

# Model Selection and Design of Storm Water Drainage Systems at Oleh, Delta State, Nigeria

I. Ologhadien and G. O. Esebene

**Abstract** — Rainfall Intensity-Duration-Frequency curves and equations present the exceedance probability of a given rainfall intensity and storm duration expected to occur at a particular location, for the design of storm water drainage systems and hydraulic structures. The aim of this study was to develop IDF curves/equations for Oleh, a municipality situated in the low-lying and flood prone region of Nigeria. The study was conducted using annual maxima rainfall series (ARMS) of 28 years obtained from Nigeria Meteorological Agency (NiMet). The AMRS were extracted into 15 Nos. storm durations between 10 minutes and 600 minutes. The AMRS of each duration was fitted to Gumbel (EVI), LN2 and Normal (N) distributions using the K-S and A-D goodness-of-fit module of Easyfit software, Version 5.6. The graphical plots, development of IDF models and computations of performance measures of  $R^2$ , NSE and RSR, were executed in Microsoft Excel, 2010. The results of GOF tests show that for K-S tests, Gumbel (EVI) is best-fit distribution in four durations, LN2 was best –fit in Nine out of fifteen durations, and Normal distribution durations scored 2. Similarly, for A-D GOF test, Gumbel (EVI) scored three (3), LN2 scored eleven (11), while Normal distribution scored one (1). Consequently, LN2 is the best-fit distribution, seconded by Gumbel (EVI). Accordingly, LN2 and Gumbel (EVI) distributions have been adopted in the development of the IDF models for Oleh municipality, while the performances of the IDF models may be presented the inequality;  $0.984 \leq R^2 \leq 0.998$ ;  $0.990 \leq NSE \leq 0.998$  and  $0.045 \leq RSR \leq 0.096$ . The graphical plots, IDF curves and models exhibited the peculiar attributes of IDF curves/equations reported in literature. The performance measures show that the equations are robust for practical application in the design of storm water drainage systems and hydraulic structures.

**Keywords** — IDF curves, frequency analysis, Kolmogorov – Smirnov, Anderson – Darling, Stormwater and Performance measures.

## I. INTRODUCTION

Rainfall is the primary component of the hydrologic cycle, and its role is crucial to the survival of natural processes. Rainfall either in extreme or scarcity has detrimental impact on society and stability of eco-systems. In the extreme, excess rainfall cause floods. Flood disaster account for about a third of all natural disasters throughout the world and they responsible for more than half of the fatalities Berz [1]. Rainfall in prolonged scarcity is responsible for drought with concomitant effects of poor agricultural productivity, poverty, and health related problems.

Engineers cannot stop the occurrence of floods, they should seek structural and non-structural measures to reduce the consequences of floods and the associated economic losses, social vulnerability, environmental damages, and loss of life. Accordingly, engineers must develop tools to confront the problems posed by excess rainfall causing excess runoff and urban flooding.

The Rainfall Intensity – Duration – Frequency curves and equations are standard tools for planning, designs, and operation of water resources engineering against floods. An efficient storm water drainage system is vital to evacuating excess surface runoff from urban areas, caused by intense rainfall during raining season. Other practical uses of IDF curves and equations include; (i) Design of hydraulic structures (such as culverts and bridges), (ii) Land-use planning and soil conservation studies, (iii) Management of municipal infrastructure including sewers, storm water management ponds and street curb (iv) Design of safe and economical structures for the control, storage, and routing of storm-water and surface drainage (v) Risk assessment of dams and bridges (vi) Design of roof and storm water drainage systems (vii) Floodplain management (viii) Soil conservation studies (ix) Water-resources management. The IDF curves and equations provide the required quantile estimates which serves as input into rainfall – runoff models used for computations of runoff rates at selected times of concentration. That is rainfall intensity – frequency (IDF) relationship provides the quantile rainfall intensity for runoff estimation.

Furthermore, due to the growing awareness of the role that atmospheric and climatic processes play on the hydrologic cycle. There is a compelling need for updating and reassessment of the IDF curves and equations on regular basis. A review of previous IDF studies at Oleh and it environ include Metibaye *et al.* [2], Ologhadien and Nwaogazie [3], Oyegoke *et al.* [4] and Nwaogazie *et al.* [5]). The review shows that IDF curves/equation for Oleh municipality are not available and consequently will be developed. In the light of the current climate change occasioned by frequent flooding and high intensity rainfall, the IDF curves and equation need to be updated. There has not been any IDF studies carried out at Oleh and its environs, leading to development of IDF curves and equations as input into rainfall – runoff models for design of storm water drainage systems mitigate the natural environmental hazards of urban flooding at Oleh Municipality. The present study is a niche for design of stormwater drainage systems to mitigate the effect of flooding in the area. An important step in the development of IDF relations is the selection of a suitable probability distribution function (PDF) that best fit the rainfall data.

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Consequently, three PDFs namely Gumbel (EV1), Log-normal (LN2) and Normal are evaluated and the best distribution will be selected through goodness – of – fit tests and performance measures. The IDF curves and equations developed this study will be recommended to the local government corporate organizations to enable them cope with the environment hazards of urban flooding which include severe traffic develop, damage to properties and infrastructure.

## II. MATERIALS AND METHODS

### A. Study Area and Climate

Oleh is a town in Isoko South Local Government Area of Delta State. The area covers a low-lying section of the larger Niger Delta Basin. The area is located one latitude of 50 271 42N and longitude of 60 121 2211 E on the geographical map.

The Niger Delta, comprising Oleh municipality and it environ display climatic characteristics that may be as Semi-Hot Equatorial type with heavy rainfall, Gobo [6].

The wet season lasts from March to October while the dry season lasts from November to February. Studies have shown that the area experience heavy rainfall and humidity from May to December and that it has short dry season from December to March. Flooding is the most common natural environmental hazard experienced in this area. Fig. 1 shows the map of Oleh municipality.

### B. Collection of Data

The rainfall data for Oleh municipality was procured from the Nigeria Meteorological Agency (NiMet). The data length is 28 years (1965-1992) and were extracted for rainfall duration ranging between 10minute (0.17 hours) to 600 minute (26 hours). The point rainfall data is therefore representative of one particular location on the catchment area. The rainfall duration refers to the time period (D) in minutes over which the rainfall occurred. However, duration is not necessary the time period for the whole storm as any event can be subdivided and analyzed for a range of durations. It is common to represent the frequency or exceedance probability of the rainfall as return period (T).

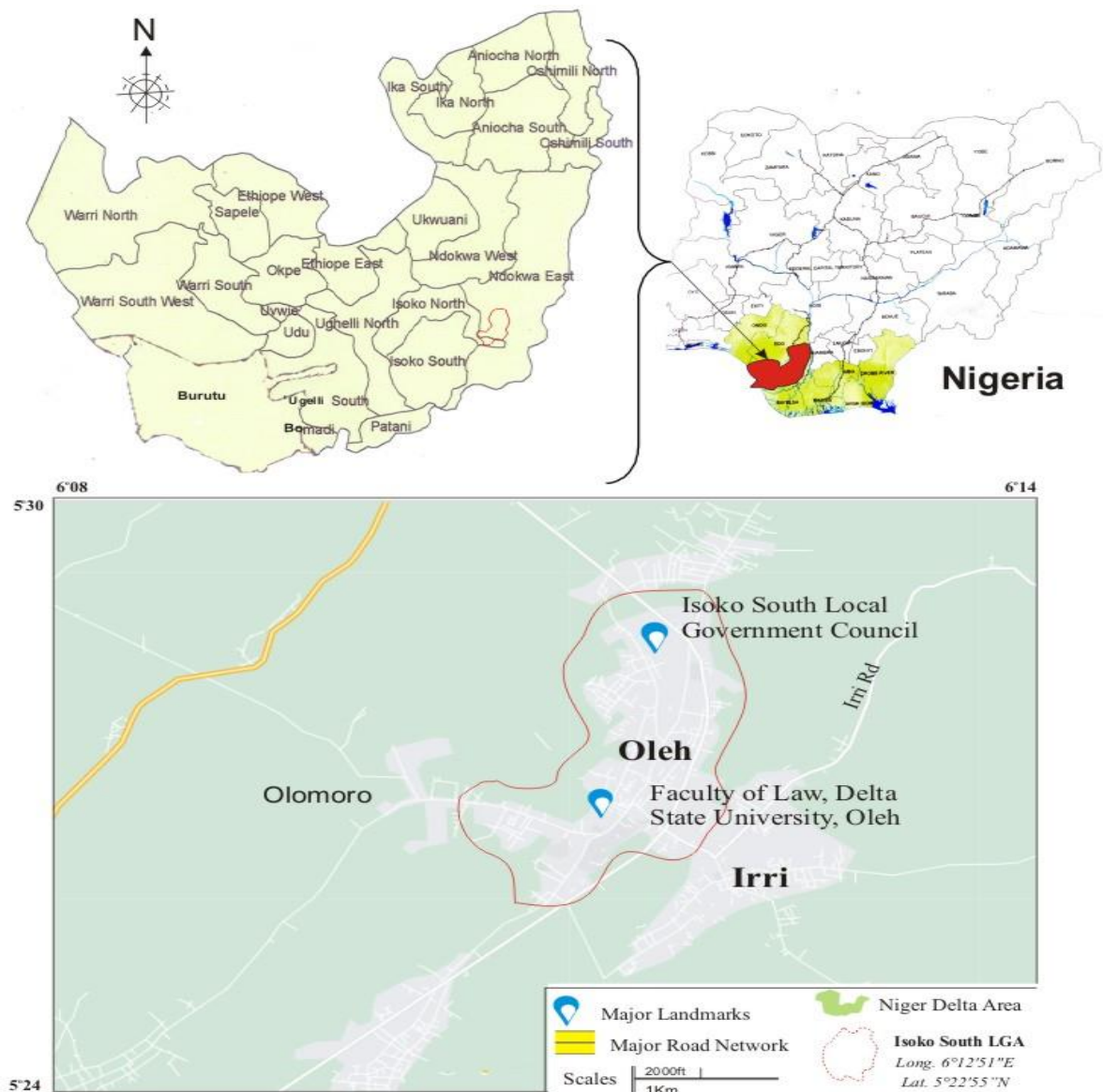


Fig. 1. Map of Oleh, Nigeria.

Preliminary data screening to ascertain the basic assumptions of independence, randomness and stationarity of the rainfall data was performed by NiMet in-house consultant. The in-house consultant adopted correlation coefficient at lag-1 and Wald-Wolfowitz tests for independence and randomness respectively. While stationarity was checked using Mann-Kendal test. The results of the above tests indicate that the data is adequate for frequency analysis.

### C. Methods and Procedures

The derivation of a preliminary intensity duration frequency relationship is important as it enables us to assign a return period that a flood storm will occur and also allow to analysis the intensities for the short duration rainfall for a range of return periods which could subsequently be used in the flood protection works.

#### a) IDF Quantile Estimation

The intensity-duration-frequency (IDF) is a frequency relationship among rainfall depth, intensity, and storm duration. They are used in the design of storm management facilities and flooding reservations. The IDF may be constructed by adopting the following steps:

- gather time series records of different durations (e.g., 5, 10, 15, 20 minutes etc.);
- extract annual extremes form the record of each duration;
- fit the annual extreme data to a probability distribution in order to estimates rainfall depths for different return periods. The Gumbel's extreme value distribution is used to fit the annual extreme rainfall data. The Gumbel probability distribution has the following form:

$$X_T = \mu_z + K_T \sigma_z \quad (1)$$

where  $X_T$  represents the magnitude of the T-year event,  $\mu_z$  and  $\sigma_z$  are the mean and standard deviation of the annual maximum series, and  $K_T$  is a frequency factor depending on the return period (T) and also distribution – specific. The frequency factor  $K_T$  for Gumbel's extreme value distribution is given by:

$$K_T = \frac{\sqrt{6}}{\pi} \left[ 0.5772 + \ln(\ln(\frac{T}{T-1})) \right] \quad (2)$$

Tabulation of annual maximum series for different durations and application of (1) to each duration.

Calculation of average intensity as follows:

$$\bar{I}_T(D) = \frac{X_T}{D} \quad (3)$$

where D is duration.

#### b) Log Normal (LN2) Distribution

Using the direct method of moments without logarithm transform of the rainfall data, the population parameters are computed using the mean and standard deviation of the sample's moments:

$$\mu_z = \text{Log } \bar{Q} - \frac{\sigma_z^2}{2} \quad (4)$$

$$\sigma_z^2 = \text{Log} \left( \frac{\sigma^2}{(\bar{Q})^2} + 1 \right) \quad (5)$$

where  $\mu_z$  and  $\sigma_z$  are population parameters of LN2 distribution,  $\bar{x}$  and  $\sigma$  are mean and standard deviation of the sample moments respectively. The frequency factor (KT) and quantile estimate (QT) are shown in (6)–(10).

Calculate the frequency factor KT is calculated:

$$W = \left[ \text{LN} \left( \frac{1}{P^2} \right) \right]^{\frac{1}{2}} \quad (6)$$

$$z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3} \quad (7)$$

when  $p > 0.5$ ,  $1 - p$  is substituted for  $p$  in (7) and the value of  $z$  computed by (7) is given a negative sign.

KT is approximated by Kite [7] as:

$$KT = Z + (z_2 - 1)k + \frac{1}{3}(z_3 - 6z)k^2 - (z_2 - 1)k^3 + z_4k + \frac{1}{3}k^5 \quad (8)$$

where  $k = C_s/6$ .

The T-year flood quantile is obtained by (9) and (10).

$$ZT = \text{LNQT} = \mu_z + K_T \sigma_z \quad (9)$$

$$QT = e^{ZT} \quad (10)$$

#### c) Construction of IDF curves/Equations

The relationship between estimated rainfall intensity and duration may be expressed according to the Wisner equation given by (11). The Ontario Drainage Management Manual (MTO) [8] recommends fitting the IDF data to the three parameter function (Wisner's formula):

$$I = \frac{C}{(D+a)^b} \quad (11)$$

where  $I$  is the rainfall intensity (mm/her);  $D$  is the rainfall duration (min) and  $a$ ,  $b$  and  $C$  are coefficients. After selecting a reasonable value of parameter  $a$ , method of least squares is used to estimate the values of  $C$  and  $b$ . The calculation is repeated for a number of different values of "a" in order achieve the closest possible fit to the data. The best fit value of coefficient "a" is one with the least error sums of squares. The constants were obtained as follows:

Taking Logarithms in both sides of (11), gives a linear equation of the form:

$$\text{Log } I = \text{log } C - b \text{ Log } (D + a) \quad (12)$$

The best values of  $a$ ,  $b$  and  $C$  are those for which the sum of the squares of these deviations as minimum:

$$SEE = \sum_{i=1}^n [\log I - \{\log C - b \log (D+a)\}]^2 \quad (13)$$

The partial differentiation of SEE with respect is b and C gives:

$$\Sigma \log I = n \log C - b \Sigma \log (D+a)$$

$$\Sigma [\log I \log (D+a)] = \log C \Sigma \log (D+a) - C \Sigma [\log (D+a)]^2 \quad (14)$$

where n is the number of observational and all the summations are over all n-value. After obtaining the required summations, Equations 12 and 14 were solved simultaneously to obtain the best values of b and C for any assumed values of constant “a” and the best value of “a” was found by trial and error.

#### D. Goodness of Fit Tests

The performance of the selected distribution fits is ranked using two goodness of fit tests namely, Kolmogorov–Smirnov test and Anderson Darling statistic. Two tests were carried out using Easyfit software, available at

##### a) Kolmogorov-Smirnov (K-S)

Test: The K-S test is a nonparametric test for measuring the differences between cumulative distribution functions. The Kolmogorov-Smirnov (KS) Statistics (D) is based on the largest vertical different between the theoretical and empirical cumulative distribution function (CDF):

$$D = \max_{1 \leq i \leq n} \left( F(X_i) - \frac{i-1}{n}, \frac{i}{n} - F(X_i) \right) \quad (15)$$

The hypothesis is rejected, if the KS Statistics is greater than the critical value at a chosen significance level  $\alpha = 0.05$

##### b) Anderson–Darling Estimate (AD)

The Anderson–Darling Estimate compares the fit of an observed cumulative distribution function (CDF) to an expected cumulative distribution function. The method gives greater weight to the tail of the distribution than the KS statistics test. The (AD) statistics (A2) is expressed as:

$$A2 = -n - \frac{1}{n} \sum_{i=1}^n (2i-1) \times (\ln F(X_i) + \ln(1-F(X_{n-i+1}))) \quad (16)$$

The test hypothesis is rejected if the AD statistics is greater than a critical value of 2.5018 at a given significance level  $\alpha = 0.05$ . For further reading on the Easy fit software. The quantile equation (10) was used to calculate maximum precipitation for return periods 10,15,20,25, 50 and 100 years in Oleh metropolis.

#### E. Evaluation of IDF Models Efficiency

The indices used are coefficient of determination (R2); Nash-Sutcliffe Efficiency (NSE),) and RMSE – observations standard deviation ratio (RSR). The computational forms of the above indices are given below:

$$(R2) = \frac{\sum_{i=1}^N (I_o - \bar{I}_o)(I_p - \bar{I}_p)}{\sqrt{\sum_{i=1}^N (I_o - \bar{I}_o)^2} \times \sqrt{\sum_{i=1}^N (I_p - \bar{I}_p)^2}} \quad (17)$$

$$NSE = 1 - \frac{\sum_{i=1}^N (I_o - I_p)^2}{\sum_{i=1}^N (I_o - \bar{I}_o)^2} \quad (18)$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = 1 - \frac{\left[ \sum_{i=1}^N (I_o - I_p)^2 \right]^{\frac{1}{2}}}{\left[ \sum_{i=1}^N (I_o - \bar{I}_o)^2 \right]^{\frac{1}{2}}} \quad (19)$$

where N is the sample size,  $I_o$  is the observed rainfall intensity discharge,  $I_p$  is the predicted rainfall intensity.  $I$  is the average observed rainfall intensity. R2 statistics is an indication of the explanatory power of the IDF equation, in terms of how the IDF equations approximate or fit the data points. The higher the value of R2, the more successful the fit or the explanatory power, if R2 is small, it indicates a poor fit, possibly to search for an alternative model. R2 lies between 0(no correlation) and 1 (perfect fit). The Nash-Sutcliffe Efficiency (NSE) lies between 1.0 (perfect fit) and  $-\infty$ . RMSE – observations standard deviation ratio (RSR) is calculated as the ratio of the RMSE, and standard deviation of measured data as shown in (19). RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower the RSR, the lower the RMSE, and the better the model simulation performance [9].

### III. RESULTS AND DISCUSSION

The results of the analysis are summarized in Table I-IV, while Fig. 2-6 show their graphical counterpart. Tables I shows the results of fitting Gumbel (EVI), Log-Normal (LN2) and Normal (N) distributions to the rainfall data. The fittings were performed using the Easyfit software version 5.6, while the graphical plots, development of IDF models and computation of performance measures were executed in Microsoft Excel 2010. After the distribution fitting, the best distribution out of each rainfall duration was selected based on K-S and A-D goodness-of-fit tests as shown in Table I.

Table I shows that, for K-S GOF test, Gumbel (EVI) is best-fit in four rainfall duration marked with a superscript of one (1), Log-Normal (LN2) is best in Nine (9) durations and Normal scored (2). Similarly, for AD GOF test, Gumbel (EVI) scored 3, LN2 scored eleven (11) and Normal distribution scored one (1). In summary, LN2 is the best fit distribution, seconded by Gumbel (EVI). Fig. 2 and 3 confirm the result of GOF test shown in Table II. In Fig. 1, the estimated quantiles by LN2 are highest for rain durations of 10-, 20- and 60 minutes while Gumbel (EVI) produced the highest estimated quantiles for rainfall durations of 30- and 45 minutes. A similar trend is



observed in Fig. 3. Thus Fig. 2 and 3 confirms that the best-fit distributions actually produce the highest estimated quantiles. Fig. 4 and 5 show the probability density functions of the fitted distributions, which also confirms that LN2 is best fit distribution, seconded by Gumbel (EVI).

Tables II and III show the computed rainfall intensities for LN2 and Gumbel (EVI) respectively. Table IV shows the developed IDF equations using the data in Tables II and III with the corresponding performance measures for each return period. Fig. 6 and 7 are the graphical equivalent of the IDF models in Table II and III respectively. It may be inferred from Table II and III that rainfall intensity increases with increasing return periods and decreases with increasing storm duration. These observations are consistent with the common IDF behaviour found in literature, e.g., Ewea *et al.* [10] and Ahmed and Ali [11]. Furthermore, it can be seen from Table II and III, that moderate differences exist between the rainfall intensities predicted by LN2 and Gumbel (EVI), as observed by Elsebaie [12] and Akpen *et al.* [13]. The predictions by LN2 are higher than those produced by Gumbel (EVI). This is particularly evident for storm durations less or equal to 60 minutes. Beyond storm durations of 60 minutes, only slight differences were observed. Storm durations less or

equal to 60 minutes (1hr) are commonly used as time of concentration and critical rainfall durations for estimating runoff from highway pavements and urban areas, see Froehlich (14). Table IV presents the derived IDF models and the corresponding statistical performance measures: R2, NSE and RSR for various return periods. All the IDF models performed very well in R2 index. All the models obtained R2 value greater or equal to 98.4 percent, which implies that 98.4 percent of the original uncertainty has been explained by the IDF models. The RSR index ranges between 0.0 and  $\infty$ , with an optimal value of 1.0. In Tables IV, the IDF models performed very good for RSR index, the range of RSR index is between 0.0 and  $\infty$ , with optimal value of 0.0. The RSR values for Gumbel (EVI) ranges between 0.082 and 0.096, while the range for LN2 is between 0.045 and 0.496. Generally, it may be observed that the errors associated with each IDF model increase with increasingly return period. Similar observation has been made by Ahilan *et al.* [15] who reported that the return period of the estimated value in a single site analysis should not exceed the length in years of available record by more than a factor of two. The excellent performances of the IDF models indicate robust models for practical applications.

TABLE I: FITTING AND RANKING OF PROBABILITY DISTRIBUTIONS ACROSS THE FIFTEEN DURATIONS

Dur (min)	Kolmogorov - Smirnov (KS) Test			Anderson – Darling (AD) Test		
	Gum	LN2	Norm	Gum	LN2	Norm
10	0.1358 <sup>2</sup>	0.09169 <sup>1</sup>	0.1779 <sup>3</sup>	0.8948 <sup>2</sup>	0.3201 <sup>1</sup>	1.919 <sup>3</sup>
20	0.1376 <sup>3</sup>	0.0975 <sup>1</sup>	0.1043 <sup>2</sup>	0.5918 <sup>3</sup>	0.2543 <sup>1</sup>	0.2606 <sup>2</sup>
30	0.0742 <sup>1</sup>	0.0774 <sup>2</sup>	0.1204 <sup>3</sup>	0.1848 <sup>1</sup>	0.1902 <sup>2</sup>	0.5182 <sup>3</sup>
45	0.0943 <sup>1</sup>	0.0957 <sup>2</sup>	0.1089 <sup>3</sup>	0.2288 <sup>2</sup>	0.2103 <sup>1</sup>	0.4408 <sup>3</sup>
60	0.1681 <sup>3</sup>	0.1018 <sup>1</sup>	0.1135 <sup>2</sup>	1.067 <sup>3</sup>	0.2683 <sup>1</sup>	0.3181 <sup>2</sup>
90	0.1232 <sup>3</sup>	0.1148 <sup>2</sup>	0.0989 <sup>1</sup>	0.4212 <sup>3</sup>	0.4022 <sup>1</sup>	0.4124 <sup>2</sup>
120	0.1575 <sup>3</sup>	0.1454 <sup>2</sup>	0.1407 <sup>1</sup>	0.7085 <sup>3</sup>	0.4217 <sup>1</sup>	0.4248 <sup>2</sup>
180	0.1146 <sup>2</sup>	0.1071 <sup>1</sup>	0.1251 <sup>3</sup>	0.2635 <sup>3</sup>	0.2277 <sup>1</sup>	0.4161 <sup>3</sup>
240	0.1031 <sup>1</sup>	0.1384 <sup>2</sup>	0.1576 <sup>3</sup>	0.3557 <sup>3</sup>	0.3455 <sup>1</sup>	0.8189 <sup>3</sup>
300	0.2216 <sup>3</sup>	0.1535 <sup>1</sup>	0.1542 <sup>2</sup>	1.883 <sup>3</sup>	0.4676 <sup>2</sup>	0.4376 <sup>1</sup>
360	0.1693 <sup>2</sup>	0.1523 <sup>1</sup>	0.2111 <sup>3</sup>	0.7892 <sup>3</sup>	0.6933 <sup>1</sup>	0.9367 <sup>2</sup>
420	0.1089 <sup>2</sup>	0.0961 <sup>1</sup>	0.1782 <sup>3</sup>	0.2685 <sup>1</sup>	0.2796 <sup>3</sup>	0.8168 <sup>3</sup>
480	0.1287 <sup>2</sup>	0.1574 <sup>1</sup>	0.1241 <sup>3</sup>	0.4149 <sup>1</sup>	0.3642 <sup>3</sup>	0.5729 <sup>3</sup>
540	0.1134 <sup>2</sup>	0.1071 <sup>1</sup>	0.1665 <sup>3</sup>	0.3854 <sup>3</sup>	0.3699 <sup>1</sup>	0.8716 <sup>3</sup>
600	0.1147 <sup>1</sup>	0.1196 <sup>2</sup>	0.1231 <sup>3</sup>	0.5770 <sup>3</sup>	0.3359 <sup>1</sup>	0.4105 <sup>2</sup>
Total:	4	9	2	3	11	1

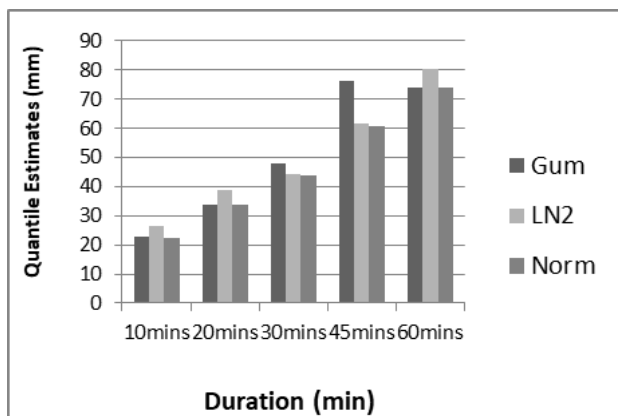


Fig. 2. Outcome of Ranking for 10 -Year Return Period.

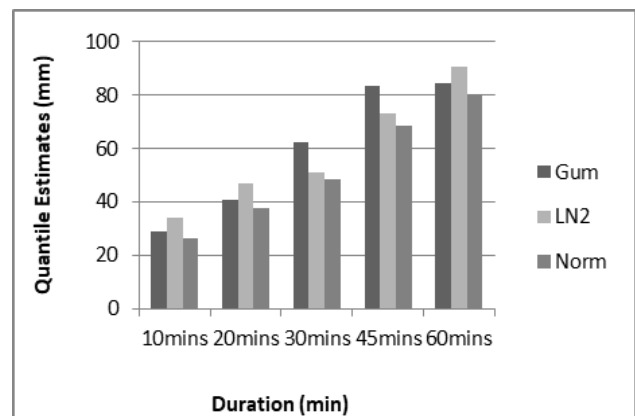


Fig. 3. Outcome of Ranking for 25-Year Return Period.

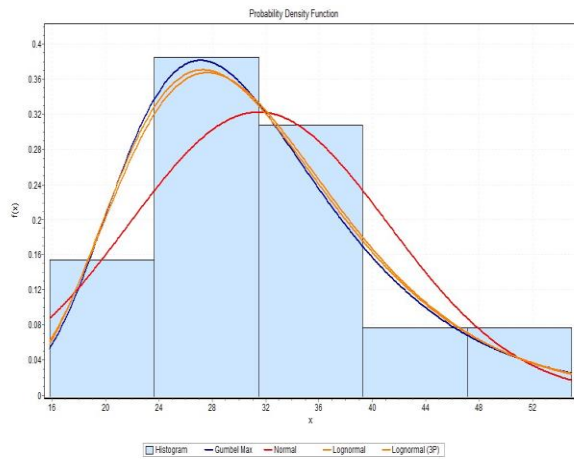


Fig. 4. PDFs for Gumbel EV1, LN2 and N for 20 minutes duration.

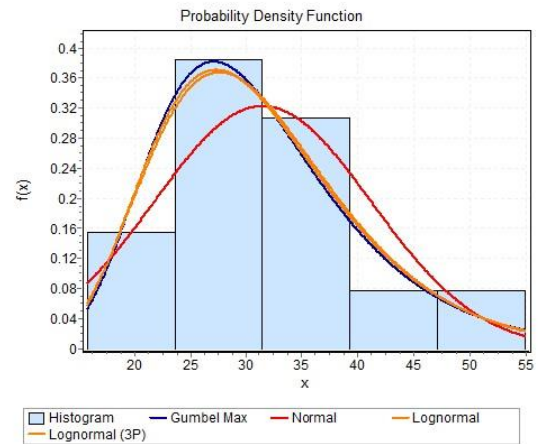


Fig. 5 PDFs for Gumbel (EV1), LN2 and N for 30 minutes duration.

TABLE II: ESTIMATED RAINFALL INTENSITIES FOR LN 2 DISTRIBUTION

Dur.(min)	10YR	20YR	25YR	30YR	40YR	50YR
10	133.4794	174.8509	204.1552	231.2208	251.2208	271.2208
20	111.8216	135.1937	175.1544	200.8825	220.8825	240.8825
30	98.5885	120.8223	148.0194	175.2313	195.2313	215.2313
45	84.7329	103.8979	128.4523	150.4417	170.4417	190.4417
60	76.2122	94.1432	115.6046	132.3356	152.3356	172.3356
90	56.1538	72.4712	87.0606	102.7571	122.7571	142.7571
120	47.4781	60.7968	70.1514	85.0794	105.0794	125.0794
180	31.5518	37.2211	44.0563	55.5628	70.5628	85.5628
240	22.3086	26.0827	32.2975	43.2924	53.2924	63.2924
300	20.1161	23.6881	29.8431	40.7908	50.7908	60.7908
360	14.8780	17.0366	22.7223	33.2809	43.2809	53.2809
420	12.5189	14.6824	20.3802	30.9521	40.9521	50.9521
480	13.1370	15.5603	21.3467	31.9930	41.9930	51.9930
540	10.7614	12.2342	17.6970	28.0786	38.0786	48.0786
600	11.4499	13.6525	19.3703	29.9611	39.9611	49.9611

TABLE III: ESTIMATED RAINFALL INTENSITIES FOR GUMBEL (EV 1) DISTRIBUTION

Dur.(min)	10YR	20YR	25YR	30YR	40YR	50YR
10	133.0836	166.6306	191.6302	206.6302	221.6302	236.6302
20	102.4695	125.7378	150.7378	175.7378	190.7378	205.7378
30	95.2340	115.9914	140.9914	155.9914	170.9914	185.9914
45	81.7636	98.8535	123.8535	138.8535	153.8535	168.8535
60	74.1418	87.0218	112.0218	127.0218	142.0218	157.0218
90	55.7291	73.9467	88.9467	103.9467	118.9467	133.9467
120	44.6355	61.3454	76.3454	91.3454	106.3454	121.3454
180	30.0764	39.6460	49.6460	59.6460	75.6460	85.6460
240	22.7061	31.3659	41.3659	51.3659	61.3659	71.3659
300	16.8986	23.9242	33.9242	43.9243	53.9242	63.9242
360	14.6124	21.6353	31.6353	41.6353	51.6353	61.6353
420	12.2277	19.1097	29.1097	39.1097	49.1097	59.1097
480	12.4487	19.3584	29.3584	39.3584	49.3584	59.3584
540	10.7442	17.2243	27.2243	37.2243	47.2243	57.2243
600	10.3120	16.8205	26.8205	36.8205	46.8205	56.8205

TABLE IV: IDF EQUATIONS AND PERFORMANCE MEASURES

Return Period	Log-Normal IDF Models	Performance Measures			Gumbel EV1 IDF Models	Performance Measures		
		R <sup>2</sup>	NSE	RSR		R <sup>2</sup>	NSE	RSR
10	$\frac{26284.1}{(D+68)^{1.216}}$	0.998	0.998	0.045	$\frac{23573.77}{(D+65)^{1.208}}$	0.994	0.994	0.086
20	$\frac{33804.63}{(D+64)^{1.233}}$	0.994	0.996	0.081	$\frac{7,416.28}{(D+45)^{0.9587}}$	0.992	0.992	0.091
25	$\frac{20644.53}{(D+55)^{1.108}}$	0.993	0.994	0.058	$\frac{3988.89}{(D+37)^{0.7957}}$	0.992	0.992	0.088
30	$\frac{7168.13}{(D+40)^{0.8782}}$	0.987	0.992	0.065	$\frac{2465.38}{(D+30)^{0.6726}}$	0.993	0.993	0.082
40	$\frac{5643.29}{(D+40)^{0.7849}}$	0.990	0.699	0.496	$\frac{2197.86}{(D+32)^{0.6165}}$	0.993	0.993	0.084
50	$\frac{5662.04}{(D+45)^{0.7595}}$	0.984	0.990	0.084	$\frac{2005.41}{(D+33)^{0.5720}}$	0.991	0.991	0.096

A dilapidated culvert is to be replaced by a new culvert installation to improve road safety during rainstorms. The drainage above the crossing is 43.7 hectares (ha). The 25-year rainfall intensity equation, from Table IV (I25)) = 20,644.53/(tc+ 55)1.108 mm/h. Take Manning's n=0.015 and bed slope, so = 0.0015. The current land use consists of 21.8 ha of motor park, 1.5 ha of commercial property (100% impervious), and 20.4 ha residential housing. The principal flow path includes 90 m of short grass at 2 percent slope, 300 m of grassed waterway at 2 percent slope, and 650 m of grassed waterway at 1 percent slope. Determine the maximum discharge that culvert must pass for the indicated design storm and the required diameter of the culvert.

The first part requires computation of peak discharge using Rational Formula Method, followed by the peak discharge (Q), finally determination of the required size of ring culvert using Manning's equation.

Part 1, the following steps are used to compute the peak discharge with the Rational method.

TABLE V: CATCHMENT DESCRIPTION AND WEIGHTED RUNOFF COEFFICIENT

Description	C-value	Area (ha)	CiAi
Park	0.2	21.8	4.36
Commercial	0.95	1.5	1.43
Residential	0.4	20.4	8.15
$\Sigma$		43.7	13.95

$$\text{Weighted Runoff Coefficient (c)} = \frac{\sum C_i A_i}{A} = 0.32$$

In order to compute the rainfall intensity for return period of twenty five years (I25). The time of concentration (tc) is computed using the National Resources Conservation Service (NRCS) equation:

$$tc = \sum \left( \frac{L}{V} \right) = \frac{90}{0.3} s + \frac{300}{0.64} s + \frac{650}{0.46} = 36 \text{ min}$$

$$I_{25} = \frac{20,644.53}{(tc + 23)^{1.108}} \text{ mm/h} = \frac{20644.53}{(36 + 55)^{1.108}} \text{ mm/h} = 139.5 \text{ mm/h}$$

Peak discharge:

$$(Q) = \frac{CIA}{360} \text{ m}^3 / \text{s} = \frac{(0.32)(139.5)(43.7)}{360} = 5.42 \text{ m}^3 / \text{s}$$

Required size of culvert using Manning's Equation:

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2} \quad (20)$$

Substituting  $A = 0.786D^2$ ,  $P = 3.142D$  and  $R = 0.25D$ , where A is area of pipe culvert flowing full, P is wetted perimeter, D is culvert diameter and R is hydraulic radius. Equation (20) becomes:

$$D^{8/3} = \frac{Q \times n}{0.311} \quad (21)$$

On substitution of  $Q = 5.42 \text{ m}^3/\text{s}$  and  $n = 0.015$ . The required diameter (D) of pipe culvert is 0.61 m. Therefore, provide a culvert diameter of  $D = 900 \text{ mm}$ .

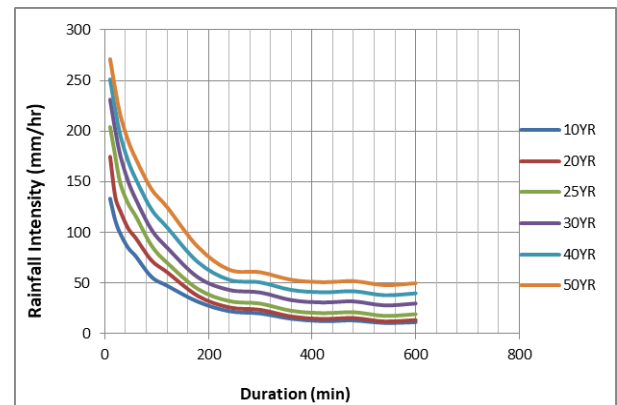


Fig. 6. Rainfall intensity curves for LN2 predictions.

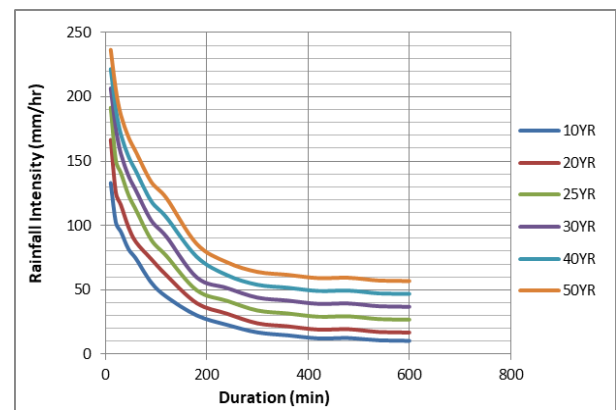


Fig. 7. Rainfall Intensity curves for EV1 predictions.

#### IV. CONCLUSION

Intensity duration- frequency curves / equations are needed by hydrologists and Engineers involved in planning and design of hydraulic structures. IDF curves and equations have been developed for many cities in Nigeria. Where they are not available, and consequently, will need to be developed. This is the purpose of this study conducted for Oleh metropolis, Delta state, Nigeria. Three probability distribution functions (PDFs) namely, Gumbel (EV1), 2 – parameter Lognormal (LN2) and Normal distributions were evaluated using K-S and A-D goodness – of – fit tests of Easyfit software, version 5.6. The performances of the three PDFs were evaluated using R2, NSE and RSR. The results show that LN2 is the best fit distribution, seconded by Gumbel (EV1). Consequently, the two distributions have been applied in the development of IDF equations / equations for Oleh metropolis. The IDF curves / equations exhibit the common attributes found in literature. Secondly the equations are robust in view of their high performance scores, therefore recommended for practical applications in the design of engineering projects against floods. The study strongly recommends periodic updating of IDF curves / equations in view of increasing flood risk caused by climate change on the hydrological cycle.

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