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Development of Intensity Duration Frequency (IDF) Curves for Rainfall Prediction within the Middle Niger River Basin

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ABSTRACT

Rainfall Intensity-Duration-Frequency (IDF) relationship remains one of the mostly used tools in hydrology and water resources engineering, especially for planning, design and operations of water resource projects. IDF relationship can provide adequate information about the intensity of rainfall at different duration for various return periods. The focus of this research was to develop IDF curves for the prediction of rainfall intensity within the middle Niger River Basin (Lokoja and Ilorin) using annual maximum daily rainfall data. Forty (40) year's annual maximum rainfall data ranging from 1974 to 2013 was employed for the study. To ascertain the data quality, selected preliminary analysis technique including; descriptive statistics, test of homogeneity and outlier detection test were employed. To compute the three hours rainfall intensity, the ratio of rainfall amount and duration was used while the popular Gumbel probability distribution model was employed to calculate the rainfall frequency factor. To assess the best fit model that can be employed to predict rainfall intensity for various return periods at ungauged locations, four empirical IDF equations, namely; Talbot, Bernard, Kimijima and Sherman equations were employed. The model with the least calculated sum of minimized root mean square error (RMSE) was adopted as the best fit empirical model. Results obtained revealed that the Talbot model was the best fit model for Ilorin and Lokoja with calculated sum of minimized error of 1.32170E-07 and 8.953636E-08. This model was thereafter employed to predict the rainfall intensity for different durations at 2, 5, 10, 25, 50 and 100yrs return periods respectively.

Keywords: Rainfall intensity, Frequency factor, Gumbel probability distribution, Mean and standard deviation

1.0. Introduction

Knowledge of intense rainfall characteristics is a useful asset in Engineering application especially for dams dimensioning and design of hydraulic projects (Pruski *et al*., 2002). Data on intense rainfall characteristics is scarce in most parts of the world especially in the continent of Africa. Even in regions with satisfactory rainfall records, the available data are poor for immediate utilization. Thus, it is necessary to determine the intensity duration- frequency (I-D-F) relations of the intense rainfall (Cardoso *et al*., 2013). Historical rainfall event statistics (in terms of intensity, duration, and return period) are used to design flood protection structures, and many other civil engineering structures involving hydrologic flows (McCuen, 1998; Prodanovic and Simonovic, 2007). An intensity duration frequency curve is a mathematical model that expresses the relation between intensity, duration, and return period of precipitation. The engineering application of rainfall intensity is mainly in the estimation of design discharge for flood control structures (El-Sayed, 2011; Ugbong, 2000). Generation of intensity duration frequency curves for flood prediction within the Niger River Basin has become imperative owing to the recent devastations caused by flood in various parts within that zone; perhaps being due to the lack of rainfall data and the subsequent design of most drainage structures without appropriate rainfall intensity values (Antigha and Ogharekpe, 2013). Rainfall Intensity-Duration-Frequency (IDF) relationship is one among the numerous tools use in hydrology and water resources engineering since it can provide concise information between the maximum intensity of rain that falls within a given period of time. IDF curves are used in combination with runoff estimation formulas such, as the rational method, in order to predict the peak runoff flow from exact point of basin. These are also used in certain aspects of hydraulic structures design such as size of pipes and culvert (Dupont and Allen, 2000).

Attempt has been made by several researchers to develop intensity duration frequency curves in different parts of the world. In a study by Hershfield (1961) various rainfall contour maps were developed to provide the design rain depths for various return periods and durations. Bell (1969) proposed a generalized IDF formula using the one hour, 10 years rainfall depths as an index. Chen (1983) further developed a generalized IDF formula for any location in the United States using three base rainfall depths: one hour 10 years, twenty four hours 10 years and one hour hundred years (P_1^{10}, P_{24}^{10}, P_1^{100}) which describe the geographical variation of rainfall. Antigha and Ogharekpe (2013) developed intensity duration frequency curves for Calabar Metropolis in South-South, Nigeria. In this study, an attempt was made to develop intensity duration frequency curves for Lokaja and Ilorin and also generate models that can be employed to predict the intensity of rainfall for ungauged sites within the study area.

2.0. Methodology

2.1. Description of study area

The study area is the middle Niger River Basin comprising of Kogi (Lokoja) and parts of Kwara State (Ilorin). Middle Niger Basin system begins at the entry point of River Niger into Nigeria to the outlet into the Gulf of Guinea. The Nigerian part of the basin receives an annual rainfall of between 1,000 and 4,000 mm (Adeaga *et al*., 2012) with Inter-annual rainfall variability in the Gulf of Guinea region ranging between 10 to 20 percent. The system has a drainage basin of about 629,545 km^2 with discharge contribution of about 117 km^3/year, this constitute about 64.3% to the total River Niger flow (Clanet, 2009). Flow in the Lower Niger region substantially increases downstream Lokoja after confluence with River Benue, with several tributaries and flows southward before emptying through the Niger Delta, an area characterized by swamps, lagoons, and navigable channels. Mean annual discharge of the Niger upstream of Jebba and downstream of the Kainji and Jebba dams is 1,454 m^3/s. Following the confluence at Lokoja, the flow increases to 5,660 m^3/s (for the period 1915-2001). Niger River Basin system has a drainage basin of 2,117,700 km^2 with annual population growth rate of 3%, which largely depend on the river for their livelihood. The estimated population is about 104.5 million (80% of which is in Lower Niger section) and will likely double by 2025 (Clanet, 2009). In addition, over the years the Lower Niger has been experiencing marked decrease in flow with mean flow of 6,055 m^3/s (191 km^3/year) for 1929-1970 compared to 5,066 m^3/s (160 km^3/year) for the period 1971-2001; a decrease of about 17%. Also recorded is reduction in annual average discharge to about 20% downstream Kainji Dam before dropping to 45% (Abam, 2001). Presently, stringent economic pressure through insufficient budget allocation has resulted in varied neglect of water resources assessment infrastructure within the Basin (Adeaga *et al*., 2012).

2.2. Data collection

The data used for this study is annual daily rainfall data obtained from Nigeria Meteorological Agency (NIMET) Abuja. This agency is saddled with the sole responsibility of measuring, analysing and storing meteorological data and forecasting the weather in Nigeria. Daily rainfall data were obtained and analysed with the aid of Microsoft Excel Program in order to determine the annual maximum daily rainfall series (AMDS). To determine the rainfall intensity (I), the popular Gumbel probability distribution model was employed.

2.3. Preliminary analysis of the data

Descriptive statistics were used to describe the basic features of the data since they provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually every quantitative analysis of data. The mean and standard deviation of rainfall intensities were computed as follows:

$$\text{Mean} = \frac{\sum(I)}{n} \tag{1}$$

Where:

I	Rainfall intensity = Daily Rainfall/24 hrs (mm/hr)
n	Number of occurrences

$$\text{Standard Deviation} = \sqrt{\frac{\sum(I-\bar{I})^2}{n-1}} \tag{2}$$

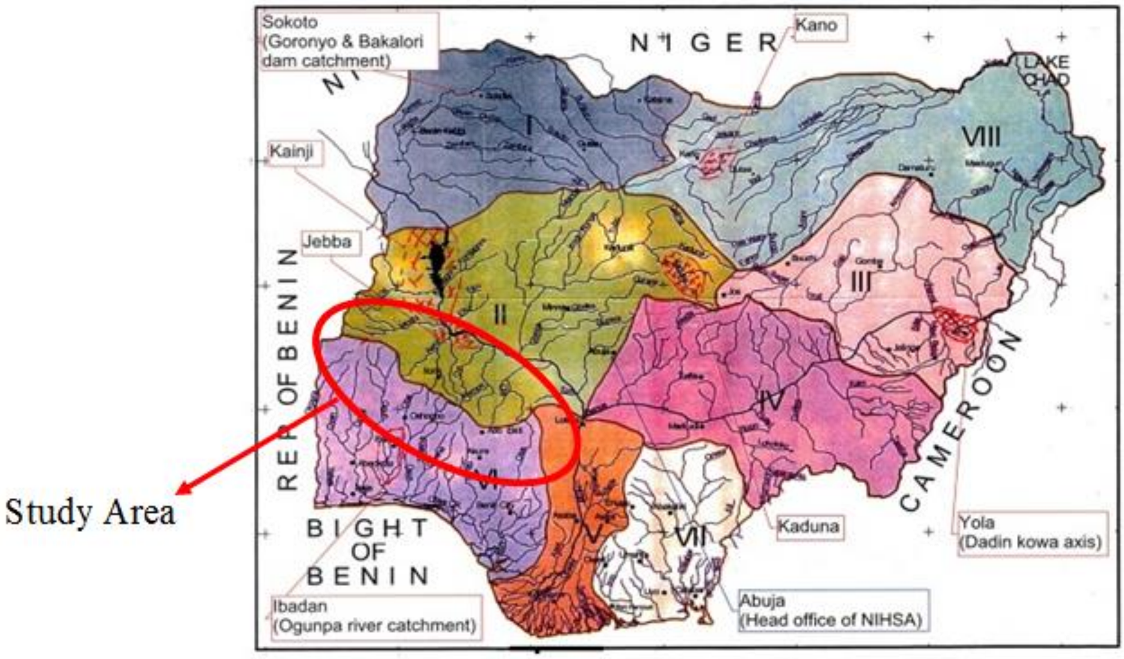

Figure 1: Map of Nigeria showing the study area

2.3.1 Test of homogeneity

Owing to the method of data collection coupled with the conditions around the observation site and reliability of the measurement procedures; non-homogeneous observation may appear in the data series and can challenge the quality of the data and the overall outcome of the results since frequency analysis of data requires that the data be homogeneous and independent. Homogeneity test was carried out to establish the fact that the data used are from the same population distribution. The test is based on the cumulative deviation from the mean as expressed using the mathematical equation proposed by Raes *et al*. (2006) as follows:

$$S_k = \sum_{i=1}^{k}(X_i - \bar{X})\ k = 1, \dots .n \tag{3}$$

Where:

X_i	The record for the series $X_1, X_2 \dots X_n$
$\bar{X}$	The mean
S_{ks}	The residual mass curve

For a homogeneous record, it is expected that the data points fluctuate around zero line as defined by the residual mass curve. To perform the homogeneity test, a software package (Rainbow) for analysing hydrological data was employed.

To further confirm that the rainfall data are statistically homogeneous, test of hypothesis was done using test of hypothesis. The null hypothesis of homogeneity was formulated as follows:

H_0: Data are statistically homogeneous
H_1: Data are not homogeneous

The null and alternate hypotheses were tested at 90%, 95% and 99% confidence interval that is 0.1, 0.05 and 0.01 degree of freedom respectively.

2.3.2. Outlier detection

Outliers are defined as data point that split off or are very different from the rest of the data (Stevens, 1986). Outliers can be caused by irregularities or errors which occur during the data recording or observation process. These points deserve further investigation in order to decide whether or not to remove them. The problem of outliers is of major concern when dealing with extreme events. Although, numerous methods abound in the literature for the analysis and determination of outliers, in this study, the labelling rule method was employed to detect the presence of outliers. The labelling rule is the statistical method of detecting the presence of outliers in a data set using the 25th percentile (lower bound) and the 75th percentile (upper bound). The underlying mathematical equation based on the lower and the upper bound as proposed by Levi *et al*. (2009) is presented as follows:

Lower Bound $$Q_1 - [2.2 \times (Q_3 - Q_1)] \quad (4)$$
Upper Bound $$Q_3 + [2.2 \times (Q_3 - Q_1)] \quad (5)$$

At 0.05 degree of freedom, any data lower than Q_1 or greater than Q_3 was considered an outlier and was removed before the analysis.

2.3.3. Generation of IDF curve

Rainfall intensity is defined as the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period It is expressed in depth units per unit time, usually as mm per hour (mm/hr). The step by step procedure for generating the IDF curves is as follows:

i. Annual maximum daily series of rainfall were obtained from the daily rainfall data
ii. The descriptive statistics of the data consisting; the mean ($\overline{X}$) and standard deviation (S) were computed using equations (2.1) and (2.2) respectively.
iii. The three hours rainfall intensity was computed using:

$$I = \frac{R}{T} \quad (6)$$

Where; I is the rainfall intensity (mm/hr), R is the amount of rainfall (mm) and T is the duration of the rainfall (3hrs).

iv. The rainfall frequency factor (K_T) for selected return periods (T= 2, 5, 10, 25, 50 and 100yrs) were computed using the quantile equation of the Gumbel probability distribution model and is presented as follows:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\langle 0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\rangle \quad (7)$$

Where; T is the selected return periods

v. The rainfall intensity corresponding to a specified return period was computed using:

$$X_T = \bar{X} + K_T S \quad (8)$$

Where; X_T is the rainfall intensity corresponding to a specified return period T (yrs), $\overline{X}$ is the average of the maximum precipitation corresponding to a specific duration and S is the standard deviation of precipitation data.

vi. Finally, the IDF curves were generated from the plot of rainfall intensities against duration for corresponding return period.

3.0. Results and Discussion

Descriptive statistics of annual maximum daily rainfall data employed for this analysis is presented in Tables 1 and 2 respectively.

Table 1: Descriptive statistics of AMDS from Lokoja

			Statistic	Std. Error
LOKOJA	Mean		79.315	3.2721
	95% Confidence Interval for Mean	Lower Bound	72.732	
		Upper Bound	85.897	
	5% Trimmed Mean		77.554	
	Median		72.500	
	Variance		513.912	
	Std. Deviation		22.6696	
	Minimum		49.5	
	Maximum		174.2	
	Range		124.7	
	Interquartile Range		32.6	
	Skewness		1.696	.343
	Kurtosis		5.015	.674

Table 2: Descriptive statistics of AMDS from Ilorin

ILORIN	Mean		79.352	3.4484
	95% Confidence Interval for Mean	Lower Bound	72.415	
		Upper Bound	86.289	
	5% Trimmed Mean		77.770	
	Median		76.000	
	Variance		570.776	
	Std. Deviation		23.8909	
	Minimum		36.6	
	Maximum		160.5	
	Range		123.9	
	Interquartile Range		24.7	
	Skewness		1.137	.343
	Kurtosis		2.113	.674

Results of the homogeneity test conducted on the annual maximum daily rainfall series for the stations employed in the study and presented in Figures 2a and 2b revealed that the data used are statistically homogeneous. Results of homogeneity statistics employed to test the strength of the null hypothesis over the alternate hypothesis is presented in Figures 3a and 3b.

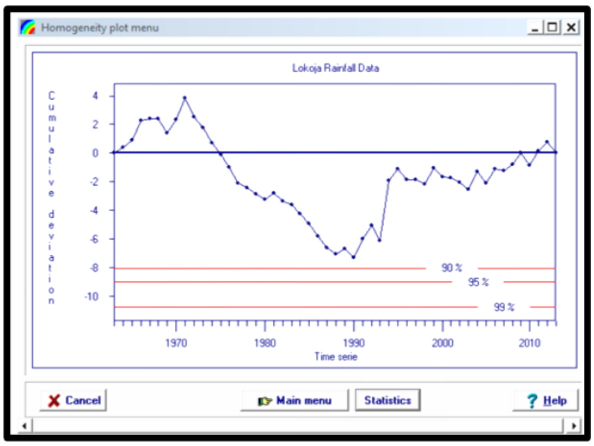

Figure 2a: Homogeneity test of Lokoja AMDS

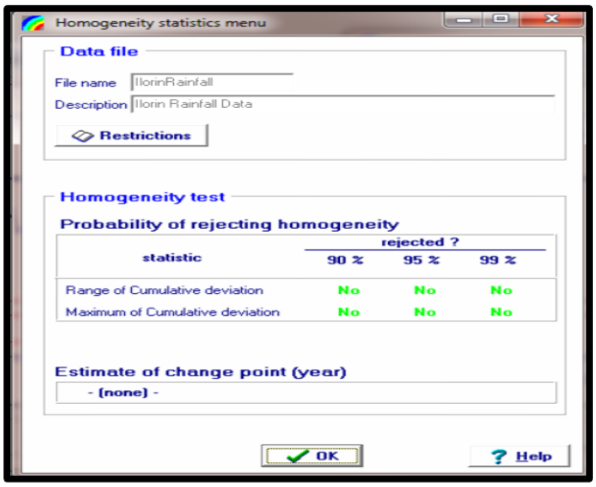

Figure 3a: Homogeneity statistics of Lokoja AMDS

Figure 2a: Homogeneity test of Ilorin AMDS

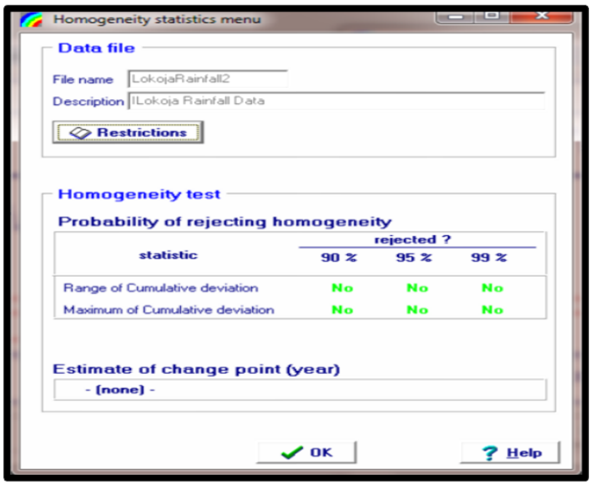

Figure 3b: Homogeneity statistics of Ilorin AMDS

Based on the computed statistics as presented in Figures 3a and 3b, the null hypothesis (H_0) was accepted, and it was concluded that the rainfall data collected from Lokoja and Ilorin are statistically homogeneous at 90%, 95% and 99% confidence interval that is 0.10, 0.05 and 0.01df. The computed rainfall percentiles presented in Table 3 was employed to analyse and determine the presence of outlier in the data.

Table 3: Computed rainfall percentiles

Percentiles

		Percentiles						
		5	10	25	50	75	90	95
Weighted Average (Definition 1)	LOKOJA	54.180	56.300	62.100	72.500	94.750	107.420	112.010
	ILORIN	46.780	52.020	65.925	76.000	90.625	111.890	132.055
Tukey's Hinges	LOKOJA			62.200	72.500	93.200		
	ILORIN			66.050	76.000	90.550		

Using the weighted average definition, the 25th percentile (Q_1) of AMDS from Lokoja was observed to be 62.10 while the 75th percentile (Q_3) was observed to be 94.75. Adopting the labelling rule equation, the lower and upper bound statistics of AMDS from Lokoja were calculated as follows:

Lower bound = 62.10 – (2.2(94.75 – 62.10)) = -9.73
Upper bound = 94.75 + (2.2(94.75 – 62.10)) = 166.58

The 25th percentile (Q_1) of AMDS from Ilorin was observed to be 65.925 while the 75th percentile (Q_3) was observed to be 90.625. Adopting the labelling rule equation, the lower and upper bound statistics of AMDS from Ilorin were also calculated as follows:

Lower bound = 65.925 – (2.2(90.625 – 65.925)) = -11.585
Upper bound = 90.625 + (2.2(90.625 – 65.925)) = 144.965

The extreme value statistics of AMDS from Lokoja and Ilorin which shows the highest and lowest case numbers are presented in Tables 4a and 4b respectively. From the result of Table 4a, it was observed that the highest AMDS from Lokoja is 174.20, which is higher than the calculated upper bound of 166.58. The lowest AMDS was observed to be 49.50, which is greater than the calculated lower bound of -9.73. To be devoid of outlier, no rainfall value must be greater than the calculated upper bound or lower than the calculated lower bound. AMDS of 174.20mm represented by case number 31 was declared an outlier since it is greater than the calculated upper bound of 166.58 and was removed before further analysis. From the result of Table 4b, it was observed that the highest AMDS from Ilorin is 160.50, which is higher than the calculated upper bound of 144.965. The lowest AMDS was observed to be 36.60 which is greater than the calculated lower bound of -11.585. To be devoid of outlier, no rainfall value must be greater than the calculated upper bound or lower than the calculated lower bound. AMDS of 160.50mm represented by case number 9 was declared an outlier since it is greater than the calculated upper bound of 144.965 and was also removed before further analysis. A further test of outliers was done using the box plots presented in Figures 4a and 4b respectively.

Table 4a: Extreme value statistics of AMDS from Lokoja

			Case Number	Value
LOKOJA	Highest	1	31	174.2
		2	8	113.0
		3	3	110.8
		4	28	108.5
		5	41	107.3
	Lowest	1	9	49.5
		2	14	54.0
		3	30	54.4
		4	11	55.4
		5	6	56.4

Table 4b: Extreme value statistics of AMDS from Ilorin

ILORIN	Highest	1	9	160.5
		2	20	136.6
		3	31	126.5
		4	19	115.4
		5	36	111.5
	Lowest	1	13	36.6
		2	4	45.7
		3	47	48.1
		4	6	49.5
		5	1	52.3

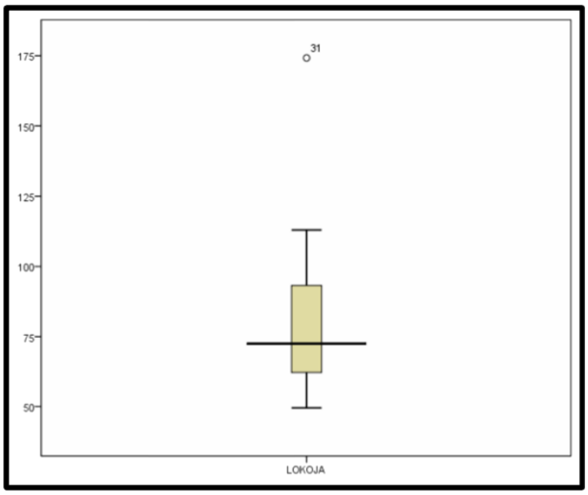

Figure 4a: Box plot of AMDS from Lokoja

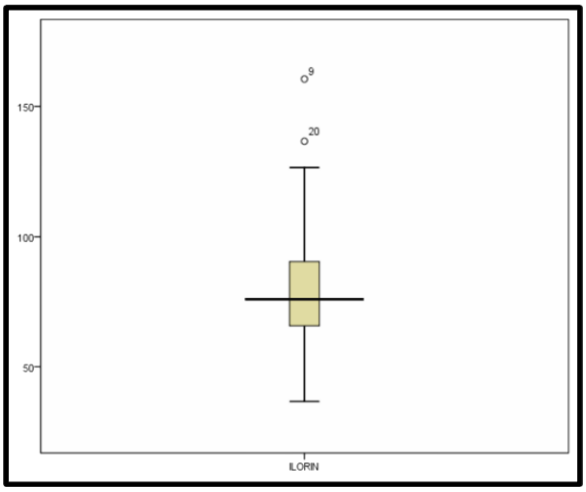

Figure 4b: Box plot of AMDS from Ilorin

It was concluded based on the results of Figures 4a and 4b that AMDS represented by case numbers 31 for Lokoja and 9 for Ilorin are outliers and were removed before further analysis. Using the final data and employing the procedures based on the Gumbel probability distribution model outlined for the calculation of rainfall intensity, the calculated rainfall intensities for Ilorin and Lokoja for the selected return periods is presented in Tables 5a and 5b respectively. Using the computed rainfall intensity, intensity duration frequency, (IDF) curves were generated and are presented in Figures 5a, 5b, 5c and 6a, 6b and 6c respectively.

Table 5a: Calculated Rainfall Intensity for Ilorin based on Gumbel distribution

Duration (hrs)	Intensity (mm/hr) (T = 2yrs)	Intensity (mm/hr) (T = 5yrs)	Intensity (mm/hr) (T= 10yrs)	Intensity (mm/hr) (T =25yrs)	Intensity (mm/hr) (T = 50yrs)	Intensity (mm/hr) (T = 100yrs)
0.0333	755.0297719	966.3721533	1106.299199	1283.097393	1414.256392	1544.446935
0.0833	301.8306291	386.3168392	442.2540616	512.9308905	565.3629996	617.4079582
0.1667	150.8247835	193.0425477	220.9943811	256.3115967	282.5119248	308.5187938
0.25	100.5699656	128.7207708	147.3590533	170.9085727	188.3789515	205.7203317
0.5	50.28498281	64.36038541	73.67952667	85.45428635	94.18947573	102.8601658
1	25.14249141	32.1801927	36.83976333	42.72714318	47.09473787	51.43008292
2	12.5712457	16.09009635	18.41988167	21.36357159	23.54736893	25.71504146
3	8.380830469	10.7267309	12.27992111	14.24238106	15.69824596	17.14336097
4	6.285622851	8.045048176	9.209940833	10.68178579	11.77368447	12.85752073
5.333	4.714511796	6.034163267	6.907887368	8.011840086	8.830815276	9.643743282

Table 5b: Calculated Rainfall Intensity for Lokoja based on Gumbel distribution

Duration (hrs)	Intensity (mm/hr) (T = 2yrs)	Intensity (mm/hr) (T = 5yrs)	Intensity (mm/hr) (T= 10yrs)	Intensity (mm/hr) (T =25yrs)	Intensity (mm/hr) (T = 50yrs)	Intensity (mm/hr) (T = 100yrs)
0.0333	756.6626242	957.2014025	1089.975523	1257.735977	1382.190265	1505.725602
0.0833	302.483378	382.6507408	435.7285105	502.7924133	552.5442474	601.9287219
0.1667	151.1509621	191.2105981	217.7335628	251.2453991	276.1063936	300.7838184
0.25	100.7874615	127.4992268	145.1847397	167.5304321	184.1077432	200.5626501
0.5	50.39373077	63.74961341	72.59236985	83.76521605	92.05387162	100.2813251
1	25.19686539	31.8748067	36.29618492	41.88260803	46.02693581	50.14066253
2	12.59843269	15.93740335	18.14809246	20.94130401	23.01346791	25.07033127
3	8.398955129	10.62493557	12.09872831	13.96086934	15.34231194	16.71355418
4	6.299216346	7.968701676	9.074046231	10.47065201	11.50673395	12.53516563
5.333	4.724707554	5.976899813	6.805960046	7.853479847	8.630589876	9.401961847

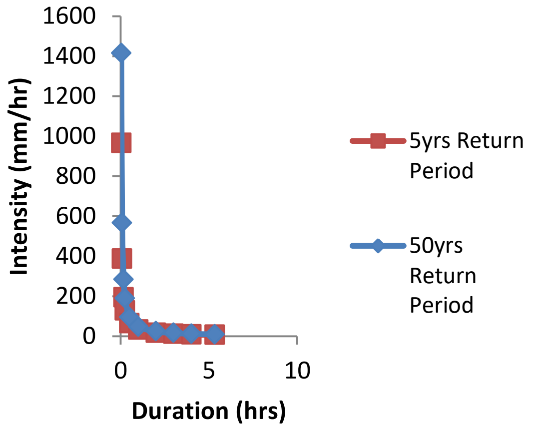

Figure 5a: IDF curves for Ilorin based on Gumbel distribution (5 and 50 yrs return period)

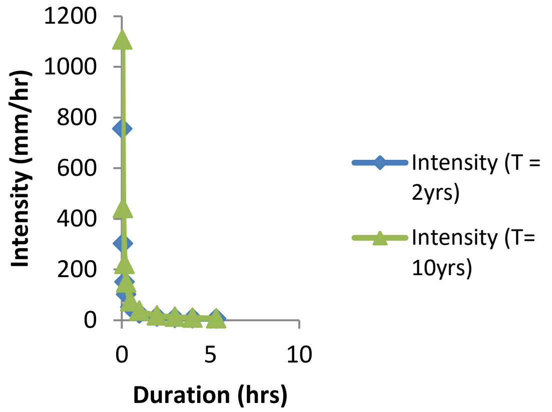

Figure 5b: IDF curves for Ilorin based on Gumbel distribution (2 and 10 yrs return period)

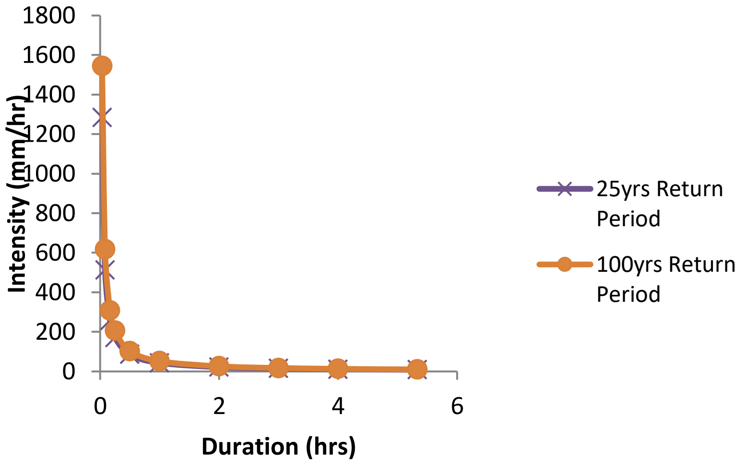

Figure 5c: IDF curves for Ilorin based on Gumbel distribution (25 and 100 yrs return period)

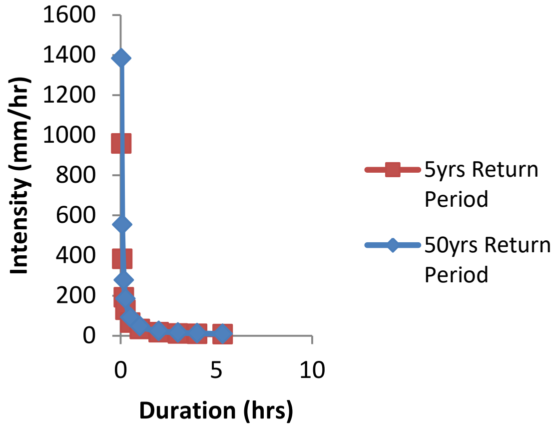

Figure 6a: IDF curves for Lokoja based on Gumbel distribution (5 and 50 yrs return period)

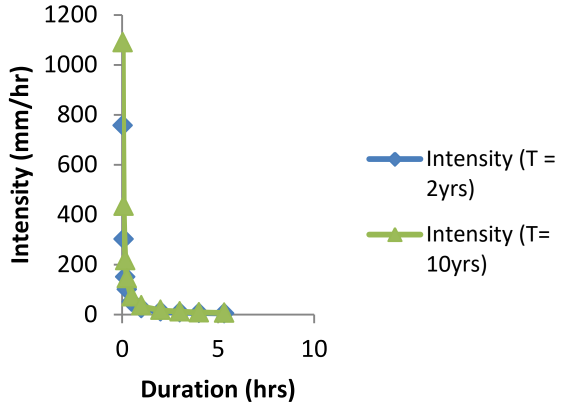

Figure 6b: IDF curves for Lokoja based on Gumbel distribution (2 and 10 yrs return period)

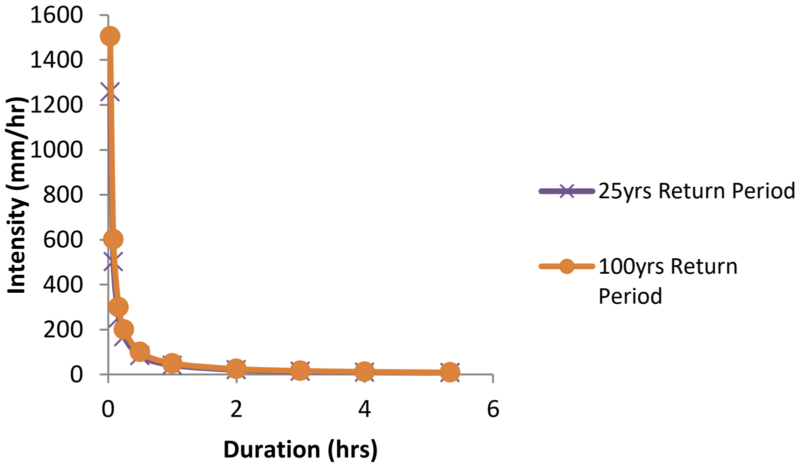

Figure 6c: IDF curves for Ilorin based on Gumbel distribution (25 and 100 yrs return period)

3.1. Fitting of empirical IDF equations

Empirical IDF equations represent the relationship between maximum rainfall intensity (as dependent variable) and other parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used equations presented in literature for hydrology applications, presented by (Chow *et al*., 1988), used for the analysis of rainfall intensity. For this study, four basic forms of equations used to describe the rainfall intensity duration relationship presented in Table 6 were employed.

Table 6: Definition of selected empirical rainfall intensity equations

S/N	Empirical Equation	Reference
1	$i = \frac{a}{d+b}$	Talbot Equation
2	$i = \frac{a}{d^e}$	Bernard Equation
3	$i = \frac{a}{d^e+b}$	Kimijima Equation
4	$i = \frac{a}{(d+b)^e}$	Sherman Equation

where:
i Rainfall intensity (mm/hr);
d Duration (hrs);

a, *b* and *e* Constant parameters related to the empirical equation.

These empirical equations show that rainfall intensity decreases with rainfall duration for a given return period. To determine the parameters of the equation, non-linear regression techniques using the Microsoft excel solver was employed. The inter phase of the non-linear regression solver is presented in Tables 7, 8, 9 and 10 respectively.

Table 7: Non-linear regression solver based on Talbot equation

A	B	C	D	E	F	G	H
d	i	Talbot Equation	Upper CI	Lower CI		a	25.5493397485865
0.0333	755.029771937681	=($H$1)/(A2+$H$2)	= C2+$H$8	=C2-$H$8		b	0.00809089069609902
0.0833	301.830629117945	=($H$1)/(A3+$H$2)	= C3+$H$8	=C3-$H$8		Mean of i	=AVERAGE(B2:B11)
0.1667	150.824783476453	=($H$1)/(A4+$H$2)	= C4+$H$8	=C4-$H$8		df	=COUNT(B2:B11)-COUNT(H1:H2)
0.25	100.569965622099	=($H$1)/(A5+$H$2)	= C5+$H$8	=C5-$H$8		SSE	=SQRT(SUM((B2:B11-C2:C11)^2)/H4)
0.5	50.2849828110496	=($H$1)/(A6+$H$2)	= C6+$H$8	=C6-$H$8		R^2	=1-SUM((B2:B11-C2:C11)^2)/SUM((B2:B11-H3)^2)
1	25.1424914055248	=($H$1)/(A7+$H$2)	= C7+$H$8	=C7-$H$8		Critical t	=TINV(0.05, H4)
2	12.5712457027624	=($H$1)/(A8+$H$2)	= C8+$H$8	=C8-$H$8		CI	=(H7*H5)
3	8.38083046850826	=($H$1)/(A9+$H$2)	= C9+$H$8	=C9-$H$8		HYBRID	=100*(SUM(((B2:B11-C2:C11)^2)/(B2:B11)))/(COUNT(B2:B11)-1)
4	6.28562285138119	=($H$1)/(A10+$H$2)	= C10+$H$8	=C10-$H$8		NSD	=100*(SQRT(SUM(((B2:B11-C2:C11)/(B2:B11))^2)/(COUNT(B2:B11)-1)))
5.333	4.71451179552312	=($H$1)/(A11+$H$2)	= C11+$H$8	=C11-$H$8		RMSE	=SQRT(SUM((B2:B11-C2:C11)^2)/(COUNT(B2:B11)-1))

Table 8: Non-linear regression solver based on Bernard equation

A	B	C	D	E	F	G	H
d	i	BERNARD EQUATION	Upper CI	Lower CI		a	4.73963937022917
0.0333	755.029771937681	=($H$1)/((A2)^$H$2)	= C2+$H$8	=C2-$H$8		e	0.00317555486873956
0.0833	301.830629117945	=($H$1)/((A3)^$H$2)	= C3+$H$8	=C3-$H$8		Mean of i	=AVERAGE(B2:B11)
0.1667	150.824783476453	=($H$1)/((A4)^$H$2)	= C4+$H$8	=C4-$H$8		df	=COUNT(B2:B11)-COUNT(H1:H2)
0.25	100.569965622099	=($H$1)/((A5)^$H$2)	= C5+$H$8	=C5-$H$8		SSE	=SQRT(SUM((B2:B11-C2:C11)^2)/H4)
0.5	50.2849828110496	=($H$1)/((A6)^$H$2)	= C6+$H$8	=C6-$H$8		R^2	=1-SUM((B2:B11-C2:C11)^2)/SUM((B2:B11-H3)^2)
1	25.1424914055248	=($H$1)/((A7)^$H$2)	= C7+$H$8	=C7-$H$8		Critical t	=TINV(0.05, H4)
2	12.5712457027624	=($H$1)/((A8)^$H$2)	= C8+$H$8	=C8-$H$8		CI	=(H7*H5)
3	8.38083046850826	=($H$1)/((A9)^$H$2)	= C9+$H$8	=C9-$H$8		HYBRID	=100*(SUM(((B2:B11-C2:C11)^2)/(B2:B11)))/(COUNT(B2:B11)-1)
4	6.28562285138119	=($H$1)/((A10)^$H$2)	= C10+$H$8	=C10-$H$8		NSD	=100*(SQRT(SUM(((B2:B11-C2:C11)/(B2:B11))^2)/(COUNT(B2:B11)-1)))
5.333	4.71451179552312	=($H$1)/((A11)^$H$2)	= C11+$H$8	=C11-$H$8		RMSE	=SQRT(SUM((B2:B11-C2:C11)^2)/(COUNT(B2:B11)-1))

Table 9: Non-linear regression solver based on Kimijima equation

A	B	C	D	E	F	G	H
d	i	KIMIJIMA EQUATION	Upper CI	Lower CI		a	4.83512327922962
0.0333	755.029771937681	=($H$1)/(((A2)^$H$10)+$H$2)	= C2+$H$8	=C2-$H$8		b	0.00898367934147887
0.0833	301.830629117945	=($H$1)/(((A3)^$H$10)+$H$2)	= C3+$H$8	=C3-$H$8		Mean of i	=AVERAGE(B2:B11)
0.1667	150.824783476453	=($H$1)/(((A4)^$H$10)+$H$2)	= C4+$H$8	=C4-$H$8		df	=COUNT(B2:B11)-COUNT(H1:H2)
0.25	100.569965622099	=($H$1)/(((A5)^$H$10)+$H$2)	= C5+$H$8	=C5-$H$8		SSE	=SQRT(SUM((B2:B11-C2:C11)^2)/H4)
0.5	50.2849828110496	=($H$1)/(((A6)^$H$10)+$H$2)	= C6+$H$8	=C6-$H$8		R^2	=1-SUM((B2:B11-C2:C11)^2)/SUM((B2:B11-H3)^2)
1	25.1424914055248	=($H$1)/(((A7)^$H$10)+$H$2)	= C7+$H$8	=C7-$H$8		Critical t	=TINV(0.05, H4)
2	12.5712457027624	=($H$1)/(((A8)^$H$10)+$H$2)	= C8+$H$8	=C8-$H$8		CI	=(H7*H5)
3	8.38083046850826	=($H$1)/(((A9)^$H$10)+$H$2)	= C9+$H$8	=C9-$H$8		HYBRID	=100*(SUM(((B2:B11-C2:C11)^2)/(B2:B11)))/(COUNT(B2:B11)-1)
4	6.28562285138119	=($H$1)/(((A10)^$H$10)+$H$2)	= C10+$H$8	=C10-$H$8		e	0.00983506846736382
5.333	4.71451179552312	=($H$1)/(((A11)^$H$10)+$H$2)	= C11+$H$8	=C11-$H$8		RMSE	=SQRT(SUM((B2:B11-C2:C11)^2)/(COUNT(B2:B11)-1))

Table 10: Non-linear regression solver based on Sherman equation

A	B	C	D	E	F	G	H
d	i	SHERMAN EQUATION	Upper Cl	Lower Cl		a	1
0.0333	755.029771937681	=($H$1)/((A2+$H$2)^$H$10)	= C2+$H$8	=C2-$H$8		b	1
0.0833	301.830629117945	=($H$1)/((A3+$H$2)^$H$10)	= C3+$H$8	=C3-$H$8		Mean of i	=AVERAGE(B2:B11)
0.1667	150.824783476453	=($H$1)/((A4+$H$2)^$H$10)	= C4+$H$8	=C4-$H$8		df	=COUNT(B2:B11)-COUNT(H1:H2)
0.25	100.569965622099	=($H$1)/((A5+$H$2)^$H$10)	= C5+$H$8	=C5-$H$8		SSE	=SQRT(SUM((B2:B11-C2:C11)^2)/H4)
0.5	50.2849828110496	=($H$1)/((A6+$H$2)^$H$10)	= C6+$H$8	=C6-$H$8		R^2	=1-SUM((B2:B11-C2:C11)^2)/SUM((B2:B11-H3)^2)
1	25.1424914055248	=($H$1)/((A7+$H$2)^$H$10)	= C7+$H$8	=C7-$H$8		Critical t	=TINV(0.05, H4)
2	12.5712457027624	=($H$1)/((A8+$H$2)^$H$10)	= C8+$H$8	=C8-$H$8		CI	=(H7*H5)
3	8.38083046850826	=($H$1)/((A9+$H$2)^$H$10)	= C9+$H$8	=C9-$H$8		HYBRID	=100*(SUM(((B2:B11-C2:C11)^2)/(B2:B11)))/(COUNT(B2:B11)-1)
4	6.28562285138119	=($H$1)/((A10+$H$2)^$H$10)	= C10+$H$8	=C10-$H$8		e	1
5.333	4.71451179552312	=($H$1)/((A11+$H$2)^$H$10)	= C11+$H$8	=C11-$H$8		RMSE	=SQRT(SUM((B2:B11-C2:C11)^2)/(COUNT(B2:B11)-1))

The non-linear regression solver was applied to estimate the parameters of the four empirical IDF equations that were used to represent intensity-duration relationships. The value of the constants corresponding to a minimum root mean square error (RMSE) between the computed rainfall intensity and the corresponding return period were selected as the exact value. Results of the estimated parameters are presented in Tables 11, 12, 13, 14, 15, 16, 17 and 18 representing Lokoja and Ilorin respectively.

Table 11: Estimated parameters of Talbot equation (Ilorin)

Return Periods T (Years)	a	b	Minimized RMSE (OF^a)	Sum of Minimized Error (SME)
2	25.181	0.00809	3.87622E-09	1.32170E-07
5	32.2234	0.00715	8.38749E-09	
10	36.8632	0.003398	2.55666E-08	
25	42.7578	0.00383	8.78360E-08	
50	47.5155	0.004765	6.00059E-09	
100	51.6486	0.002266	5.03231E-10	

Table 12: Estimated parameters of Bernard equation (Ilorin)

Return Periods T (Years)	a	e	Minimized RMSE (OF^a)	Sum of Minimized Error (SME)
2	4.73964	0.003176	1.21257E-07	4.90162E-07
5	6.95028	0.05267	1.09076E-08	
10	6.92913	0.00183	4.17068E-08	
25	8.01204	1.465E-05	1.94787E-07	
50	8.84136	0.000713	1.06478E-07	
100	10.18342	0.032529	1.50257E-08	

Table 13: Estimated parameters of Kimijima equation (Ilorin)

Return Periods T (Years)	a	b	e	Minimized RMSE (OF^a)	Sum of Minimized Error (SME)
2	4.83512	0.008984	0.009835	4.12099E-08	1.08253646E-06
5	6.21772	0.013150	0.010228	9.57006E-09	
10	6.98678	0.00775	0.00219	2.21864E-07	
25	8.03047	0.000672	0.000987	1.87725E-08	
50	8.83466	0.000427	5.039E-06	2.2828E-07	
100	10.28963	0.03746	0.017377	5.6284E-07	

Table 14: Estimated parameters of Sherman equation (Ilorin)

Return Periods T (Years)	a	b	e	Minimized RMSE (OF^a)	Sum of Minimized Error (SME)
2	4.7171	0.91445	0.000295	2.50979E-08	1.3948737E-06
5	6.43554	0.91334	0.03515	9.9194E-09	
10	7.23422	0.91419	0.025194	2.11926E-07	
25	8.01756	0.91445	0.0003895	8.85173E-08	
50	8.83718	0.914448	0.0003931	1.06131E-06	
100	10.48347	0.913803	0.045572	1.10314E-09	

Table 15: Estimated parameters of Talbot equation (Lokoja)

Return Periods T (Years)	a	b	Minimized RMSE (OF[a])	Sum of Minimized Error (SME)
2	25.2447	0.010117	1.17022E-08	8.953636E-08
5	31.9614	0.01453	3.55266E-09	
10	36.30716	0.001613	3.51542E-08	
25	41.88335	9.49E-05	1.22965E-08	
50	46.40096	4.33E-05	1.42290E-08	
100	50.45183	3.31E-05	1.26018E-08	

Table 16: Estimated parameters of Bernard equation (Lokoja)

Return Periods T (Years)	a	e	Minimized RMSE (OF[a])	Sum of Minimized Error (SME)
2	4.74632	0.00273	3.23766E-08	2.795093E-06
5	6.511715	0.051198	4.91264E-07	
10	6.81525	0.000815	2.36245E-09	
25	7.89531	0.0031732	8.79262E-08	
50	8.644688	0.000975	1.92134E-08	
100	9.62440	0.013969	2.23395E-06	

Table 17: Estimated parameters of Kimijima equation (Lokoja)

Return Periods T (Years)	a	b	e	Minimized RMSE (OF[a])	Sum of Minimized Error (SME)
2	4.83554	0.009896	0.008047	6.14915E-09	2.70062315E-06
5	6.07776	0.00465	0.007258	3.73719E-07	
10	6.97995	0.009022	0.0098017	4,70746E-07	
25	7.94581	0.011668	5.2597E-05	6.85129E-07	
50	8.63231	6.236E-05	8.2038E-05	2.36767E-07	
100	9.79126	0.021345	0.011866	9.28113E-07	

Table 18: Estimated parameters of Sherman equation (Lokoja)

Return Periods T (Years)	a	b	E	Minimized RMSE (OF[a])	Sum of Minimized Error (SME)
2	4.72472	0.91445	1.27276E-06	6.74459E-08	1.3681693E-06
5	6.42970	0.913507	0.039861	1.60538E-08	
10	6.80779	0.91445	0.0001464	5.74636E-08	
25	7.85796	0.914449	0.0003113	1.04931E-06	
50	8.63145	0.91445	5.45999E-05	1.72538E-07	
100	10.03473	0.91332	0.035553	5.35803E-09	

The regional IDF formula parameters were mostly generated for ungauged areas to estimate rainfall intensity for various return period and rainfall duration. Using 40 years annual maximum daily rainfall data (1974 – 2013), for two locations within the lower Niger River Basin (Ilorin and Lokoja), the parameters of Talbot, Bernard, Kimijima and Sherman equations were estimated based on the minimum root mean square error (RMSE) using the non-linear regression solver. To select the model that best fit each location, the sum of minimized error was employed and the model with the least sum of minimized error was selected as the best fit model. Based on the results of Tables 11, 12, 13 and 14, it was observed that Talbot equation had the least sum of minimized error of 1.32170E-07 and was declared the best fit model for Ilorin. Using the Talbot model, the following equations were generated for Ilorin in order to estimate the rainfall intensity.

For 2 years return period; $$i = \frac{25.181}{d + 0.00809} \quad (9)$$

For 5 years return period; $$i = \frac{32.2234}{d + 0.00715} \quad (10)$$

For 10 years return period; $$i = \frac{36.8632}{d + 0.003398} \quad (11)$$

For 25 years return period; $$i = \frac{42.7578}{d + 0.00382} \quad (12)$$

For 50 years return period; $$i = \frac{47.5155}{d + 0.004765} \quad (13)$$

For 100 years return period; $$i = \frac{51.6486}{d + 0.002266} \quad (14)$$

More also, based on the results of Tables 15, 16, 17 and 18, it was observed that Talbot equation had the least sum of minimized error of 8.953636E-08 and was again declared the best fit model for Lokoja. Using the Talbot model, the following equations were generated for Lokoja in order to estimate the rainfall intensity.

For 2 years return period; $$i = \frac{25.2447}{d + 0.010117} \quad (15)$$

For 5 years return period; $$i = \frac{31.9614}{d + 0.01453} \quad (16)$$

For 10 years return period; $$i = \frac{36.30716}{d + 0.001613} \quad (17)$$

For 25 years return period; $$i = \frac{41.88335}{d + 9.4876E - 05} \quad (18)$$

For 50 years return period; $$i = \frac{46.40096}{d + 4.3340E - 05} \quad (19)$$

For 100 years return period; $$i = \frac{50.45183}{d + 3.3096E - 05} \quad (20)$$

Where; *d* is duration (hrs). Based on the Talbot equation, the predicted rainfall intensity for Ilorin and Lokoja were computed and presented in Tables 19 and 20 respectively; while the IDF curves are presented in Figures 7 and 8 respectively.

Table 19: Predicted rainfall intensities for Ilorin using Talbot equation

Duration (hrs)	Intensity (mm/hr) (T = 2yrs)	Intensity (mm/hr) (T = 5yrs)	Intensity (mm/hr) (T= 10yrs)	Intensity (mm/hr) (T =25yrs)	Intensity (mm/hr) (T = 50yrs)	Intensity (mm/hr) (T = 100yrs)
0.0333	608.3836676	796.6229913	1107.006401	1151.880388	1248.272691	1452.190294
0.0833	275.5334282	356.2564953	442.5388122	490.792011	539.5503321	603.6112475
0.1667	144.0643057	185.35174	221.138371	250.7494722	277.1148631	305.6745144
0.25	97.56674028	125.3097414	147.456198	168.4571744	186.5071733	204.7386489
0.5	49.5601173	63.53820369	73.729798	84.86721448	94.1339039	102.8311691
1	24.97892053	31.99463834	36.866598	42.59508677	47.29016238	51.53182888
2	12.5397766	16.05430586	18.434998	21.33814414	23.7012817	25.79507418
3	8.37109262	10.7155945	12.29113133	14.23447477	15.81338308	17.20320585
4	6.282543556	8.041475862	9.219198	10.67925131	11.86474113	12.90483941
5.333	4.714580732	6.03417507	6.915680018	8.011849753	8.901759444	9.680604491

Table 20: Predicted rainfall intensities for Lokoja using Talbot equation

Duration (hrs)	Intensity (mm/hr) (T = 2yrs)	Intensity (mm/hr) (T = 5yrs)	Intensity (mm/hr) (T= 10yrs)	Intensity (mm/hr) (T =25yrs)	Intensity (mm/hr) (T = 50yrs)	Intensity (mm/hr) (T = 100yrs)
0.0333	581.4473593	668.2291449	1090.306718	1254.184923	1391.611038	1514.039696
0.0833	270.2366807	326.7034652	435.8618771	502.2292976	556.7446661	605.4995124
0.1667	142.7730365	176.3582188	217.8010131	251.1069345	278.2777411	302.6093154
0.25	97.0513269	120.8233471	145.230253	167.4698445	185.5716693	201.7890298
0.5	49.48805862	62.11766078	72.615933	83.75080812	92.79387663	100.8990873
1	24.99185738	31.50365194	36.308773	41.87937665	46.39894907	50.45068679
2	12.5588212	15.8654376	18.155193	20.94068162	23.19997726	25.22562919
3	8.38661753	10.60244881	12.10399967	13.96067516	15.46676322	16.81714964
4	6.295252732	7.961430105	9.078403	10.47058915	11.60011431	12.61288605
5.333	4.724714057	5.976852865	6.809631001	7.85347926	8.700653087	9.460269198

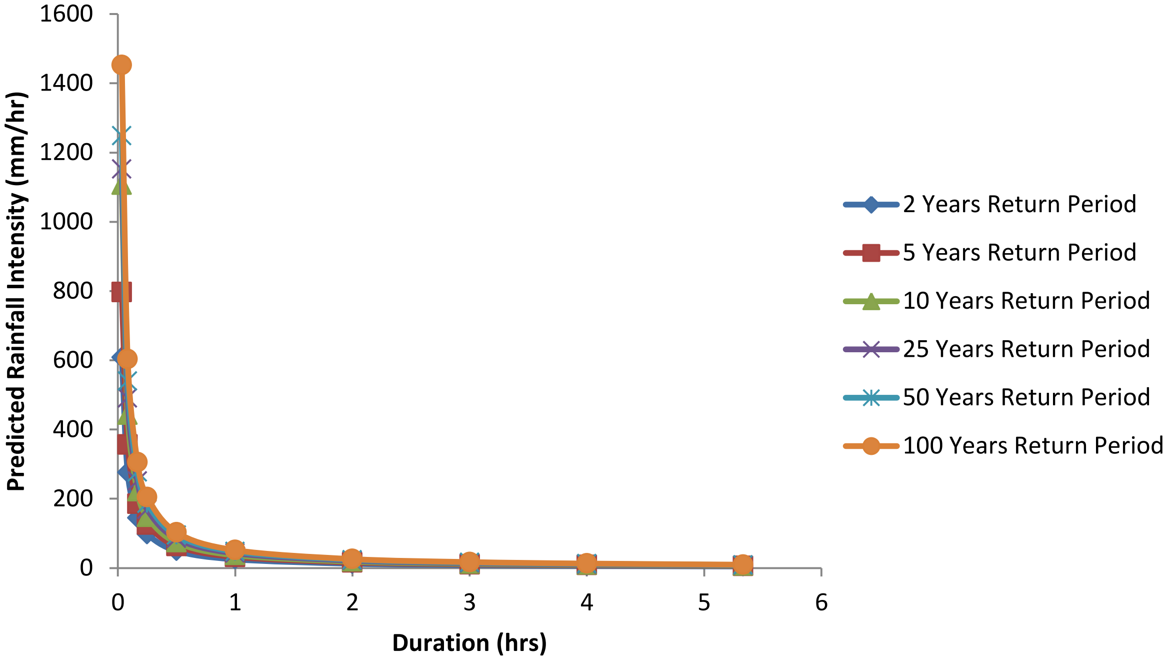

Figure 7: IDF curves for Ilorin using Talbot equation

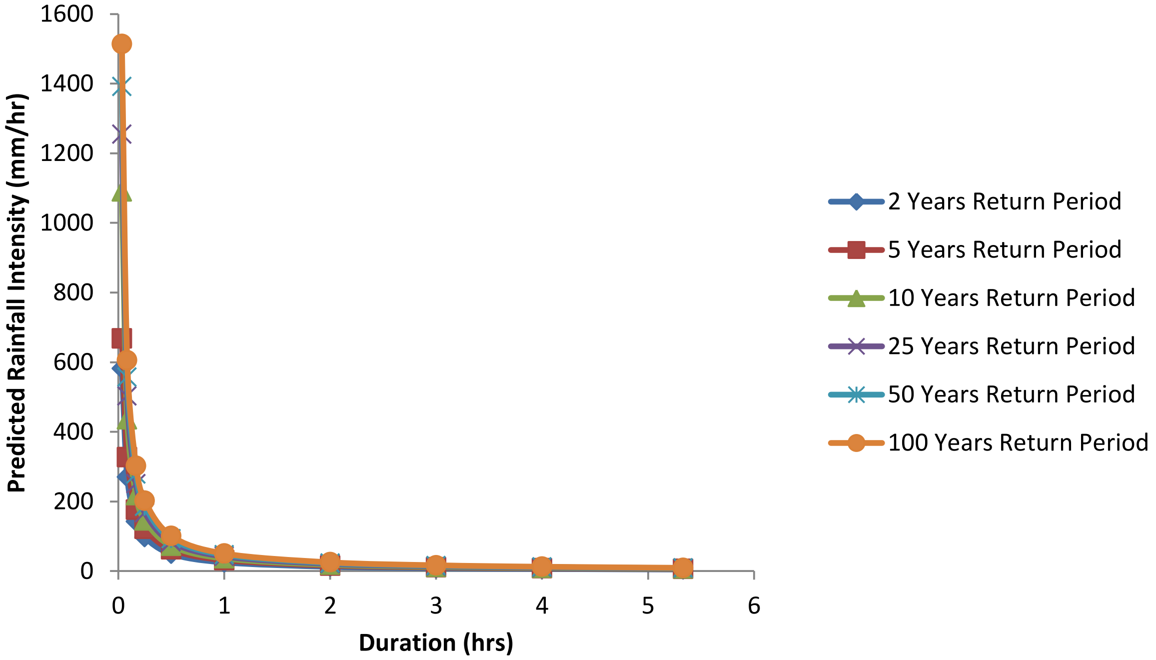

Figure 8: IDF curves for Lokoja using Talbot equation

4.0. Conclusions

The data used in this study represent annual daily rainfall data obtained from Nigerian Meteorological Agency, NIMET. In the study, descriptive statistics were used to describe the basic features of the data. Homogeneity test was carried out to establish the fact that the data used comes from the same population distribution. Outliers were identified and removed using the labeling rule before statistical analysis was carried out. Rainfall intensity duration curves were generated from the plot of rainfall intensities against duration for corresponding return periods.

Results of the homogeneity tests carried put on the annual maximum daily rainfall season for Lokoja and Ilorin revealed that the data used are statistically homogeneous. After removal of outliers, Gumbel probability distribution model was used in calculating the rainfall intensity for the two stations based on the selected Return Periods. From the computed rainfall intensity, IDF curves were generated. Intensity Duration Frequency data are needed by hydrologists and Engineers during the planning and design of water resource projects. The achievement of a set of empirical equations for rainfall intensity prediction is of importance in hydrology for various applications including Flood Frequency Analysis and Flood Prediction and Management.

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