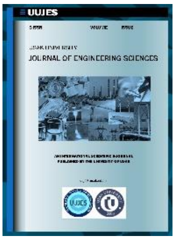

Usak University

Journal of Engineering Sciences

An international e-journal published by the University of Usak

Journal homepage: dergipark.gov.tr/uujes

Research article

FREQUENCY MODELING OF RAINFALL INTENSITIES FOR ABUJA METROPOLIS, NIGERIA

*Gabriel Delian Akpen, Ejeh Dandy Omale, Oloche Robert Ekwule**

Dept. of Civil Engineering, Federal University of Agriculture, Makurdi, Nigeria

Received: 23 April 2020 Revised: 1 July 2020 Accepted: 2 July 2020 Online available: 9 July 2020
Handling Editor: Jülide Öner

Abstract

The aim of this study is to analyze rainfall data so as to develop rainfall intensity – duration – frequency (IDF) models and curves for Abuja metropolis, Nigeria. A thirty-one years data set was obtained, checked for consistency and then used for the modeling. The method of Annual Series was used to select the data sets for the rainfall analysis. The data were fitted to Gumbel Extreme Value Type – 1 (GEVT – 1), Log Pearson Type III (LPT – 3), Pearson Type III (PLT – 3), Normal and Log Normal (LN) Distributions. Probability distribution function (PDF) and Non-Probability distribution function (nPDF) were calibrated to obtain the IDF models. Chi-squared goodness-of- fit test was used to confirm the appropriateness of the fitted distributions for the location. The Gumbel Extreme Value distribution has the best fit and was adopted in developing models using the PDF (power model). The location parameters resulting from GEVT – 1 were determined thus: c = 23.16, m = 0.21 and e = 0.55. Five IDF models were developed using the nPDF (quotient model) for return periods of 2, 5, 10, 16 and 32 years. The coefficient of correlation (R^2) for different return periods for all models developed showed very high values ranging from 0.7538 to 0.9927, an indication of good curve fitting. The IDF models developed for Abuja showed no significant difference when compared with results from locations within the same zone using t-test of significance though durations of 12 and 24 hours had exceptions. The application of IDF models (power law and quotient) with return period of 10 years and rainfall duration of 2 hours for design of a typical rectangular drainage channel was found to be okay. The IDF models and curves are recommended for the prediction of rainfall events for Abuja.

Keywords: *Frequency modelling; probability and non-probability functions; intensity duration frequency curve; Abuja.*

*Correspondingauthor: Oloche Robert Ekwule
E-mail: ekwule.robert.uam@gmail.com (ORCID: 0000-0002-4835-3951)

1. Introduction

The uncertainty in the behavioral pattern of rainfall events over the last few years and it's adverse effect, has given credence to the emphases placed on the need to accurately estimate the rainfall intensity of a particular locality. Moreover, rainfall events round the world have different characteristics where they occur [1]. The most popular instrument that can be adopted in obtaining the general characteristics of rainfall in any given watershed area is the rainfall intensity – duration – frequency (IDF) model [2]. These models are usually calibrated from a long span of rainfall data that are most times enhanced by carrying out consistency test due to the unavailability of sufficient data.

Rainfall intensity-duration-frequency (IDF) models can be translated into curves which are represented graphically to show the amount of water precipitating on the catchment area. These curves also represent the mathematical relationship of rainfall intensity, duration and return period [3]. IDF curves are widely applied in the field of water resources engineering [4-6]. These curves can also be used at the planning stage of an Engineering design to cater for factors that may lead to structural failure resulting from flooding. Even though IDF curves have been developed for different localities across the world, they have not been adequately formulated for most places especially in developing countries.

However, in Nigeria, such relationships are yet to be developed for many parts of the country. Notwithstanding, studies have also been carried out in the north- central region of Nigeria especially as it concerns Lokoja [7-12]. The Federal Capital Territory of Nigeria has recorded series of flooding events in recent times. In September 2012, heavy rainstorm accompanied by torrential flood claimed one life in Karu abattoir area and submerged many residential houses and stores [13]. Similarly, another incident occurred on the 27th of September, 2012 when an overnight downpour flooded and submerged 50 houses and 7 cars in Kubwa [14]. Therefore, crucial tools like the IDF Models can be employed for the design of flood mitigation structures in the Federal Capital Territory.

The investigation of extreme rainfall events as encompassed in the study of Intensity – Duration – Frequency (IDF) relationship has long been a major focus of both theoretical and applied hydrology. IDF or Depth-Duration-Frequency (DDF) curves as called sometimes, allows for calculation of the average design depth (rainfall intensity) for a given probability exceedence over a range of durations which serves as the result of an IDF analysis. Not to over emphasize, the estimates of IDF forms the core statistical summary of rainfall records used for hydrologic engineering design.

Mohammad and Najib [15] studied the application of various methods in the analysis of rainfall intensities in different areas across Israel, Jordanian and Palestinian. The purpose of that study was to define the meteorological conditions and precipitation data for the selected study areas within the region and develop models that will be used to analyze precipitation data in the region. The methods included computer software developed specifically for rainfall data compilation and analysis by the core parties, the management and analysis of precipitation data. Kim et al. [16] improved the accuracy of IDF curves by adopting long and short duration separation technique along with cumulative distribution function (CDF) which they combined to obtain Intensity-Duration-Frequency (IDF) curves. The application of this model showed that the developed IDF curve was more accurate than the previously suggested IDF curves and the duration separation method could be applied automatically without hand calculations.

Rainfall data and its analysis are known to serve many useful purposes in developing countries like Nigeria. It measures the resulting depth–duration–frequency (or probability curves) as used in various ways. For example, IDF curves are commonly used in the design of drainage structures such as parking lots, culverts and storm drains. The curves are also used as input to rainfall–runoff models, helping scientists and engineers to predict floods and landslides. Dam failure predictions and spillway designs are often based on the magnitude of an extremely rare, large flood. Rainfall intensity-duration-frequency (IDF) curves are used for the estimation of peak discharge of runoff in a catchment area, by the rational method, for subsequent sizing of hydraulic channels and other water ways. For selected storm duration and frequency, the design rainfall intensity is normally estimated from a set of statistically derived rainfall intensity – duration frequency or IDF curves appropriate to that region. It is for some of these reasons amongst many that this study was done to develop Rainfall Intensity Duration Frequency Models for Abuja metropolis.

2. Materials and Methods

2.1 Study area

Abuja is the capital city of Nigeria. It lies between Latitude 8° 24' 35" N and 9° 22' 11" N and Longitudes 6° 47' 23" E and 7° 40' 47" E. The study area has a landmass of approximately 7,315 square kilometers of which the actual city Abuja, occupies 275.3 square kilometers. Its natural resources include marble, tin, mica, zinc, lead, tantalite and clay. There are two distinct seasons (rainy and dry) experienced at the study area The temperature of the study area is generally high during the day between the month of February and March because of its location in the tropical sub-humid climatic belt. The onset of rains in April ushers in a remarkable decline in temperature due to the blanket effect of cloud cover over the region. This continues until the end of October when further decline is made possible in November/December by the advent of the harmattan winds. A temperature level as high as 41°C can be reached in the month of March when high temperatures are observed. On the other hand, a minimum temperature as low as 16°C and 20°C is also observed in December and January respectively. The general relief of Abuja is an undulating lowlands and a network of hills developed by granites, migmatites, pegmatites and gneisses [17].

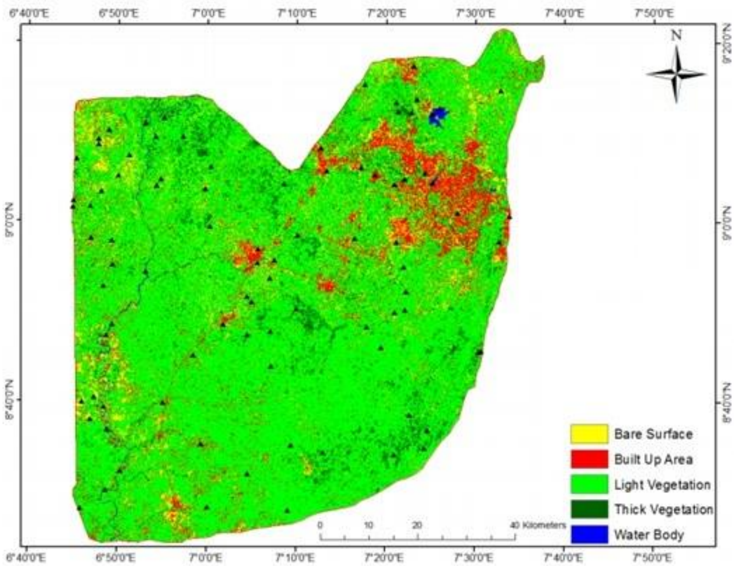

Fig. 1 Map of the Study Area- Abuja metropolis, FCT, Nigeria[18]

2.2 Data Collection

Rainfall data from the climatological stations in Abuja were obtained from the Nigeria Meteorological Agency (NIMET). The rainfall data obtained presented the amount of precipitation for thirty - one years, ranging from 1988 – 2018. The annual maximum rainfall amounts were selected and the durations presented thus; 10, 20, 30, 60, 120, 180, 360, 720 and 1440 minutes for each of the year.

2.3 Data Analysis

The rainfall data obtained from NIMET was sorted and the annual maximum rainfall amounts at specified durations of 10, 20, 30, 60, 120, 180, 360, 720 and 1440 minutes were extracted. To obtain the rainfall intensities in mm/hr, the rainfall amounts was divided by the corresponding durations in hours which were then ranked in descending other as presented in Table 1. In the same vein, the log- equivalent was also computed along with statistical parameters such as mean, standard deviation and coefficient of skewness. The Weibull formula (see Equation 1) was used in calculating the return periods for the non-probability distribution function (nPDF) IDF models.

$$T_r = \frac{n+1}{m} \tag{1}$$

Where T_r = return period (years), m = order of ranking and n = total number of observations

2.4 Probability distribution function (PDF)

Several probability distribution functions were used to develop the IDF relationships. Maximum rainfall intensities were also computed using the commonly available probability distribution functions (PDF) which include – Gumbel Extreme Value Type-1 (Gumbel EVT-1), Normal (N), Log Normal (LN), Pearson Type-3 (PT-3) and Log-Pearson Type-3 (LPT-3) distributions. IDF curves were obtained by plotting rainfall intensities against the durations for specified return periods. Equation 2 as developed by Chow [19] and cited by Nwaogazie and Sam [2] gave the approximate magnitude of a randomly selected event of rainfall intensity as:

$$P_T = P_{ave} + K_T S \tag{2}$$

Where K_T = frequency factor, S = standard deviation, and P_{ave} = mean. The parameters S and K_T are functions of return period T and the PDF type. Hence, to determine the value of the rainfall intensity required, the frequency factor is then computed along with the mean and standard deviation of the observed data and substituted into Equation (2). The frequency factor K_T for the various PDF is given thus:

2.4.1 Gumbel EVT-1 Distribution function

$$K_T = \frac{\sqrt{6}}{\pi}\left[0.5772 + In\left[In\left[\frac{T}{T-1}\right]\right]\right] \tag{3}$$

Where T = return period in years.

2.4.2 Normal Distribution

$$K_T = Z = W - \frac{2.515517+0.802853w+0.010328w^2}{1+1.432788w+0.189269w^2+0.001308w^3} \quad (4)$$

$$\text{Where } W = \left[In\left(\frac{1}{P^2}\right)\right]^{1/2} \text{ for } (0 < P \leq 0.5 \quad (5)$$

$P = \frac{1}{T}$ = Probability function and z = standard normal variate

2.4.3 Pearson Type-3 (PT-3) Distribution

The frequency factor can be obtained from a standard frequency factor table which is provided in various well published literatures. On the other hand, it can be obtained from an approximate method given in Equation (6) by Sangal and Kallio [20].

$$K_T = Z + (z^2 - 1)k + 1/3(z^3 + 6z)k^2 - (z^2 - 1)k^3 + zk^4 + 1/3k^5 \quad (6)$$

Where $k = \frac{C_s}{6}$ for $C_s \neq 0$, but as $C_s = 0$, $K_T = Z$.

2.4.4 Log-Pearson Type-3 (LPT-3) Distribution

The frequency factor is computed similar to the PT-3 distribution but with an exception. The mean, standard deviation and coefficient of skewness were obtained by transforming the data logarithmically. The rainfall intensity value can also be computed using Equation (7) below by Chow [19].

$$logP_T = \log P_{ave} + K_T logS \quad (7)$$

2.4.5 Log-Normal Distribution

The frequency factor is obtained from Equations (4) and (5) after all the rainfall values are converted to logarithmic form to include statistical parameters such as (P_T, S and C_s). The magnitude of the rainfall intensities was computed using equation (7).

2.5 Probability and non-probability IDF derived Models

The IDF models involved calibrating the PDF (power model) using rainfall intensity-duration data for specified return periods 2, 5, 10, 25, 50 and 100 years and the nPDF (quotient model) using weibull formula to determine the frequencies. A total of 5 probability distribution functions comprising GEVT - 1, PT - 3, LPT-3, Normal and LN distributions were used to develop the IDF models for the PDF. The parameters of the design storm intensity for a given period of recurrence were estimated. The models were developed by calibrating the power-quotient models. The calibration involved determination of the numerical values of the regional constants as presented in Equation (8). Additional Equations were also adopted as presented in Equation (9) and (10).

$$I = \frac{cT^m}{t^e} \quad (8)$$

$$I = \frac{c}{b + t} \quad (9)$$

$$I = ct^{e} \quad (10)$$

Where I = rainfall Intensity (mm/hr), t = duration (minutes) and T = return period (years); c, m, e and b location parameters of the study area.

2.6 Chi-squared goodness of fit test

The Chi-squared goodness of fit test was executed in the downloadable software called EasyFit available at *http://www.mathwave.com/easyfit-distribution-fitting.html*. All test values and statistics were produced from this program. The goodness of fit test was used to examine the relationship between observed and expected frequencies in order to determine the type of probability distribution function (PDF) that best fit the rainfall data of the study area.

3. Results and discussion

The study aims at developing IDF curves, and by extension formulate or derive models for the purpose of estimating rainfall intensities of the locality under study. The annual rainfall intensities for different durations and their ranking are presented in Table 1. Parameters like mean, standard deviation, and coefficient of skewness were also presented in Table 1. Tables 2 - 6 shows the computed frequency precipitation values (P_T) and intensities (I_T) for different durations and return periods using methods such as the Gumbel EVT – 1, Normal, Log – Normal, Pearson Type – 3 and Log – Pearson Type 3 for Abuja metropolis. The summaries of Chi-Squared Goodness of Fit test for the Distribution functions used were presented in Table 7. The summary of the general rainfall IDF models developed for each PDF along with their R^2 values, which gave rise to the selection of Gumbel's method as the best in estimating rainfall intensities is presented in Table 8. The frequency duration curves plotted from Gumbel's Model based of the highest R^2 is presented in Figure 2. The summary of nPDF-IDF (quotient) model developed for Abuja metropolis for some specified return periods along with their R^2 values is presented in Table 9. The parameter values of the different PDF models which specified location parameters c, m and e is presented in Table 10. The test of significance of difference between the authors results and [21] as well as [22] using t-test were presented in Tables 11 &12.

Table 1 Annual Rainfall intensities for different Durations and their ranking

Rank	Duration (Min)								
	10	**20**	**30**	**60**	**120**	**180**	**360**	**720**	**1440**
1	128.24	96.67	64.20	34.10	20.35	23.77	14.68	12.18	8.27
2	126.47	88.79	56.40	32.30	17.85	22.70	14.47	11.78	7.21
3	105.29	70.61	55.20	31.80	16.15	22.27	14.37	11.43	7.21
4	93.88	69.09	53.80	26.50	15.50	21.13	13.32	11.06	6.80
5	90.59	66.97	52.80	25.20	15.40	20.80	11.83	10.62	6.39
6	84.71	64.85	43.40	23.90	14.55	18.53	11.20	9.83	6.26
7	80.59	55.76	40.60	22.00	14.30	17.93	11.13	8.30	4.01
8	77.65	53.64	37.80	21.80	14.30	17.69	10.52	7.49	0
9	72.35	52.73	36.40	21.40	14.10	17.57	10.35	7.46	0
10	71.76	49.39	35.60	21.20	13.95	16.83	10.22	7.12	0
11	71.18	48.79	35.20	20.70	13.95	16.73	10.05	7.03	0
12	69.41	47.88	35.20	19.70	13.65	16.63	9.93	6.67	0
13	68.82	46.97	35.00	19.20	13.55	16.30	9.80	6.48	0
14	67.06	45.76	34.40	18.70	12.40	16.20	9.57	6.47	0
15	66.47	44.85	33.40	17.80	12.40	16.17	9.15	6.33	0
16	63.53	44.85	32.80	17.20	12.25	16.13	8.77	6.28	0
17	61.76	43.64	32.60	16.60	11.95	15.53	8.65	0	0
18	60.59	42.12	31.40	16.60	11.95	15.47	8.58	0	0
19	58.82	41.52	30.20	16.00	11.80	15.10	8.40	0	0
20	57.06	41.21	29.60	16.00	11.75	15.07	7.97	0	0
21	54.71	40.30	29.40	15.80	11.55	15.03	7.82	0	0
22	53.53	39.70	29.40	15.80	11.35	14.60	7.68	0	0
23	51.76	38.48	27.80	15.80	11.35	13.43	7.47	0	0
24	48.82	37.88	27.60	15.20	11.25	12.43	7.35	0	0
25	48.24	36.97	25.20	15.10	11.15	12.37	7.32	0	0
26	46.47	36.06	25.20	14.40	10.85	10.77	6.45	0	0
27	45.88	35.15	22.60	14.20	10.80	10.07	6.28	0	0
28	45.29	34.55	22.40	14.10	10.30	9.97	5.53	0	0
29	45.29	31.21	20.20	13.50	9.90	7.87	5.47	0	0
30	37.65	30.00	18.80	13.20	9.55	6.70	5.42	0	0
31	35.88	24.55	18.60	13.20	8.95	5.43	4.48	0	0
Mean	67.41	48.42	34.62	19.32	12.87	15.39	9.17	4.40	1.49
Standard Deviation	22.99	16.33	11.55	5.70	2.47	4.47	2.70	4.61	2.86
Coefficient of Skewness	1.18	1.40	0.96	1.27	1.05	-0.32	0.44	0.30	1.52

Table 2 Computed frequency precipitation values (p_t) and intensities (I_t) for different durations and return periods using gumbel method for Abuja

Computed precipitation (P_T) and intensity (I_T) Gumbel method

T (yrs)	**10min**			**20min**			**30min**		
	P_{ave} = 11.46		**S = 4.07**	**P_{ave} = 15.98**		**S = 5.99**	**P_{ave} = 17.31**		**S = 6.36**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	-0.16	10.79	64.63	-0.16	14.99	44.99	-0.16	16.27	32.53
5	0.72	14.39	86.14	0.72	20.28	60.85	0.72	20.55	41.1
10	1.305	16.77	100.41	1.31	23.79	71.37	1.31	24.27	48.55
25	2.04	19.78	118.41	2.04	28.21	84.65	2.04	28.97	57.95
50	2.59	22	131.76	2.59	31.49	94.49	2.59	32.46	64.92
100	3.14	24.22	145.04	3.14	34.76	104.28	3.14	35.92	71.85
	60min			**120min**			**180min**		
	P_{ave} = 19.32		**S = 6.31**	**P_{ave} = 35.07**		**S = 6.92**	**P_{ave} = 46.18**		**S = 14.71**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	-0.16	18.29	18.29	-0.16	34.78	17.39	-0.16	43.77	14.59
5	0.72	23.86	23.86	0.72	40.04	20.02	0.72	56.76	18.92
10	1.31	27.55	27.55	1.31	44.1	22.05	1.31	65.38	21.79
25	2.04	32.21	32.21	2.04	49.21	24.6	2.04	76.26	25.42
50	2.6	35.67	35.67	2.59	53	26.5	2.59	84.32	28.11
100	3.14	39.11	39.11	3.14	56.77	28.38	3.14	92.34	30.78
	360min			**720min**			**1440min**		
	P_{ave} = 55.01		**S = 17.94**	**P_{ave} = 102.38**		**S = 29.03**	**P_{ave} = 158.20**		**S = 38.63**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	-0.16	52.07	8.68	-0.16	97.62	8.14	-0.164	151.87	6.33
5	0.72	67.91	11.32	0.721	23.26	10.27	0.72	185.97	7.75
10	1.31	78.42	13.07	1.311	40.27	11.69	1.31	208.61	8.69
25	2.04	91.68	15.28	2.04	161.73	13.48	2.04	237.16	9.88
50	2.6	101.5	16.92	2.59	177.64	14.8	2.59	258.32	10.76
100	3.14	111.3	18.55	3.14	193.47	16.12	3.14	279.38	11.64

Table 3 Computed frequency precipitation values (p_t) and intensities (I_t) for different durations and return periods using (pearson type III) method for Abuja

Computed precipitation (P_T) and intensity (I_T) Pearson Type III method									
T(yrs)	10min			20min			30min		
	P_{ave} = 11.46		S = 4.07	P_{ave} = 15.98		S = 5.99	P_{ave} = 17.31		S = 6.36
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.21	10.6	63.6	-0.21	14.72	44.15	-0.15	16.35	32.7
5	0.72	14.38	86.27	0.72	20.28	60.84	0.77	22.19	44.37
10	1.34	16.91	101.44	1.33	23.96	71.89	1.34	25.82	51.65
25	2.11	20.04	120.26	2.11	28.6	85.8	2.02	30.17	60.33
50	2.67	22.32	133.94	2.67	31.94	95.82	2.51	33.24	66.48
100	3.22	24.55	147.29	3.21	35.21	105.62	2.97	36.18	72.36
	60min			120min			180min		
	P_{ave} = 19.32		S = 6.31	P_{ave} = 35.07		S = 6.92	P_{ave} = 46.18		S = 14.71
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.19	18.09	18.09	-0.183	3.84	16.92	0.05	46.94	15.65
5	0.73	23.94	23.94	0.75	40.23	20.12	0.85	58.74	19.58
10	1.34	27.77	27.77	1.34	44.35	22.17	1.24	64.48	21.49
25	2.09	32.48	32.48	2.06	49.34	24.67	1.64	70.3	23.43
50	2.63	35.88	35.88	2.58	52.92	26.46	1.88	73.91	24.64
100	3.15	39.18	39.18	3.08	56.38	28.19	2.1	77.03	25.68
	360min			720min			1440min		
	P_{ave} = 55.01		S = 17.94	P_{ave} = 102.38		S = 29.03	P_{ave} = 158.20		S = 38.63
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.07	53.76	8.96	-0.09	99.75	8.31	0.2	165.77	6.91
5	0.81	69.62	11.6	0.8	125.73	10.48	0.84	190.79	7.95
10	1.32	78.66	13.12	1.33	140.87	11.74	1.08	200.1	8.34
25	1.89	88.85	14.81	1.92	158.24	13.19	1.28	207.62	8.65
50	2.27	95.76	15.96	2.33	170.15	14.18	1.38	211.33	8.81
100	2.63	102.2	17.03	2.72	181.33	15.11	1.45	214.01	8.92

Table 4 Computed frequency precipitation values (P_T) and intensities (I_T) for different durations and return periods using log pearson Type III method for Abuja

Computed precipitation (P_T) and intensity (I_T) Log Pearson Type III method

T (yrs)	Duration (min)											
	10min				**20min**				**30min**			
	K	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**
2	-0.04	1.03	10.72	64.32	-0.06	1.20	14.79	44.37	-0.03	1.21	16.13	32.26
5	0.83	1.15	14.23	85.38	0.82	1.30	19.91	59.73	0.83	1.34	21.80	43.60
10	1.31	1.22	16.63	99.78	1.31	1.37	23.50	70.53	1.30	1.41	25.67	51.34
25	1.84	1.30	19.77	118.60	1.86	1.45	28.29	84.87	1.81	1.49	30.70	61.40
50	2.19	1.35	22.18	133.08	2.23	1.51	32.05	96.15	2.15	1.54	34.53	69.06
100	2.51	1.39	24.65	147.90	2.57	1.56	35.96	107.88	2.46	1.59	38.46	76.92
	60min				**120min**				**180min**			
	K	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**
2	-0.07	1.26	18.12	18.12	0.03	1.54	34.59	17.30	0.08	1.65	44.89	14.96
5	0.81	1.37	23.48	23.48	0.85	1.61	40.83	20.42	0.86	1.78	60.11	20.04
10	1.32	1.44	27.24	27.24	1.26	1.65	44.46	22.23	1.22	1.84	68.85	22.95
25	1.89	1.51	32.23	32.23	1.66	1.68	48.08	24.04	1.56	1.90	78.58	26.19
50	2.28	1.56	36.12	36.12	1.69	1.69	48.53	24.26	1.77	1.93	85.03	28.34
100	2.64	1.60	40.17	40.17	2.20	1.73	53.83	26.91	1.95	1.96	90.90	30.30
	360min				**720min**				**1440min**			
	K	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**	**K**	**P***	**P_T**	**I_T**
2	0.01	1.72	52.45	8.74	-0.03	1.99	97.91	8.16	0.05	2.19	155.90	6.50
5	0.85	1.84	69.20	11.53	0.83	2.09	124.00	10.33	0.85	2.29	195.20	8.13
10	1.27	1.90	79.79	13.30	1.30	2.15	141.10	11.75	1.25	2.34	217.90	9.08
25	1.72	1.97	92.70	15.45	1.82	2.21	162.60	13.55	1.65	2.39	243.70	10.15
50	2.01	2.01	102.00	17.00	2.16	2.25	178.50	14.86	1.89	2.42	261.20	10.88
100	2.27	2.05	111.10	18.52	2.47	2.29	194.50	16.21	2.11	2.44	277.40	11.56

Table 5 Computed frequency precipitation values (P_T) and intensities (I_t) for different durations and return Periods using normal distribution for Abuja.

Computed precipitation (P_T) and intensity (I_T) Normal Distribution method									
T(yrs)	**10min**			**20min**			**30min**		
	P_{ave} = 11.46		**S = 4.07**	**P_{ave} = 15.98**		**S = 5.99**	**P_{ave} = 17.31**		**S = 6.36**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	0.00	11.46	68.76	0.00	15.98	47.93	0.00	17.31	34.62
5	0.84	14.88	89.30	0.84	21.01	63.04	0.84	22.66	45.32
10	1.28	16.67	100.05	1.28	23.65	70.95	1.28	25.46	50.92
25	1.75	18.58	111.50	1.75	26.46	79.38	1.75	28.44	56.88
50	2.05	19.82	118.90	2.05	28.27	84.82	2.05	30.37	60.74
100	2.33	20.93	125.55	2.33	29.91	89.72	2.33	32.10	64.21
	60min			**120min**			**180min**		
	P_{ave} = 19.32		**S = 6.31**	**P_{ave} = 35.07**		**S = 6.92**	**P_{ave} = 46.18**		**S = 14.71**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	0.00	19.32	19.32	0.00	35.07	17.54	0.00	46.18	15.39
5	0.84	24.63	24.63	0.84	40.89	20.45	0.84	58.56	19.52
10	1.28	27.41	27.41	1.28	43.94	21.97	1.28	65.04	21.68
25	1.75	30.37	30.37	1.75	47.18	23.59	1.75	71.95	23.98
50	2.05	32.28	32.28	2.05	49.28	24.64	2.05	76.41	25.47
100	2.33	34.00	34.00	2.33	51.16	25.58	2.33	80.42	26.81
	360min			**720min**			**1440min**		
	P_{ave} = 55.01		**S = 17.94**	**P_{ave} = 102.38**		**S = 29.03**	**P_{ave} = 158.20**		**S = 38.63**
	K	**P_T**	**I_T**	**K**	**P_T**	**I_T**	**K**	**P_T**	**I_T**
2	0.00	55.01	9.17	0.00	102.38	8.53	0.00	158.20	6.59
5	0.84	70.11	11.68	0.84	126.82	10.57	0.84	185.97	7.95
10	1.28	78.00	13.00	1.28	139.60	11.63	1.28	208.61	8.65
25	1.75	86.43	14.40	1.75	153.23	12.77	1.75	237.16	9.41
50	2.05	91.86	15.31	2.05	162.03	13.50	2.05	258.32	9.90
100	2.33	96.75	16.13	2.33	169.94	14.16	2.33	279.38	10.34

Table 6 Computed frequency precipitation values (P_T) and intensities (I_T) for different durations and return periods using log normal method for Abuja

Computed precipitation (PT) and intensity (IT) Log Normal method

T(yrs)	10min				20min				30min			
	P^*_{ave} = 1.04		S* = 0.14		P^*_{ave} = 1.18		S* = 0.15		P^*_{ave} =0.21		S* = 0.15	
	K	P*	P_T	I_T	K	P*	P_T	I_T	K	P*	P_T	I_T
2	0.00	1.04	10.86	65.19	0.00	1.18	15.07	45.19	0.00	1.21	16.29	32.59
5	0.84	1.16	14.30	85.77	0.84	1.30	20.04	60.12	0.84	1.34	21.87	43.74
10	1.28	1.22	16.50	99.03	1.28	1.37	23.27	69.79	1.28	1.41	25.51	51.19
25	1.75	1.28	19.24	115.41	1.75	1.44	27.28	81.83	1.75	1.48	30.06	60.12
50	2.05	1.33	21.24	127.42	2.05	1.48	32.05	90.68	2.05	1.52	33.42	66.84
100	2.33	1.37	23.21	139.27	2.33	1.52	35.96	99.48	2.33	1.57	36.76	73.52
	60min				120min				180min			
	P^*_{ave}=1.26		S* = 0.13		P^*_{ave}=1.55		S* = 0.09		P^*_{ave} =1.64		S* = 0.16	
	K	P*	P_T	I_T	K	P*	P_T	I_T	K	P*	P_T	I_T
2	0.00	1.26	18.28	18.28	0.00	1.55	35.08	17.54	0.00	1.64	43.45	14.48
5	0.84	1.37	23.42	23.42	0.84	1.62	41.60	20.80	0.84	1.78	59.74	19.91
10	1.28	1.43	26.65	26.65	1.28	1.66	45.49	22.74	1.28	1.85	70.58	23.53
25	1.75	1.49	30.59	30.59	1.75	1.70	50.04	25.02	1.75	1.93	84.31	28.10
50	2.05	1.52	33.44	33.44	2.05	1.73	53.21	26.61	2.05	2.00	94.56	31.52
100	2.33	1.56	36.23	36.23	2.33	1.75	56.23	28.12	2.33	2.02	104.83	34.94
	360min				720min				1440min			
	P^*_{ave}= 1.72		S* = 0.15		P^*_{ave}= 2.00		S* = 0.12		P^*_{ave}=2.19		S* = 0.12	
	K	P*	P_T	I_T	K	P*	P_T	I_T	K	P*	P_T	I_T
2	0.00	1.72	52.24	8.71	0.00	2.00	98.86	8.24	0.00	2.19	153.82	6.41
5	0.84	1.84	69.15	11.53	0.84	2.10	124.48	10.37	0.84	2.29	194.67	8.11
10	1.28	1.90	80.09	13.35	1.28	2.15	140.41	11.70	1.28	2.34	220.24	9.18
25	1.75	1.97	93.67	15.61	1.75	2.20	159.66	13.31	1.75	2.40	251.13	10.46
50	2.05	2.02	103.61	17.27	2.05	2.24	173.46	14.46	2.05	2.44	273.40	11.39
100	2.33	2.05	113.48	18.91	2.33	2.27	186.94	15.58	2.33	2.47	295.05	12.29

Table 7 Summary of Chi-Squared goodness of fit test for the PDF

Station	PDF	Duration								
		10	20	30	60	120	180	360	720	1440
Abuja	Gumbel EVT-1	3.45	0.99	3.12	24.84*	8.81	0.37	1.62	1.66	2.93
	Normal	10.55	5.3	14.01*	35.88*	15.01*	2.43	5.45	0.71	1.04
	Log-Normal	2.57	1.36	6.62	33.52*	10.49	0.71	3.2	0.21	1.3
	Log-Pearson Type -3	1.39	1.74	3.25	21.45*	9.22	0.58	1.31	1.46	3.14
	Pearson Type -3	5.65	1.75	8.57	26.37*	8.9	2.09	2.3	1.52	2.52

For α = 0.05, degree of freedom = 5, the critical region is $\chi_{cal} > 11.070$

For α = 0.01, degree of freedom = 5, the critical region is $\chi_{cal} > 15.086$
* means χ^2 significant at α = 0.05

Table 8 Summary of the general rainfall IDF models developed for each distribution function

Distributions	Models	R^2
Gumbel EVT-1	$I=\frac{23.16T^{0.21}}{t^{0.55}}$	0.9927
Pearson Type III	$I=\frac{25T^{0.19}}{t^{0.56}}$	0.9323
Log Pearson Type III	$I=\frac{24.84T^{0.18}}{t^{0.54}}$	0.9304
Normal	$I=\frac{25.43T^{0.19}}{t^{0.53}}$	0.9323
Log Normal	$I=\frac{26T^{0.18}}{t^{0.52}}$	0.9304

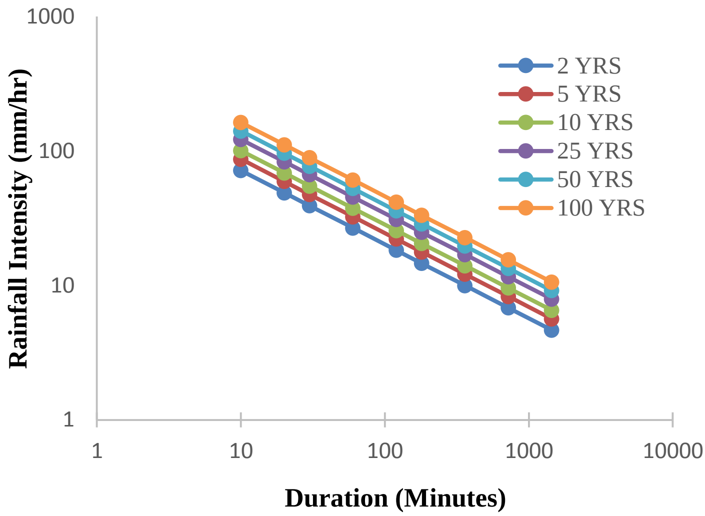

Fig. 2 Frequency duration curves from Gumbel's Model

Table 9 Summary of nPDF-IDF (Quotient) model developed for Abuja metropolis

Model	Return Period	R^2
$I = \frac{64.94}{t + 1.71}$	2	0.8296
$I = \frac{79.37}{t + 1.59}$	5	0.8245
$I = \frac{101.01}{t + 1.75}$	10	0.7538
$I = \frac{100}{t + 1.52}$	16	0.8043
$I = \frac{100}{t + 1.32}$	32	0.8634

Table 10 The parameter values of the different PDF models

Region	**Parameter**	**Methods**				
Abuja		Gumbel	Normal	Log-Normal	LPT-3	PT-3
	c	23.16	25.43	26	24.84	25
	m	0.25	0.19	0.18	0.18	0.19
	e	0.55	0.53	0.52	0.55	0.56

Table 11 Test of significance of difference between the Author's results and Oyebande and Longe (1990) using t-test

Rainfall duration (hr)	Calculated t value	Level of significance (α)	Degree of freedom	Critical value	Remarks
0.17	-1.7858	0.05	10	2.228	No significant difference
		0.01	10	3.169	
0.33	-1.9437	0.05	10	2.228	No significant difference
		0.01	10	3.169	
0.5	-2.0347	0.05	10	2.228	No significant difference
		0.01	10	3.169	
1	-2.1872	0.05	10	2.228	No significant difference
		0.01	10	3.169	
2	-0.7053	0.05	10	2.228	No significant difference
		0.01	10	3.169	
3	0.2437	0.05	10	2.228	No significant difference
		0.01	10	3.169	
6	1.8878	0.05	10	2.228	No significant difference
		0.01	10	3.169	
12	3.403	0.05	10	2.228	Significantly different
		0.01	10	3.169	
24	4.6561	0.05	10	2.228	Significantly different
		0.01	10	3.169	

Table 12 Test of significance of difference between the Authors results and Akpen*et al.* (2019) using t-test

Rainfall duration (hr)	Calculated t value	Level of significance (α)	Degree of freedom	Critical value	Remarks
0.17	-12.68	0.05	10	2.228	Significantly different
		0.01	10	3.169	
0.33	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
0.5	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
1	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
2	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
3	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
6	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
12	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	
24	-12.9684	0.05	10	2.228	Significantly different
		0.01	10	3.169	

The rainstorms with high intensity in Abuja were those of relatively short durations (0.17hr to 0.5hr). Their occurrence in any given year could likely trigger a flash flood especially in flood plain areas. However the magnitude of the flood to be triggered by the high rainstorms would vary with different rainfall intensities. As the rainfall intensity increases, the volume of the flood will also increase. The highest rainfall intensity was that of duration 0.16 hr with value of 163.18 mm/hr. This is a rare storm with return period of 100 years (Figure 2). The occurrence of this rainstorm can lead to flash flood. For a two 2 years return period, the value of 0.16 hr duration gives an intensity of 71.76 mm/hr. This can also result in flood when it occurs. The rainfall intensities of durations 1 to 3hrs were medium and lower than the intensities of shorter durations. The lowest value of the one hour rainstorm was 26.79 mm/hr with a return period of 2 years. Rain storms of 6 to 24 hrs durations in Abuja had the lowest rainfall intensities. The highest intensity of these rainstorms was that of 6 hours having an intensity of 22.74 mm/hr with a return period of 100 years. The lowest intensity was 10.00 mm/hr with a return period of 2 years. The intensities of these rainstorms might not be able to contribute significantly to flood occurrence in Abuja like those of the medium and high rainstorms.

The chi-squared test was used to test the reliability of the techniques used and to decide which of the type of distributions best fit the data available. The result of the chi-squared test was presented in Table 7. As it is seen, most of the data fit the distributions at the level of significance of α = 0.05. However, the fitting was not good at 60 minutes for all the techniques. Gumbel distribution was ranked the best fit among the statistical techniques used and was adopted. This implies that the Gumbel distribution was more reliable for prediction of rainfall events in the study area.

A validation process carried out to check the predictive capacity of the developed models produced a Standard Error Estimate of 17.06. This shows that the models have high capacity to estimate the rainfall events of the study area. The IDF models developed using PDF and nPDF were applied in the determination of discharge using the rational method to design a typical rectangular channel. Both model types were found good for use in design of hydraulic structures.

The t-test of significance was used in comparing the derived IDF models with that of [21 & 22] using GEV distribution method, at degree of freedom of 10 and levels of significance of 0.05 and 0.01. The result showed that there were no significant difference observed between the results of this study and the results of work done by [21] except at durations of 12 hours and 24 hours. However, significant difference was observed between the results of this study and the results of work done by [22]. This suggests that the location of the study area and Lokoja are not in the same rainfall zone.

3.1 Application of Developed IDF Models

One of the practical applications of these developed models is in drain and culvert design. These calibrated models help Engineers to determine the maximum design discharge. A hydraulic drain design used to demonstrate the practical application of these models calibrated is presented as follows:

Frequency (Return Period), R = 10 years

Duration of Rainfall, t = 2hr (120mins)

Transverse slope, s = 0.005

Area of Runoff, A =0.52km^2(520x10^{3}m^2)

Rational Formula Coefficient, C = 0.5

a. Power Model: Substituting design parameter into the model equation for 120 minutesrainfall duration and return period of 10 years, the Rainfall Intensity is given as;

$$I = \frac{23.16T^{0.21}}{t^{0.55}} \tag{11}$$

$$I = \frac{23.16\ X10^{0.21}}{2^{0.55}} \tag{12}$$

I = 25.65 mm/hr = 7.13 x 10^{-6} m/s

By inputting the value of I in the discharge model

$$Q = CIA \tag{13}$$

Q = 0.50 (7.13 x 10^{-6}) m/s x 520 x 10^3 m^2

Q = 1.8538 m^3/s

Using Manning's Equation, [23] we obtain:

$$Q = \frac{AR^{2/3}S^{1/2}}{n} \tag{14}$$

For best hydraulic section for rectangular channels, the hydraulic radius is given by Equation 15 [24]:

$$R_{max} = \frac{y}{2} \tag{15}$$

Substituting hydraulic radius, R_{max} into Manning's equation,

where b = 2y, A = $2y^2$ and A = y x b gives:

$$Q = \frac{2y^2 (\frac{y}{2})^{2/3} S^{1/2}}{n} \tag{16}$$

$$= \frac{1.2599 y^{8/3} S^{1/2}}{n}$$

Solving for y:

$$y = \left(\frac{Qn}{1.2599 S^{\frac{1}{2}}}\right)^{3/8} \tag{17}$$

$$y = \left(\frac{1.8538 \text{ X } 0.013}{1.2599 \text{X } 0.005^{\frac{1}{2}}}\right)^{3/8}$$

$$= \quad 0.61 \text{ m}$$

b = 2y =1.22m

Select 1.2 m x 0.70 m

Check for velocity using Equation 17 [24]:

$$V = \frac{Q}{A} \tag{18}$$

$$V = \frac{1.8538}{1.2 \text{ X } 0.70}$$

V= 2.2 m/s O.K

All the drainage channels of a basin with velocities ranging from 2 to 4m/s are said to be okay [25].

b. Quotient Model: Substituting design parameter into the model equation for 120 minutes (2 hrs)rainfall duration and return period of 10 years, the Rainfall Intensity is given as;

$$I = \frac{101.01}{2+1.75} \quad (19)$$

$$I = \frac{101.01}{2 + 1.75}$$

I = 26.94 mm/hr = 7.482 x 10^{-6} m/s

Substituting in Equation (13),
Q = 0.50 (7.482 x 10^{-6}) m/s x 520 x $10^3 m^2$

Q = 1.945 m^3/s

Substituting Q in 16;

$$y = \left(\frac{1.945 \text{ X } 0.013}{1.2599X\ 0.005^{\frac{1}{2}}}\right)^{3/8}$$

= 0.624 m
b = 1.248 m
For practical reasons select a section 1.20 m x 0.70 m
Check for velocity,

$$V = \frac{1.945}{1.2\ X\ 0.70}$$

V= 2.2 m/s O.K

4. Conclusion

Intensity-duration-frequency data are needed by hydrologists and engineers involved in planning and design of hydraulic structures. Extracted rainfall data obtained from the Nigerian Metrological Agency were used to generate the IDF models and curves for Abuja. The intensities and inverse relationship of rainfall amounts and durations for 31 years were determined. The PDF and nPDF model types were used to determine rainfall intensity and the inverse relationship from its amount and duration for the rainfall data. The result of the IDF curves showed that shorter duration of rainfall has higher intensities. Five probability distribution functions of Gumbel Extreme Value EVT-1, Pearson Type III (PT-3), Log Pearson Type III (LPT-3), Normal and Log-Normal Distributions were used to develop the IDF models. However, the model developed using Gumbel Extreme Value ranked the best fit with an R^2 value of 0.9927 (see Table 8). Also, five models were developed using the nPDF (quotient equation). All the models have high values of coefficient of correlation ranging from 0.7538 to 0.8634. The IDF models developed for Abuja from 1951 - 1978 showed no significant difference when compared with results from [19] for Lokoja using t-test of significance except for durations of 12 and 24 hours. This is possibly because Abuja and Lokoja falls within the same geographic zones as at then, thus making it possible to share same rainfall characteristics. But in comparison with the values obtained from 1979 – 1991, the results differ significantly with results of [20] for Lokoja at all durations likely because of the extent climate change has distorted our geographic formation. The developed Intensity -Duration-Frequency models were found good in the practical application of the design of hydraulic structures where velocity was accurately estimated. This will help in determining the type and size of hydraulic structures to be constructed. This is so because the velocity estimated from the models developed earlier falls within the velocity specified by Adaba and Agunwamba (2014) [25].

Acknowledgement

We sincerely appreciate the Nigerian Metrological Agency Abuja for making available the data that was used for the study.

References

1. Adewale FO and Adejoh I. Intensity, Duration And Frequency of rainstorms in Lokoja. ScienceWorld Journal, 2017;12(2):36 – 40.
2. Nwaogazie IL and Sam MG. Probability and non-probability rainfall Intensity-Duration-Frequency modeling for port-harcourt metropolis, Nigeria. International Journal of Hydrology, 2019;3(1):66 –75.
3. Rapheal MW. Estimating Rainfall Intensity – Duration – Frequency (IDF) curves for a tropical river basin. International Journal of Advanced Research and Publications, 2019;3(4):99 – 106.
4. Alemaw BF and Chaoka RT. Regionalization of rainfall Intensity-Duration Frequency (IDF) curves in Botswana. Journal of WaterResource and Protection, 2016;8(12): 1128-1144.
5. Carlier E and Khattabi JE. Impact of global warming on Intensity-Duration-Frequency (IDF)relationship of precipitation, a case study of Toronto,Canada. Open Journal of Modern Hydrology, 2016; 6 (1): 1-7.
6. Wagesho N and Claire M. Analysis of rainfall Intensity-Duration Frequency relationship forRwanda. Journal of Water Resource and Protection, 2016;8(7):706-723.
7. Nwaogazie LL and Duru EO. Developing Rainfall-Intensity-Duration-Frequency Models for PortHarcourt City. Nigeria Society of Engineers TechnicalTransaction, 2002;37(2):19-32.
8. Nwoke HU and Okoro BC. Rainfall-Intensity-Frequency Regime for Warri, South-South. Nigeria Journal of New Clues in Sciences, 2012;2:42-49.
9. Oyebande L. Rainfall Intensity-Duration-Frequency Curves and Maps for Nigeria. Occasional PaperSeries, 1980; No. 2, Department of Geography, Univ. of Lagos.
10. Oyebande L. Deriving Rainfall Intensity-Duration-Frequency relationships and estimates for regions withinadequate data. Hydrological Sciences Journal, 1982; 27(3):1024 –1031.
11. Akpan SU and Okoro BC. Dev eloping Rainfall Intensity-Duration- Frequency Models for Calabar City, South-South,Nigeria. American Journal of EngineeringResearch, 2013;2(6):19- 24.
12. Antigha REE and Ogarekpe NM. Development of Intensity, Duration and Frequency Curves for CalabarMetropolis, South-South Nigeria. The InternationalJournal of Engineering and Science, 2013;2(3):39 - 42.
13. Itodo D. Two die in Mararaba Rainstorm. Daily Trust.[Document on the Internet]. Online MSc. Thesis, Ahmadu Bello University; 2012 [cited 2020 March 29]. Available from: http//;www.DailyTrust.com.ng
14. Umeh O. Floods: States Count Losses. The SUN. [Document on the Internet]2012[cited 2020 March 29]. Available from: http://www.sunnewsonline.com

15. Mohammad, S. and Najib, S. (2004).Application of methods for analysis of rainfall intensity in areas of Israeli, Jordanian, and Palestinian Interest.Jordanian Meteorological Department, Ministry of Water and Irrigation, Amman, Jordan.
16. Kim, T. Shin, J. Kim, K. and Hoe, J. Improving Accuracy of IDF Curves Using Long and Short Duration Separation and Multi-objective Genetic Algorithm, World Environmental and Water Resources Congress 2008, Ahupua's ASCE.
17. Nicholas JE. Assessment of the 2012 Flooding in MararabaKaru Local Government Area of Nasarawa State, Nigeria. M.Sc. Thesis, Department of Geography, Faculty of Science, Ahmadu Bello University, Zaria, Nigeria. 2014.
18. Adeyeri OE, Akinsanola AA, Ishola KA. Investigating surface urban heat island characteristics over Abuja, Nigeria: relationship between land surface temperature and multiple vegetation indices. Remote Sens. Appl.: Soc. Environ. 2017; 7: 57–68.
19. Chow VT. A General Formular for Hydrologic Analysis. Trans AmerGeophys Union, 1951;32: 231 – 237.
20. Sangal BP and Kallio RW. (1977). Magnitude and Frequency of flood in southern Ontario. Tech. Bull. Series No. 99, In Land water directorate, Water Planning and Management branch, Ottawa, Canada.
21. Oyebande L and Longe D. Regionalized Rainfall Intensity-Duration Frequency Relationships for planning and Engineering Designs: Proceeding of 1st Biennial National Hydrology, 1990. p. 373 – 379.
22. Akpen GD, Aho MI and Musa AA. Rainfall intensity-duration-frequency models for Lokoja Metropolis, Nigeria Global Journal of Pure and Applied Sciences, 2019; 24: 81-90.
23. Munson BR, Young DF and Okiishi TH. Fundamentals of Fluid Mechanics. 3rd edition. John Wiley and Sons, Inc. 1998.
24. Bengtson HH.(Remove authors if they are not seen). Spreadsheet Use for Partially Full Pipe Flow Calculations. CED Engineering.com [Document on the Internet] 2017 [cited 2020 April 2]Available from: https://www.cedengineering.com
25. Adaba CS and Agunwamba JC. Adequacy of Drainage Channels in a Small Urban Watershed in Nigeria. Nigerian Journal of Technology (NIJOTECH), 2014;33(4):584 594.