo *et al*. (2012), the environment is characterized by existence of extensive flat, green field which have led to intensification of agriculture and rapid urbanization. Flooding in the ecosystem has several profound negative consequences ranging from loss of properties, disruption of human activities to loss of lives as well as spread of several diseases such as cholera and typhoid (Nkeki *et al*., 2013; Nwilo *et al*., 2012; NEMA, 2010; Galtima and Bashir, 2002). A study conducted by Olayinka (2013) stated that, the 2012 floods in Nigeria started as flash flooding in different parts of the country since the onset of the rainy season in April and suddenly became intensive by late August, with unprecedented flooding in most states. The study identified heavy rainfall due to changing climate as a major cause of the floods. This has necessitated the need for detailed information regarding space and time of rainfall distribution. Almazroui *et al*. (2012) opined that any change in climate produces modifications in extreme weather events, such as heavy rainfall, heat and cold waves, in addition to prolonged drought occurrences. This assertion was corroborated by NOAA (2007) who noted that changes in climate can result to conditions which are warmer or colder, wetter or drier, stormier or more quiescent. Changes in earth's climate may be due to persistent anthropogenic changes in the composition of the atmosphere or in land use (Bruno *et al.*, 2018; Pokhrel *et al.*, 2018; Bates, 2008).

Rainfall has gained its importance as a valuable alternative or supplementary water resource over the years giving its multiple uses (Logah *et al*., 2013). For instance, in the design water of structures, rainfall information is utilized. The pattern of rainfall in spatial and temporal dimensions can be studied using different approaches including; mean monthly, mean annual, Probable Maximum Precipitation, Intensity-Duration-Frequency (IDF), and Principal Component Analysis (PCA) (Kueh and Kuok, 2016; Torgersen *et al*., 2015; Eum and Simonovic, 2012; Satyanarayana and Srinivas, 2011). Rainfall statistics are used to plan flood protection structures and many other civil engineering structures involving hydrologic flows (Vanitha and Ravikumar, 2018, 2017; Prodanovic and Simonovic, 2007; McCuen, 1998). El-Sayed (2011) posited that IDF relationship is a useful tools for accessing the flood risk, among others in water resources engineering. The IDF is a mathematical equation representing the relationship between maximum rainfall intensity as a dependable variable, the rainfall duration and the return period as independent variable (Antigha and Ogarekpe, 2013).

Rainfall intensity is the time rate of precipitation, that is, depth per unit time (mm/hr or in/hr) (Mah *et al*., 2018; Kuehler *et al*., 2017; Wilson and Wieczorek, 1995). Intensity analysis process involves estimation of short duration rainfall which gives insight on the correlation between observed and reduced maximum 24hr rainfall and the development of Intensity Duration Frequency Curve (IDF) which relates rainfall intensity, duration, and frequency (or return period) (Innocenti *et al*., 2017; Koutsoyiannis and Papalexiou, 2017; De Paola *et al*., 2015). The most common method of determining the design flood event is using IDF curves. The importance of developing IDF curves for a location or region for engineering application was highlighted by Logan *et al*. (2013) as follows: (i) it helps to predict when a location or a region will be flooded; (ii) it helps to pinpoint when a certain rainfall rate or a specific volume of flow will recur in a location or region in the future; and (iii) it helps in the estimation of maximum flood (or design discharge) for flood control structures. Rainfall is the primary source of water for flood generation over the land surface (Karamage *et al*., 2018; Dimri *et al*., 2016; Wulf *et al*., 2016; Schneider *et al*., 2014; Freeze, 1972). Studies have shown that climatic factors associated with the characteristics of precipitation affects maximum flood (Kingston and Taylor 2010; Black, 1972). Examples of such climatic factors includes type of precipitation, rainfall intensity, rainfall duration, and rainfall distribution. Of all the factors, rainfall intensity has a dominating effect on discharge yield (Bookhagen and Burbank, 2010; Hewlett *et al*., 1977; Freeze, 1972).

Existing works in literature on flooding and related field identified three factors (heavy rainfall, extreme increase in river discharge and release of excess water from Lagdo dam) as the main causes of flooding in the Benue River basin of Nigeria (Adzandeh *et al*., 2019; Olayinka *et al*., 2013; Nwilo *et al*., 2012). Since heavy rainfall induced by current climate changes is pinpointed as contributor to the seasonal flood problem in the investigated area, this study is aimed at assessing the temporal variation of rainfall in the Adamawa Catchment located in the Upper Benue River basin, in view of providing necessary information for developing an appropriate flood control strategy in the Catchment.

2.0 Data and Methods

This present study was conducted in Adamawa catchment, along river Benue in the Upper Benue drainage basin of Nigeria. The land area coverage is about 6,685km^2. The site occupies large amount of lowlands/floodplain in Adamawa State (Nwilo *et al*., 2019). The relief is nearly level to gentle undulating plain with few outcrops. The study area border is approximately defined by longitudes 11^o 46'E and 14^o 14'E and latitudes 8^o 37' N and 9^o 41'N (Nwilo *et al*., 2019) as shown in Figure 1. Adamawa is a tropical region. The area is characterized by two seasons: wet or rainy season (from May to October) and dryness (from November to April) (Nwilo *et al*., 2019). Yearly rainfall averages 900 to 1,500mm (Adzandeh *et al*., 2019). Jamala and Oke (2013) noted that the Harmattan season is very dry and as a result, humidity may be as low as 10-20%. Temperature in the region can be as high as 40^0C and as low as 18^0C (Nwilo *et al*., 2019). The major rock components of the catchment under study are colluvium deposits over granitic materials; old alluvium; recent alluvium; sandstones, mudstones and shales; and undifferentiated basement complex. Generally, there are three geological zones in Adamawa State corresponding to three structural types which in turn correspond to three associated rock types namely, the Basement complex rocks, the oldest known rock-types and are areas of uplift which consist of igneous and metamorphic rocks other than volcanic; sedimentary rocks, corresponding to areas of sedimentation, i.e. the Benue trough lying wholly within the Basement complex rocks; and volcanic rocks which are isolated volcanic areas along the Benue trough and the Cameroun Volcanic line to the east and north- eastern parts of the State (Adzandeh *et al*., 2019; Ashafa, 2009). The soil types found in the area include clay loamy, loamy sandy, sandy clay, and sandy loam (Adzandeh *et al*., 2020).

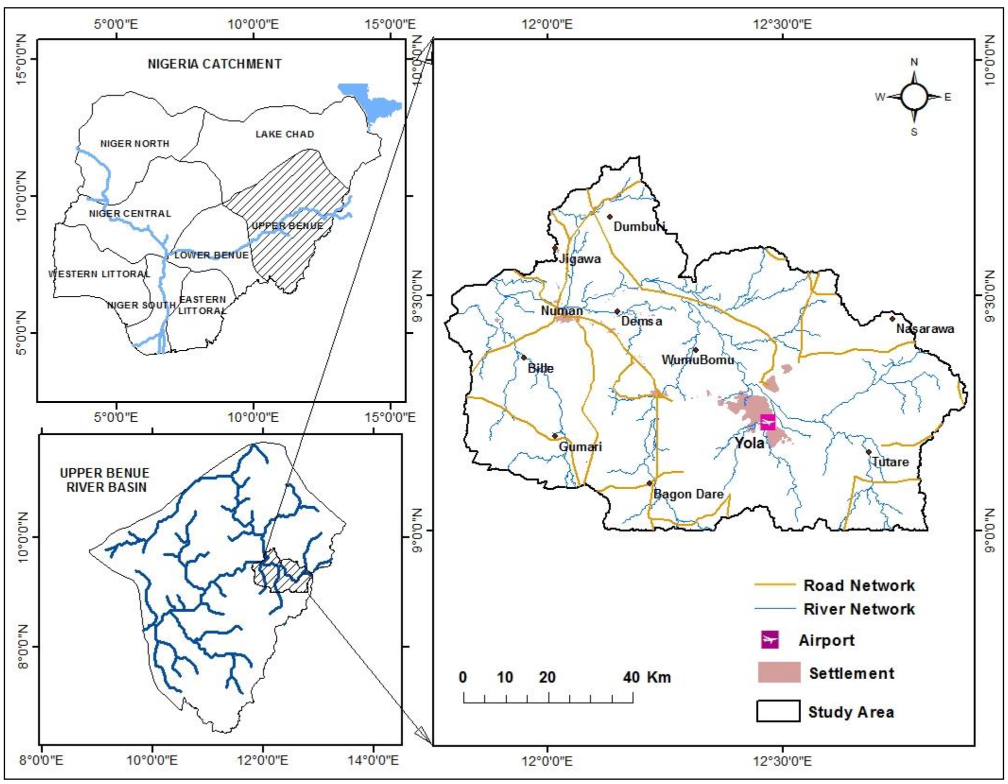

Figure 1: Study area location (Nwilo *et al*., 2019)

2.1 Rainfall analysis in the study catchment

The operations required collecting and analyzing datasets from different sources. The specific datasets and their sources are shown in Table 1. The datasets included data downloads from websites such as World-wide agro climate database (FAOCLIM2, 2018); Institutions/Agencies such as Upper Benue River Basin Development Authority (UBRBDA, 2019), and Nigeria Meteorological Agency (NiMET, 2019).

Table 1: Data used and sources of data

S/N	Data	Period	Sources
1	Total rainfall: mean monthly and mean annual	1978 to 2018	World-wide agro climate database, Food and Agriculture Organisation of the United Nation. www.fao.org/land-water/database-and-software/faoclim. Pluviometric stations data.
2	Annual rainfall	1960 to 2019	Upper Benue River Basin Development Authority (UBRBDA), Yola. Jimeta Bridge Station, Adamawa State.
3	Average monthly precipitation data and annual	1979 to 2019	Nigeria Meteorological Agency (NiMET). NiMET office, Yola Airport Authority, Adamawa State
4	Annual runoff	1960 to 2019	Upper Benue River Basin Development Authority (UBRBDA), Yola. Jimeta Bridge Station, Adamawa State.

2.1.1 Preliminary assessment rainfall and runoff datasets of the catchment

Preliminary investigation was carried out using the mean monthly precipitation distributions obtained from NiMET, Yola Airport and annual rainfall/runoff datasets acquired from the UBRBDA, Jimeta. Simple percentages was used to analyse the monthly NiMET time series data and the results were graphed in MS-Excel. Annual runoff and rainfall series were used to analyze trend. The datasets were plotted in Matrix Laboratory software (MATLAB 2015a) and MS-Excel environment to show pattern over time.

2.1.2 Spatial analysis of mean monthly and mean annual rainfall variability

Variations of mean monthly and mean annual rainfall distributions for 40 years were investigated using total rainfall data acquired from World-wide agro climatic database. FAOCLIM 2 software was used in extracting the rainfall information and coordinates of each of the World-wide agro climatic data. The extracted data was edited in MS-Excel. The Excel sheet was saved in CSV delimited format and added in ArcGIS 10.4 software environment. Interpolation was carried out using the Spatial Analyst extension tools. The Kriging geostatistical interpolation procedure was used to generate Isohyet representing precipitation and smoothed maps in ArcGIS 10.4.

2.1.3 Probable Maximum Precipitation (PMP) Calculation

PMP is a characteristic of rainfall at a particular location that can be used in designing water impounding structures. It is used to estimate design flood. In literature, PMP is estimated using either meteorological method or the Harshfield technique which is statistical (Singh *et al*., 2018; Fernando and Wickramasuriya, 2007). The meteorological method requires more site-specific data. The Harshfield method is adopted for the calculation of PMP in this study. Annual maximum rainfall series for the required storm durations was utilized. The technique of estimating PMP is defined as shown in Equations (1) and (2) (Wangwongwiroj and Khemngoen, 2019; Afzali-Gorouh *et al*., 2018; Casas-Castillo *et al*., 2018):

$$PMP = X_n + k_m S_n \quad (1)$$

$$K_m = \frac{X_M - \ddot{X}_{n-1}}{S_{n-1}} \quad (2)$$

where $X_M, \ddot{X}_n$, and S_n are the highest value, the mean, and the standard deviation, respectively, for a series of n annual maximum rainfall values of a given duration, $\ddot{X}_{n-1}$, and S_{n-1} are, respectively the mean and standard deviation for this series excluding the highest value for this series, and K_m is a frequency factor. Hydrologic frequency factor, K_m, is used to compare and relate results and attach probabilities to several sets of maximum rainfall data. It is a primarily function of the recurrence interval for a particular probability distribution. PMP was determined in this study based on annual maximum rainfall series (1960 to 2019) of the study area. The time series data was used and all the parameters in equations 1 and 2 were defined for the computation of PMP and frequency factor of the region respectively. The frequency factor was calculated using equation (2); where 226.8055556 and 38.75578441 are, respectively the mean and standard deviation for this series excluding the highest value for this series, and 339.7 is the highest value. Substituting the values in Equation (2), K_m will be given as:

$$K_m = \frac{339.7 - 226.8055556}{38.75578441} = 2.9129$$

2.1.4 Flood magnitude (probability of occurrence) prediction

Statistical analysis of precipitation data was conducted to characterize the behaviour of rainfall in the study area. Precipitation information spanning from 1979 to 2019 obtained from NiMET at Yola was used in this study. Gumbel method (Farooq *et al*., 2018; Elsebaie, 2012; Viessman *et al.*, 1989) was adopted as statistical approach to compute the probability of occurrence for the record. This method was chosen because it is widely used in literature (Farooq *et al*., 2018; Elsebaie, 2012). The method requires the following steps (Farooq *et al*., 2018; Elsebaie, 2012; Viessman *et al.*, 1989);

Step 1: sort precipitation records from lowest to highest

Step 2: computing the probability of not-being exceeded using equation (3) provided by Weibull (1939) as follows.

.

$$P = Exceedance\ probability\ (\%) = \frac{m}{n+1}\ \ (percent) \quad (3)$$

where, *n* is the number of records and *m* is the rank value assigned to the records, starting with a value for the lowest record and until a value n (= number of records) for the highest one.

Step 2: compute the return period (R) which in this case is given by equation (4) as follows.

$$R = \frac{1}{1-p} \quad (4)$$

Step 3: compute the position (*Y*). This is given by equation (5).

$$Y = -\ln(-\ln(P)) \quad (5)$$

Step 4: compute the probability of occurrence. This is achieved by using the Gumbel method defined in Equation 6 (Viessman *et al.,* 1989):

$$P_r = e^{-e-Y} \quad (6)$$

where P_r is the probability of occurrence and $e = 2.718$

The resulting output of the process are equation for the computation of return periods and predicted flood magnitude.

2.1.5 Rainfall intensity estimation

Rainfall intensity was estimated in this study using annual maximum series. The intensity analysis process involves break down annual maximum rainfall values into short duration rainfall estimate, defining frequency precipitation with specific return period, and development of flood frequency curves (IDF). Details of the process are provided in sections 2.1.5.1 and 2.1.5.2.

2.1.5.1 Estimation of short duration rainfall:

In order to break down annual maximum rainfall values into short duration rainfall estimate (like 0.16-hr, 0.25-hr, 0.5hr, 1-hr, 2-hr, 3-hr, 5-hr, 6-hr 12-hr and 24-hr rainfall values), the Indian Meteorological Department (IMD) empirical reduction formula (Chowdhury *et al*., 2007), shown in Equation 7 was used;

$$P_t = P_{24}\left(\frac{t}{24}\right)^{1/3} \quad (7)$$

where P_t is the required rainfall depth in mm at t-hr duration, P_{24} is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in hour (Rashid *et al*., 2012).

2.1.5.2 Intensity Duration Frequency Curve (IDF)

In many hydrological design projects the first step is to determine the maximum rainfall event. This event is hypothetical, and is usually said to be the design storm event. The most common method of determining the design storm event is using IDF curves. The importance of developing IDF curves for a location or region for engineering application was highlighted by Logan *et al*. (2013) as follows: (i) it helps to predict when a location or a region will be flooded; (ii) it helps to pinpoint when a certain rainfall rate or a specific volume of flow will recur in a location or region in the future and (iii) it helps in the estimation of design discharge for flood control structures. Mathematically, the IDF relation can be presented as a function of the return period and the duration of rainfall provided in Equation (8).

$$i = f(T, d) \quad (8)$$

where i is the rainfall intensity, T is the return period and d is the rainfall duration (hr). The average intensity (*I*) is commonly used and can be expressed in Equation (9) as (Sule and Ige, 2016):

$$I = \frac{P}{t} \quad (9)$$

Where P is the rainfall depth (mm or in) and t is the duration, usually in hours.
The most widely used distribution in literature for IDF analysis owing to its suitability for modelling maxima is the Gumbel theory of distribution (Elsebaie, 2012). According to Elsebaie (2012), Gumbel method calculates the 2, 5, 10, 25, 50 and 100-year return intervals for each duration period. Frequency precipitation P_T (in mm) for each duration with a specified return period T (in year) is given in Equation (10) as (Elsebaie, 2012):

$$P_T = P_{ave} + KS \quad (10)$$

where the Gumbel frequency factor (*K*), the arithmetic average of the maximum precipitation corresponding to a specific duration (P_{ave}) and the standard deviation of P data (*S*) are respectively given by Equations (11, 12, and 13) (Elsebaie, 2012):

$$K = -\frac{\sqrt{6}}{\pi}\left(0.5772 + ln\left(ln\left(\frac{T}{T-1}\right)\right)\right) \quad (11)$$

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (12)$$

Where $P_i =$ the individual extreme value of rainfall, and n is the number of events or year of record.

$$S = \left(\frac{1}{n-1}\left(\sum_{i=1}^{n} P_I - P_{ave}\right)^2\right)^{1/2} \quad (13)$$

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The frequency factor (K), which is a function of the return period and sample size, when multiplied by the standard deviation gives the departure of a desired return period rainfall from the average. Then the rainfall intensity, I (in mm/h) for return period T is calculated using Equation (10). The formulae were applied by substituting the rainfall values into the equations as required and results were returned at each stage. Excel software was used to plot the IDF curve and generate the rainfall IDF empirical equation and their correlation coefficient for Adamawa catchment. The rainfall intensity estimation procedure is summarized in Figure 2.

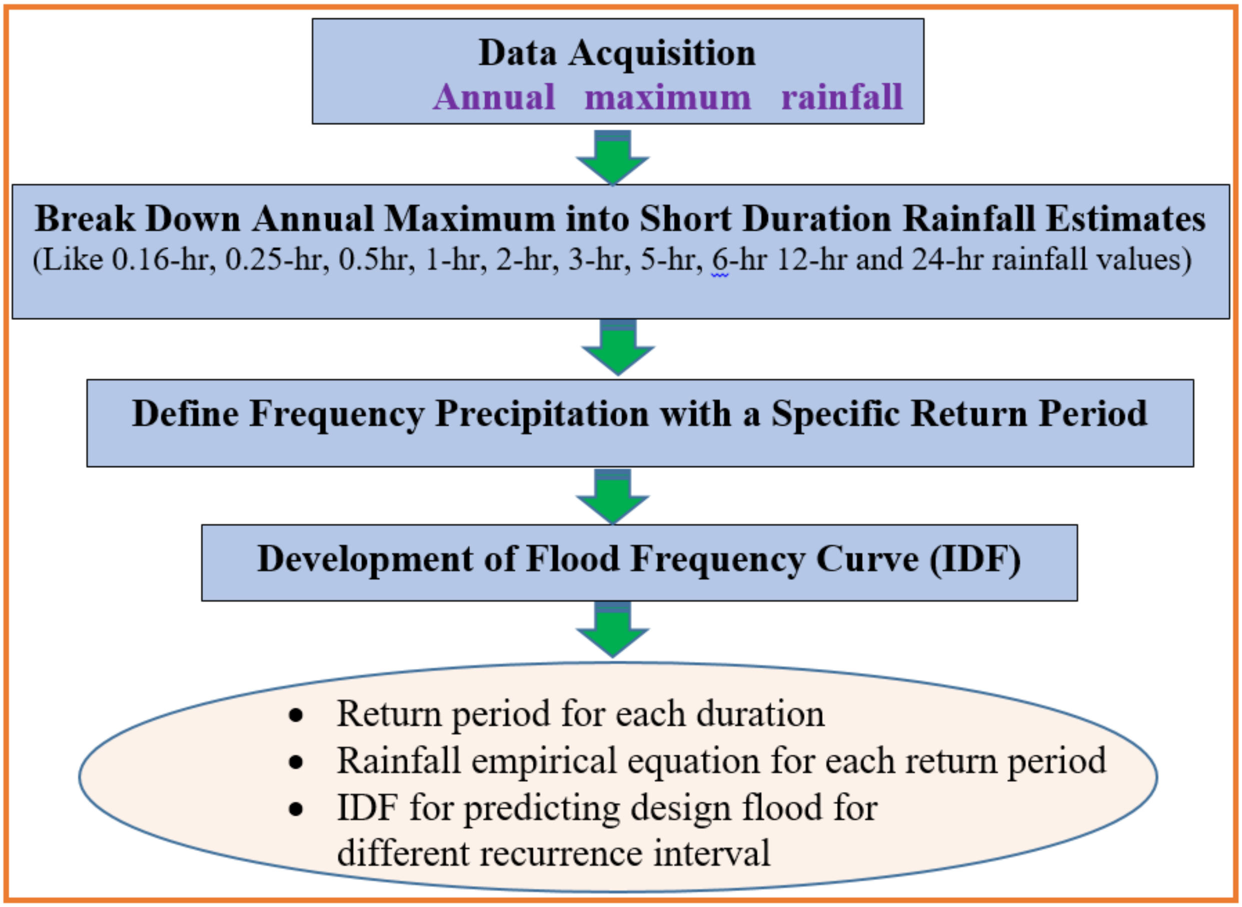

Figure 2: General method for rainfall intensity estimation

3.0 Results and discussion

3.1 Rainfall variations

The variations of mean monthly rainfall distributions in Adamawa catchment were investigated using NiMET station in Yola Airport as a representative. A total of 62% of the annual rainfall in this region falls between July and September as shown in Figure 3. The highest and lowest average monthly rainfall at the Yola station is 188.1mm in August and 6.4mm in March respectively. The monthly rainfall pattern is displayed in Figure 4. From the results no rain was observed in January, February, November and December. Monthly rainfall in most of the months is less than 200mm. The monthly pattern show that rainfall only rose above 1600mm in July.

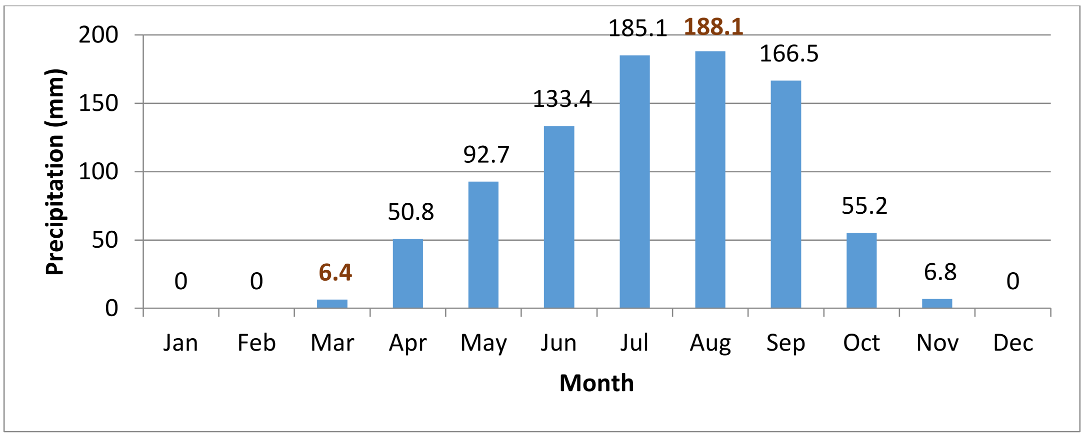

Figure 3: Average monthly precipitation from Yola meteorological station

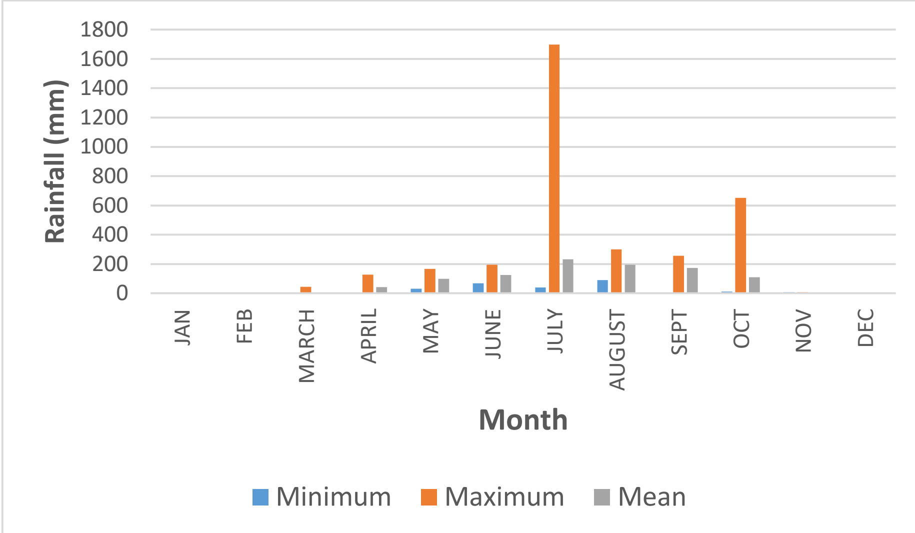

Figure 4: Monthly rainfall pattern

Figure 5 show the annual rainfall amount using the annual maximum rainfall data sourced from Upper Benue River Basin Development Authority (UBRBDA) spanning from 1960 to 2019. The annual rainfall has exceeded 1000mm at least 13 times in 59 years. Average annual rainfall was 929.8mm. Based on the average annual rainfall figure, the largest amount of the rainfall was recorded in 1963 (1356.0mm) and 2016 (1260.1mm). Runoff trend graph is presented in Figure 6. The highest (35,281m^3) and lowest (8,152m^3) runoff values were recorded in 1969 and 1987 respectively. The basin has an average runoff of 20,285m^3.

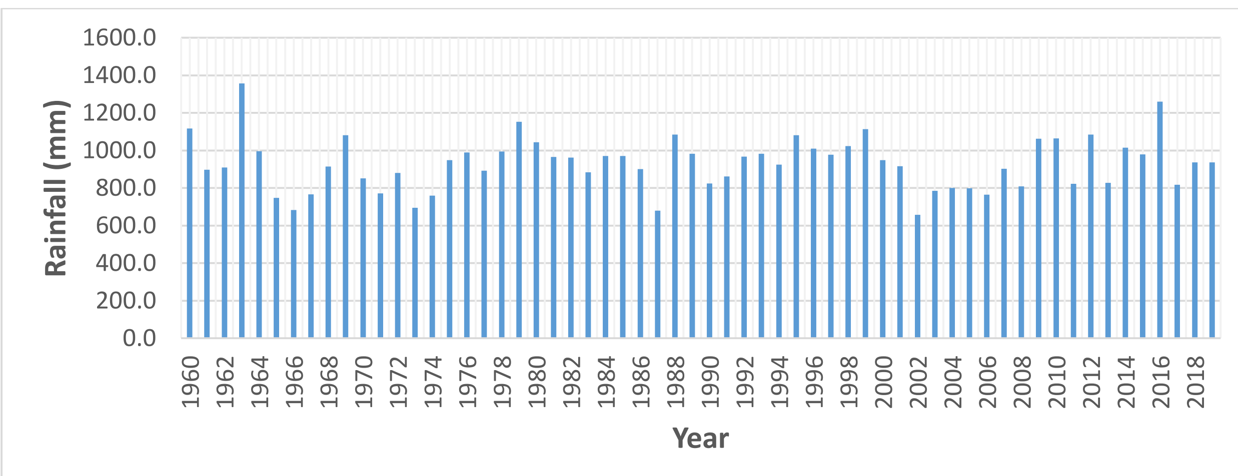

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Figure 5: Annual rainfall amount

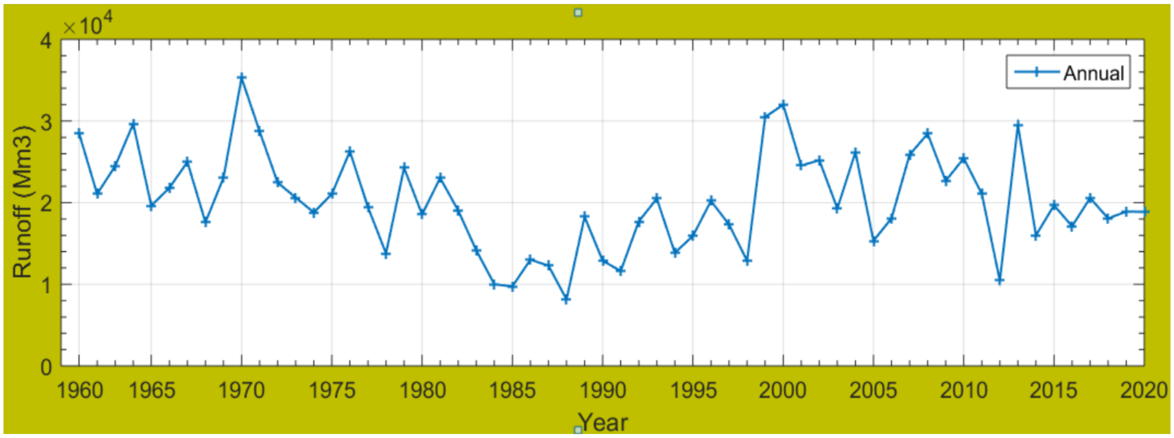

Figure 6: Annual runoff pattern in the region

Furthermore, from the Kriging geostatistical interpolation procedure engaged in this study, rainfall mean monthly and mean annual maps are presented in Figures 7 and 8. The results show that, the east and west regions of the study area experience the highest rainfall. As it is observed from Figure 8, the spatial variability of rainfall in the catchment shows that the mean annual rainfall is low at the central part.

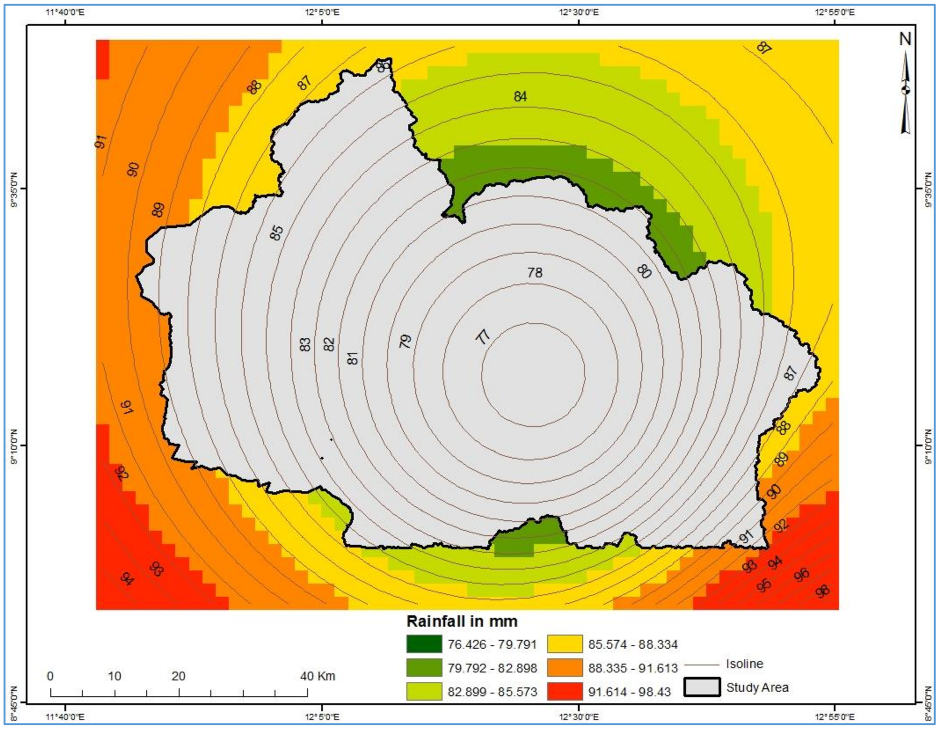

Figure 7: Isohyet representing precipitation - mean monthly rainfall

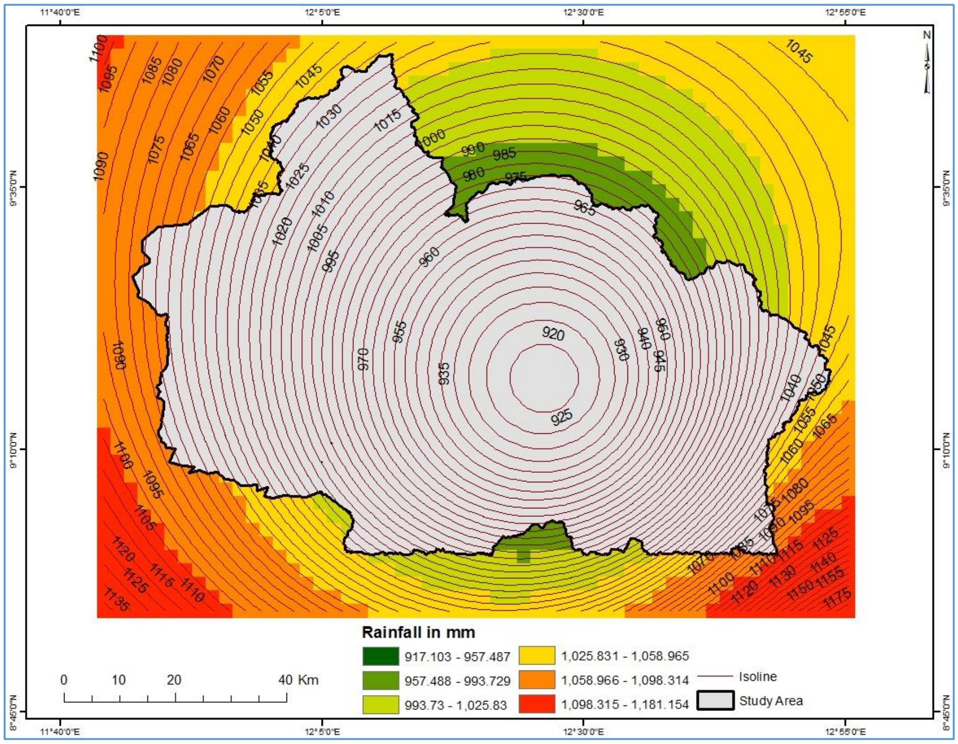

Figure 8: Isohyet representing precipitation - mean annual rainfall

3.2 Probable Maximum Precipitation

Results of Probable Maximum Precipitation computed using 59 years record from the Upper Benue River Basin Development Authority, Jimeta revealed 353.596 mm or 35.36cm with a flood frequency factor of 2.9129 using mean (X_n = 229.85), and standard deviation (S_n = 42.48237243), as presented below.

$$PMP = 229.85 + (2.9129 * 42.48237243) = 353.596\text{mm or } 35.36\text{cm}$$

This result shows that 35.36cm is the physical upper limit to the amount of precipitation that can occur within the Adamawa Catchment in a given period. That is, it is the greatest amount of rainfall that is physically possible within the Adamawa Catchment for a given duration as measured within the catchment area. Even in a scenario where the rainfall value/intensity approaches the PMP, it would produce a flood with no risk of being exceeded. Also, this computed PMP, along with its spatial and temporal distribution serves as a key parameter for computing the Probable Maximum Flood (PMF) in other studies which is a conceptual flood event with applications in the safe design of hydrological structures.

3.3 Probability of occurrence of precipitation

From the analysis of probability of occurrence of precipitation conducted, graph of precipitation against plotting position was generated as depicted in Figure 9.

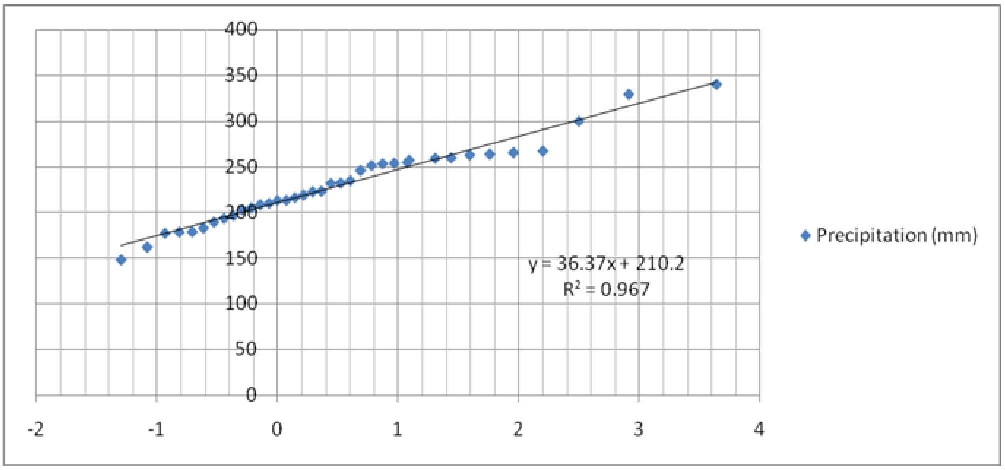

Figure 9: Precipitation (mm) Vs. Plotting Position Y.

Precipitation records and computed recurrence interval were employed to produce the required frequency curve. Frequency curve is a graph that plots precipitation in mm versus recurrence interval in years. Frequency curve (Figure 10) was used in this study to predict the design flood for x = 2-years, 5-years, 10-years, 25-years, 50-years, 100-years and 200-year recurrence interval.in the basin. Equation 14 was generated for the computation of return periods, where y is flood magnitude and x is the predicted years. Results show that the 1% flood (100-years) is 343.45mm. Details are presented in Table 2.

$$y = 68.4\ln(x) + 28.455 \quad (14)$$

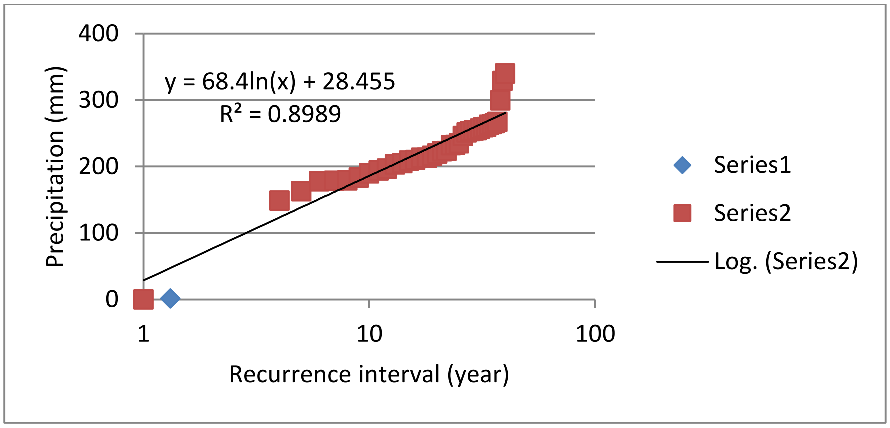

Figure 10: Precipitation versus recurrence interval

Table 2: Design flood for different return periods

Return Period (years)	Design flood (mm)
2	75.86
5	138.54
10	185.95
25	248.62
50	296.04
100	343.45
200	390.86

3.4 Rainfall intensity duration relationship

Rainfall intensity was estimated using annual maximum series. The intensity analysis process involves estimation of short duration rainfall which give insight on the correlation between observed and reduced maximum 24hr rainfall and the development of Intensity Duration Frequency Curve (IDF) which relate rainfall intensity, duration, and frequency (or return period). From the raw data, the maximum precipitation (P) and the statistical variables (average and standard deviation) for each duration (10, 20, 30, 60, 120, 180, 360, 720, 1440 minutes) were computed. Table 3 show the computed frequency precipitation (P_T) values and intensities (I_T) for different durations and seven (7) return periods following the methodology described in Section three (Sub-section 2.1.4). Figure 11 show the IDF curve produced.

Table 3: Frequency precipitation values and intensities for different durations and return periods

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Computed Precipitation (P_T) and Intensity (I_T) Gumbel method

T (year)	10 minutes			15 minutes			30 minutes		
	P_{ave} = 174.992		S = 26.538	P_{ave} = 203.060		S = 30.795	P_{ave} = 255.840		S = 38.799
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.164	170.639	1066.499	-0.164	198.010	792.040	- 0.164	249.476	498.953
5	0.719	194.072	776.291	0.719	225.202	900.808	0.719	283.737	567.474
10	1.305	209.624	1310.151	1.305	243.247	972.991	1.305	306.473	612.947
25	2.044	229.235	916.943	2.044	266.005	1064.021	2.044	335.146	670.293
50	2.592	243.778	1523.616	2.592	282.881	1131.524	2.592	356.408	712.817
100	3.137	258.241	1032.967	3.137	299.664	1198.657	3.137	377.554	755.109
200	3.678	272.598	1703.742	3.678	316.324	1265.297	3.678	398.545	797.090
	60 minutes			120 minutes			180 minutes		
	P_{ave} =322.338		S = 48.884	P_{ave} = 406.120		S = 61.057	P_{ave} = 464.892		S = 69.893
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.164	314.321	314.321	-0.164	396.107	198.053	- 0.164	453.429	151.143
5	0.719	357.485	357.485	0.719	450.020	225.010	0.719	515.145	171.715
10	1.305	386.131	386.131	1.305	485.800	242.900	1.305	556.102	185.367
25	2.044	422.257	422.257	2.044	530.921	265.460	2.044	607.754	202.584
50	2.592	449.045	449.045	2.592	564.380	282.190	2.592	646.055	215.351
100	3.137	475.687	475.687	3.137	597.656	298.828	3.137	684.147	228.049
200	3.678	502.133	502.133	3.678	630.688	315.344	3.678	721.959	240.653
	360 minutes			720 minutes			1440 minutes		
	P_{ave} = 585.727		S = 88.060	P_{ave} = 737.970		S = 110.948	P_{ave} = 929.784		S = 141.007
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.164	571.285	95.214	-0.164	719.776	59.981	- 0.164	906.659	37.777
5	0.719	649.042	108.173	0.719	817.736	68.144	0.719	1031.168	42.965
10	1.305	700.645	116.774	1.305	882.747	73.562	1.305	1113.799	46.408
25	2.044	765.722	127.620	2.044	964.731	80.394	2.044	1218.003	50.750
50	2.592	813.979	135.663	2.592	1025.526	85.460	2.592	1295.275	53.969
100	3.137	861.971	143.661	3.137	1085.989	90.499	3.137	1372.125	57.171
200	3.678	909.612	151.602	3.678	1146.007	95.500	3.678	1448.410	60.350

The curves allow the engineer to design safe and economical flood control measures. The IDF curves revealed that, rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. Rainfall intensities rise in parallel with the rainfall return periods. Empirical equations and their correlation coefficient for different return period are shown in Table 4. The correlation coefficient for each equation is above 0.82 which indicates a strong relationship in IDF equations.

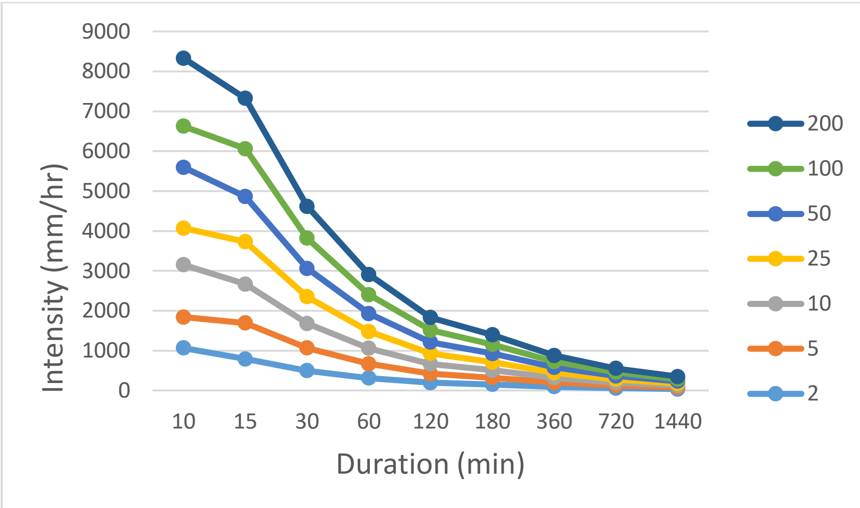

Figure 11: Rainfall IDF curve for the studied catchment

Table 4: Rainfall IDF empirical equation and their correlation coefficient for Adamawa catchment

Return Period (yr)	Equation	Correlation coefficient, R
2	$Y = 1828.8X^{-1.516}$	0.9001
5	$Y = 1591.6X^{-1.363}$	0.8263
10	$Y = 2247.2X^{-1.516}$	0.9002
25	$Y = 1880.3X^{-1.363}$	0.8264
50	$Y = 2613.7X^{-1.517}$	0.9003
100	$Y = 2118.5X^{-1.364}$	0.8265
200	$Y = 2923X^{-1.517}$	0.9004

4.0 Conclusion

This study has provided information on the behaviour of rainfall necessary to provide guidance for development of flood control strategy in Adamawa Catchment, Nigeria. The study assessed the mean monthly and annual variations, compute the Probable Maximum Precipitation (PMP), and the probability of occurrence of precipitation as well as generated Rainfall Intensity Duration Frequency (RIDF) curves. Harshfield approach, Gumbel analysis and Geostatistical techniques have thus been applied. The monthly rainfall pattern in the region show that more than half of the total annual rainfall falls between July and September. The highest and lowest average monthly rainfall were recorded in August and March respectively. Most of the months experienced less than 200mm monthly rainfall. The monthly pattern show that rainfall only rose above 1600mm in July. Isohyets showing the pattern of rainfall revealed that, the east and west regions of the catchment experienced the highest rainfall. The spatial variability of rainfall show that mean annual rainfall is low at the central part. RIDF revealed that rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. Regression model results for each return period show that the correlation coefficient for each equation is above 0.82 which indicates a strong relationship in RIDF equations. It can be noted that the PMP estimate (35.36cm) resulting from Hershfield approach is the greatest amount of rainfall that is physically possible within the Adamawa Catchment for a given duration as measured within the catchment area. Even in a scenario where the rainfall value/intensity approaches the PMP, it would produce a flood with no risk of being exceeded. Also, this computed PMP, along with its spatial and temporal distribution serves as a key parameter for computing the Probable Maximum Flood (PMF) in other studies which is a conceptual flood event with applications in the safe design of hydrological structures. Due to current climate change and expected modification in rainfall events, future work should update the information focusing on space and time of rainfall characteristics using other methods like Principal Component Analysis. Future work should also investigate the spatial and temporal distribution of PMP in Adamawa Catchment and compute the PMF in the area. In addition, there is need for further study to compare PMP value(s) and previous flood records capturing mean maximum flow and water level of River Benue in Adamawa Catchment.

References

Adeboye, O.B., and Alatis, M.O., (2007). Performance of probability distributions and plotting positions in estimating the flood of River Osun at Apoje Sub-basin, Nigeria. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript LW 07 007, Vol. IX. Pp 1-20.

Adzandeh, A.E., Nwilo, P.C., and Olayinka, D.N., (2020). Application of Particle Swarm Optimization based Fuzzy AHP for Evaluating and Selecting Suitable Flood Management Reservoir Locations in Adamawa Catchment, Nigeria. *Journal of Engineering Research.* JER-25, No. 1 (SP), 116-138.

Adzandeh**,** A.E**.,** Nwilo, P.C., and Olayinka, D.N., (2019). Application of Particle Swam Optimization based Fuzzy AHP and Fuzzy Extent Analysis Method for evaluating and selecting suitable flood management reservoir locations in Adamawa catchment, Nigeria. *Technical Proceedings for the Faculty of Engineering International Conference (FEIC2019)* on Managing the Environment for Tomorrow at the University of Lagos, Akoka.

Afzali-Gorouh, Z., Bakhtiari, B., and Qaderi, K., (2018). Probable maximum precipitation estimation in a humid climate. *Natural Hazards and Earth System Sciences*, *18*(11), 3109-3119.

Almazroui, M., Islam, M.N., Athar, H., Jones, P.D., Rahman, M.A., (2012). Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. *International Journal of Climatology*, 32, 953–966.

Antigha, R.E., and Ogarekpe, N.M., (2013). Development of Intensity Duration Frequency Curves for Calabar Metropolis, South-South, Nigeria. *The International Journal of Engineering and Science*, Vol. 2(3), 39-42.

Ashafa, T., (2009). Mineral Resources of Adamawa State: Nepad. Adamawa.

Bates, B.C., (2008). Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, pp: 210. Accessed: 08/10/2018. Available at: http://www.ipcc.ch/meetings/session28/doc13.pdf.

Bell F. C., (1969). Generalized rainfall-duration-frequency relationship. *ASCE J. Hydraulic Eng*., 95, 311–327.

Black, P.E., (1972). Hydrograph responses to geomorphic model watershed characteristics and precipitation variables. *Journal of hydrology*, *17*(4), 309-329.

Bookhagen, B., and Burbank, D.W., (2010). Toward a complete Himalayan hydrological budget: Spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge. *Journal of Geophysical Research: Earth Surface*, *115*(F3), 1-25.

Bruno, J. F., Bates, A. E., Cacciapaglia, C., Pike, E. P., Amstrup, S. C., van Hooidonk, R., ... and Aronson, R. B. (2018). Climate change threatens the world's marine protected areas. *Nature Climate Change*, *8*(6), 499.

Casas, M.C., Rodrıguez, R., Nieto, R., and Redano, A., (2008). Trends and Directions in Climate Research. *Ann. N.Y. Acad. Sci*. 1146: 291–302. doi: 10.1196/annals.1446.003

Casas-Castillo, M. C., Rodríguez-Solà, R., Navarro, X., Russo, B., Lastra, A., González, P., and Redaño, A. (2018). On the consideration of scaling properties of extreme rainfall in Madrid (Spain) for developing a generalized intensity-duration-frequency equation and assessing probable maximum precipitation estimates. *Theoretical and applied climatology*, *131*(1-2), 573-580.

Chen C. L., (1983). .Rainfall intensity-duration-frequency formulas. *ASCE J. Hydraulic Eng*., 109, 1603–1621.

Chow, V.T. (1951). A general formula for hydrologic frequency analysis. *Trans. Am. Geophys. Union* **32:** 231–237.

Chowdhury, R., Alam, J.B., Das, P., and Alam M. A., (2007). "Short Duration Rainfall Estimation of Sylhet: IMD and USWB Method" *Journal of Indian Water Works Association*. pp. 285-292.

De Paola, F., Galdiero, E., Giugni, M., and Pugliese, F. (2015). Sustainable development of storm-water systems in African cities considering climate change. *Procedia Engineering*, *119*, 1181-1191.

Dimri, A. P., Thayyen, R. J., Kibler, K., Stanton, A., Jain, S. K., Tullos, D., and Singh, V. P., (2016). A review of atmospheric and land surface processes with emphasis on flood generation in the Southern Himalayan rivers. *Science of the Total Environment*, *556*, 98-115.

Drogue, G., Pfister, L., Leviandier, T., El Idrissi, A., Iffly, J.F., Matgen, P., Humbert, J., Hoffmann, L., (2004). Simulating the spatio-temporal variability of streamflow response to climate change scenarios in a meso scale basin. *Journal of Hydrology* 293, 255–269.

Elsebaie, I.H., (2012). Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia. *Journal of King Saud University – Engineering Sciences*. 24, 131–140. doi:10.1016/j.jksues.2011.06.001

El-Sayed, E.A., (2011) .Generation of Rainfall Intensity Duration Frequency Curves for Ungauged Sites., Nile Basin, *Water Science & Engineering Journal*, 4(1), 112-124.

Eum, H.I., and Simonovic, S.P., (2012). Assessment on variability of extreme climate events for the Upper Thames River basin in Canada. *Hydrological Processes*, *26*(4), 485-499.

FAOCLIM2 (2018). Total rainfall. World-wide agro climatic database. *Food and Agriculture Organisation of the United Nation*. Accessed: 28/12/2018. Retrieved from: www.fao.org/land-water/database-and-software/faoclim

Farooq, M., Shafique, M., and Khattak, M. S., (2018). Flood frequency analysis of river swat using Log Pearson type 3, Generalized Extreme Value, Normal, and Gumbel Max distribution methods. *Arabian Journal of Geosciences*, *11*(9), 216.

Fernando, W.C.D.K., and Wickramasuriya, S. S., (2007). Estimating Probable Maximum Precipitation -From Research to Design. *Engineer* - Vol. XXXX, No. 04, pp. 116-122.

Freeze, R.A., (1972). Role of subsurface flow in generating surface runoff: 2. Upstream source areas. *Water Resources Research*, *8*(5), 1272-1283.

Galtima, M., and Bashir, B.A., (2002). The impact of Floods on the Riverine Communities of the Lower Benue Reaches: The Experience in Adamawa Area. *Proceedings on the Expert Group Meeting on Pollution and Sediment Sources in the Nigerian Inland Waterways and Strategies for their Management. Lokoja, Nigeria* 23-24 October, 2002, p64-72.

Hewlett, J.D., Fortson, J.C., and Cunningham, G.B., (1977). The effect of rainfall intensity on storm flow and peak discharge from forest land. *Water Resources Research*, *13*(2), 259-266.

Huq, S., Kovats, S., Reid, H. and Satterthwaitte, D., (2007). Editorial: "Reducing Risks to Cities from Disasters and Climate Change", *Environment and Urbanization*, 19 (1): 3-15.

Innocenti, S., Mailhot, A., and Frigon, A., (2017). Simple Scaling of extreme precipitation in North America. *Hydrology and Earth System Sciences*, *21*(11), 5823-5846.

Jamala, G.Y., and Oke, D.O., (2013). Soil Profile characteristics as affected by Land use system in the Southeastern Adamawa State, Nigeria. *IOSR Journal of Agriculture and Veterinary Science.* ISSN: 2319-2380, Vol. 6, Issue 4, p04-11.

Karamage, F., Liu, Y., Fan, X., Francis Justine, M., Wu, G., Liu, Y., ... and Wang, R., (2018). Spatial relationship between precipitation and runoff in Africa. *Hydrology and Earth System Sciences Discussions*, 2018 (424), 1-27.

Kingston, D.G., and Taylor, R.G., (2010). Sources of uncertainty in climate change impacts on river discharge and groundwater in a headwater catchment of the Upper Nile Basin, Uganda. *Hydrology & Earth System Sciences*, *14*(7), 1297–1308.

Kolawole, O.M., Olayemi, A.B., and Ajayi, K.T., (2011). Managing Flood in Nigerian Cities: Risk Analysis and Adaptation Options – Ilorin City as a Case Study. Archives of Applied Science Research 3(1):17-24 Available online at www.scholarsresearchlibrary.com

Koutsoyiannis, D., Kozonis, D., and Manetas, A., (1998). A mathematical framework for studying rainfall intensity-duration-frequency relationships. *Journal of Hydrology*, 206(1-2), 118-135.

Koutsoyiannis, D., and Papalexiou, S. M. (2017). Extreme rainfall: Global perspective. *Handbook of Applied Hydrology; McGraw-Hill: New York, NY, USA*, 74-1.

Kueh, S. M., and Kuok, K.K., (2016). Precipitation downscaling using the artificial neural network BatNN and development of future rainfall intensity-duration-frequency curves. *Climate Research*, *68*(1), 73-89.

Kuehler, E., Hathaway, J., and Tirpak, A., (2017). Quantifying the benefits of urban forest systems as a component of the green infrastructure stormwater treatment network. *Ecohydrology*, *10*(3), e1813.

Logah, F.Y., Kankam-Yeboah, K., and Bekoe, E.O., (2013). Developing Short Duration Rainfall Intensity Frequency Curves for Accra in Ghana. *International Journal of Latest Research in Engineering and Computing* (IJLREC). Volume 1, Issue 1: Page No.67-73.

Mah, D. Y. S., Loh, S. L., Mannan, M. A., and Ibrahim, W.H.W., (2018). Modelling of Surface Permeation in Multiple-Orifice Permeable Road. *International Journal of Engineering & Technology*, *7*(3.18), 40-43.

McCuen, R., (1998). Hydrologic analysis and design. Prentice- Hall, Englewood Cliffs, N.J., Mirhosseini, G., Srivastava, P., Stefanova, L., 2013. The impact of climate change on rainfall Intensity–duration–frequency (IDF) curves in Alabama. *Reg Environ Change* 13(1), 25–33.

Meyer, W.B., (1995). Past and Present land use and land cover in the USA. *Consequences*, 1(1): 25-33.

NEMA, (2010). Adamawa flood. Nigeria Emergency Management Agency. Retrieved from: *Daily Trust, 2010.*

NFDP-II (2003). Environmental and Social Impact Assessment of the Second National FADAMA Development. *Federal Ministry of Agriculture and Rural Development, Project Coordination Unit*. E776, 1, 2728-2829.

Nhat, L., Tachikawa, Y., and Takara, T., (2006) Establishment of Intensity-Duration-Frequency Curves for Precipitation in the Monsoon Area of Vietnam", *Annuals of Disas. Prev.Res.Inst*., Kyoto Univ., No. 49 B.

NiMET, (2018). Rainfall data. Acessed 116/12/2018. Retrieved from: Nigerian Meteorological Agency (NiMET). NiMET office, Yola Airport Authority, Adamawa State.

Nkeki, F.N., Henah, P.J., and Ojeh, V.N., (2013). Geospatial techniques for the assessment and analysis of flood risk along Niger-Benue in Nigeria. *Journal of Geographic Information System.* 5, 123-135.

NOAA, (2007). Observing Climate Variability and Change. Accessed: 08/10/2018. Available at: http://www.oar.noaa.gov/climate/t_observing.html

Nwilo, P.C., Olayinka, D.N., and Adzandeh, E.A., (2012). Flood Modelling and Vulnerability Assessment of Settlements in the Adamawa State Floodplain using GIS and Cellular Framework Approach. *Global Journal of Human Social Science*. 12, (3), Version 1.0. ISSN: 2249-460X. Pp11-20.

Nwilo P.C., Olayinka N.D. and Adzandeh A.E., (2019). Analysis of Impact of Exposures and Hydrological Modelling of Flood Peak Zones in Adamawa Catchment, Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 3(2), pp. 256-267. https://doi.org/10.36263/nijest.2019.02.0148

Olayinka, D.N., Nwilo, P.C., and Adzandeh, E.A**.,** (2013). From Catchment to Reach: Predictive Modelling of Floods in Nigeria. TS06D-Hydrography in Practice**.** *Technical Proceedings for the International Federation of Surveyor* (FIG 2013) Annual conference on Surveying Disaster Management and Global Warming. 06-10th May, 2013 at the International Conference Centre, Abuja, Nigeria.

Pokhrel, Y., Burbano, M., Roush, J., Kang, H., Sridhar, V., and Hyndman, D. W. (2018). A review of the integrated effects of changing climate, land use, and dams on Mekong river hydrology. *Water*, *10*(3), 266.

Prodanovic, P., and Simonovic, S.P., (2007). Development of rainfall intensity duration frequency curves for the city of London under the changing climate. *Water Resour Res Report*, London.

Raiford J.P., Aziz, N.M., Khan, A.A., and Powell, D.N., (2007). Rainfall Depth-Duration-Frequency Relationships for South Carolina, North Carolina, and Georgia. *American Journal of Environmental Science* 3(2): 78-84.

Rashid, M.M., Faruque, S.B., and Alam, J.B., (2012). Modelling of short duration rainfall intensity duration frequency (SDRIDF) equation for Sylhet City in Bangladesh. *ARPN Journal of Science and Technology*, Vol. 2, No. 2, pp. 92-95, 2012.

Satyanarayana, P., and Srinivas, V.V., (2011). Regionalization of precipitation in data sparse areas using large scale atmospheric variables–A fuzzy clustering approach. *Journal of Hydrology*, *405*(3-4), 462-473.

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M., and Rudolf, B., (2014). GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. *Theoretical and Applied Climatology*, *115*(1-2), 15-40.

Singh, A., Singh, V.P., and Byrd, A.R., (2018). Computation of probable maximum precipitation and its uncertainty. *Int J Hydro*. Vol. 2, Issue 4, p504-514. DOI: 10.15406/ijh.2018.02.00118

Sule, B.F., and Ige, T., (2016). Synthesis of Isopluvial Maps for Nigeria Using IDF Equations Derived from Daily Rainfall Data. *Journal of Scientific and Engineering Research*, 3(3):505-514.

Torgersen, G., Bjerkholt, J.T., Kvaal, K., and Lindholm, O.G., (2015). Correlation between extreme rainfall and insurance claims due to urban flooding–case study Fredrikstad, Norway. *Journal of Urban and Environmental Engineering*, *9*(2), 127-138.

UBRBDA, (2018). Annual maximum rainfall records. Acessed 11/11/2018. Retrieved from: Upper Benue River Basin Development Authority (UBRBDA), Jimeta Bridge, Adamawa State.

UNWWD, (2006). Water: A Shared Responsibility. World Water Assessment Programme (WWAP). *UNESCO Division of Water Sciences*, Paris Cedex 15, France, United Nations World Water Development Report 2.

Vanitha, S., and Ravikumar, V., (2017). Construction of Intensity-Duration-Frequency Curves for Precipitation with Annual Maxima Data in Kumulur Region. *International Journal of Bio-resource and Stress Management.* 8(5):721-726. Doi: HTTPS://DOI.ORG/10.23910/IJBSM/2017.8.5.1823

Vanitha, S., and Ravikumar, V., (2018). Rainfall Intensity-Duration-Frequency relationship for Trichy and Kumulur. *Journal of Soil and Water Conservation*, *17*(4), 335-343.

Viessman, Jr. W., Lewis, G.L., and Knapp, J.W., (1989). Introduction to hydrology. *Harper and Raw Publishers*. Third edition.

Wangwongwiroj, N., and Khemngoen, C., (2019). Probable maximum precipitation in tropical zone (Thailand) as estimated by generalized method and statistical method. *International Journal of Climatology*, *39*(13), 4953-4966.

Weibull, W., (1939). A statistical theory of strength of materials. *Ing. Vet. A.K*, *Handl*., 151, Genelstabens Litografiska Anstals Forlg Stocklholm, Sweden.

Wilson, R.C., and Wieczorek, G.F., (1995). Rainfall thresholds for the initiation of debris flows at La Honda, California. *Environmental & Engineering Geoscience*, *1*(1), 11-27.

Wulf, H., Bookhagen, B., and Scherler, D., (2016). Differentiating between rain, snow, and glacier contributions to river discharge in the western Himalaya using remote-sensing data and distributed hydrological modeling. *Advances in Water Resources, 88,* 152-169.