Analysis of Rainfall Intensity for Southern Nigeria

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ABSTRACT
The estimation of rainfall intensity is commonly required for the design of hydraulic and water resources engineering control structures. Considering notable changes in rainfall trends as a result of global and regional changing of climate and weather in recent times, the need for intense study of rainfall and accurate estimation of rainfall intensity duration frequency (IDF) curves cannot be over emphasized. In this paper, rainfall Intensity-Duration-Frequency (IDF) studies were undertaken for Southern Nigeria using annual extreme rainfall series available for 10 cities. A Microsoft Excel model was developed to conduct frequency analysis using the Extreme-Value Type 1 (Gumbel) Distribution. IDF relationships and curves for 1, 2, 5, 10, 25, 50 and 100 yrs return periods were then generated for Ondo, Ibadan, Warri, Benin, Oshogbo, Ikeja, Port-Harcourt, Umudike, Calabar and Enugu. The results were compared for a storm of 10 yr return period with a time duration of 9 minutes. It was observed that Port-Harcourt had the highest rainfall intensity (207.40mmhr^{-1}.), followed by Enugu (164.53 mmhr^{-1}.) and then Ikeja (114.65mmhr^{-1}.). The computer model developed in this study will be of immense help to engineers in developing a database for the continuous (or long term) analysis of rainfall in Nigeria and generation of IDF curves for the design of hydraulic and water resources engineering control structures, few of which were done in this work.

Key words: *Climate, Flood, Hydraulic, Model, Water*

1.0 INTRODUCTION

Rainfall is a climate parameter that affects the way and manner man lives. It affects every facet of the ecological system, flora and fauna inclusive. It is the source of fresh water replenishment for planet Earth. However, too much or too little can mean the difference between prosperity and disaster. Rainfall is a random hydrologic event whose occurrence cannot be predicted with certainty. The distribution of the precipitation over time and space is very complex and irregular. Such irregularity is especially pronounced with respect to the occurrence of the exceptionally heavy storm events. However, it is possible, by the use of rainfall data spanning a long period of time, to estimate the likelihood of the rainfall of a particular magnitude or more occurring within a specified period of time referred to as return period or recurrence interval. The ability to predict the possibility of occurrence of rainfall of a particular magnitude or more which is one of the preliminary stages of storm water drainage design can help individuals, authorities and engineers to plan for such extreme eventualities as flood, drought, landslides, thunderstorms etc.

Hence, the study of rainfall is extremely important and should be encouraged in our world of today as it cannot be over emphasized.

Following recent global and regional changing of climate and weather made visible especially when focusing on important climatic factors such as temperature, rainfall, humidity etc., which have shown significant variability, a matter of urgency in research is raised as rainfall trends in most parts of Nigeria have shown tremendous changes. This has rendered past records of rainfall data less effective in providing solutions to various engineering problems as well as in achieving efficient designs for major and minor hydraulic structures such as crossroad culverts, levees, drainage ditches, urban storm drain systems, and spillway appurtenances of small dams.

Taking Southern Nigeria as a case study, this project therefore generated a computer model that would be of immense help to hydrologists, hydro climatologists and civil engineers in the analysis of very recent and future rainfall records for various locations of interest.

The computer model was generated with the Microsoft excel software by using old rainfall data from various states in the southern part of Nigeria to conduct a detailed analysis of rainfall comprising majorly of frequency analysis, regression analysis, rainfall intensity duration frequency (IDF) relationships and curves for varying return periods.

This therefore, serves to enhance a better and more efficient design of flood control systems to help preserve and protect our society for today's occupants as well as tomorrows.

Extreme and very comprehensive studies on rainfall, especially as pertaining to rainfall intensity duration frequency (IDF) analysis in Nigeria, date as far back as 1980. Many researchers majorly in the hydrology, climatology, hydro climatology, geography and civil engineering fields have conducted several studies relating to rainfall in the relentless bid to adequately cater for future storms in the design of hydraulic and drainage structures to prevent unanticipated flood disasters. However, in conducting these different rainfall studies, the researchers had different aspects in mind to which they supposed frequency analysis of rainfall could be applied. Rainfall intensity duration frequency to establish IDF relationships and plotting IDF curves for several regions or locations within the country in order to enhance effective design of hydraulic, drainage and water retaining structures had been studied (Oyebande, 1982; Awokola. 2002; Nwadike, 2008; Salami and Sule, 2009; Okonkwo and Mbajiorgu, 2010; Nwoke and Nwaogazie, 2013; Akpan and Okoro, 2013; Ologhadien and Nwaogazie, 2014; and Ogarekpe, 2014). Their work, however, suffered the limitations of data inadequacy in that available data are short length and cover few locations/areas. Nwaogazie and Duru (2002) plotted IDF with 10 yr rainfall data for Port Harcourt, Nwaogazie and Uba (2001) used 10 yr rainfall data for Uyo, and Nwoke (2013) used 10 yr rainfall data for Owerri. Okonkwo and Mbajiorgwu (2010) worked on rainfall data for Abakaliki, Enugu, Ebonyi, Umuahia, Owerri, Port Harcourt, and Uyo but complained of unavailability of (and didn't use) short duration rainfall data. Ologhadien and Nwaogazie (2014) on the other hand used only 24 hr daily rainfall for Warri, Port Harcourt, Calabar, Benin City, and Onitsha. The most data-laden and locations/areas covered study was done by Oyebande (1982), and Oyegoke and Oyebande (2008) who extended data length by merging different rainfall stations with similar characteristic rainfall into zones.

The works by Dike and Nwachukwu (2003), Olofintoye, Sule and Salami (2009) on frequency analysis were mainly for the purpose of investigating the different probability distribution functions mostly used in frequency analysis to check for the ones that are most suitable for estimation of flood magnitudes and frequencies in different locations within the country. Ologunorisa (2006) and Udosen (2012) in their studies were majorly interested in investigating rainfall trends in different areas of the country and checking for the primary cause of flooding in those regions.

The present study used short duration of 0.2, 0.4, 1, 3, 6, 12, and 24 hr rainfall data for 10 cities in Southern Nigeria and the lengths of period of data varying between 8 and 29 yrs. This is significant because major flooding in the tropics often result from shorter duration rainfall of high intensity as is used in this study.

Generally speaking, IDF curves are important as they are the basis on which the design and function of municipal water resources management infrastructures (such as storm sewers, overland drainage facilities, street curbs and gutters, catch basins, culverts, dikes, bridges, etc.) are done. Hence, the need for accurate estimation of rainfall intensity duration frequency curves cannot be over emphasized. Thus, in a bid to eliminate any form of human errors and avoid the very tasking and rigorous stress associated with the manual approach to IDF analysis, this study aims at generating a Microsoft Excel Spreadsheet model that will enhance a continuous analysis of long term rainfall for use in the design of water resources management infrastructure.

2.0 MATERIALS AND METHOD

In this study, the states of the federation considered were majorly from 3 of the 6 geopolitical zones in the nation. These 3 geopolitical zones are the South-Eastern, South-Southern and South-Western States which all make up the whole of the Southern part of Nigeria as shown in **Figure 1**.

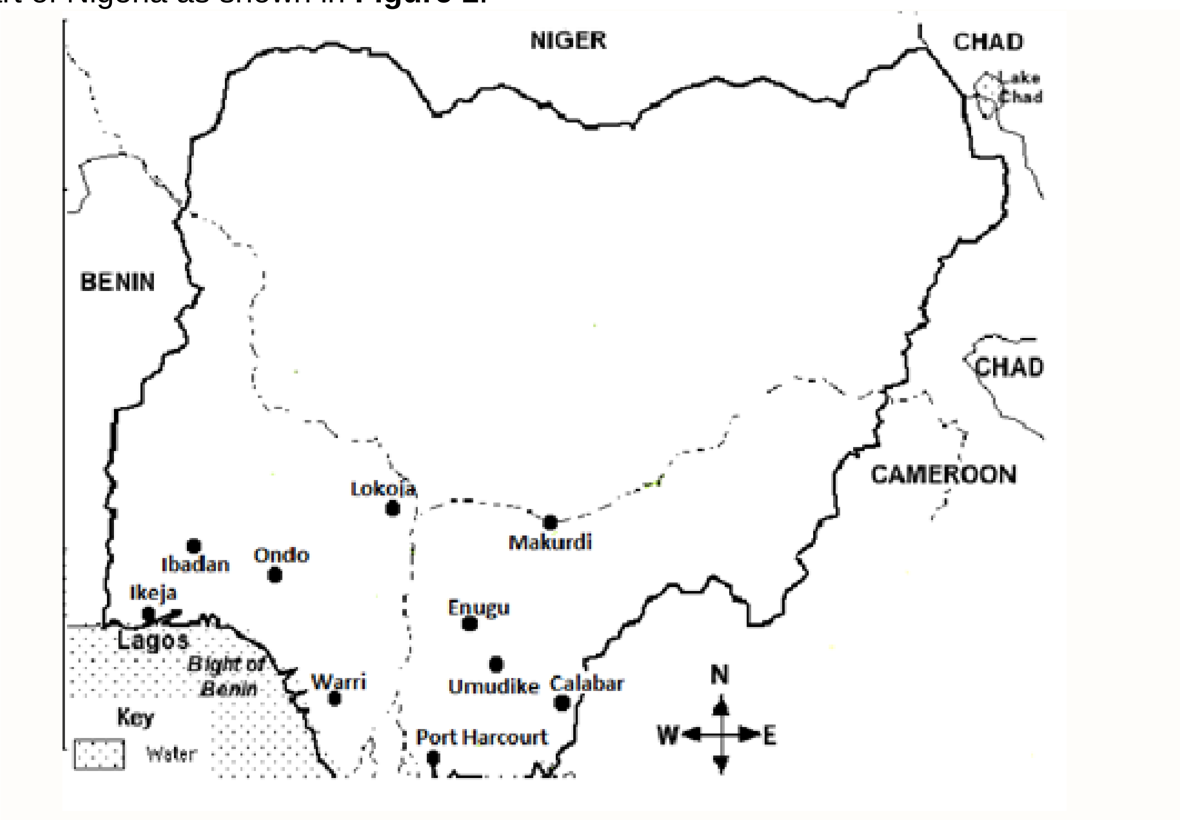

Figure 1: Location of the Cities considered for the Study
Source: *Nigerian Meteorological Agency, Lagos*

The data used for this study that spanned between 1950 and 1980, were obtained from past rainfall archives of the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos-Nigeria. The rainfall data obtained comprised of rainfall intensities ($mmhr^{-1}$.) for durations of 0.2, 0.4, 1, 3, 6, 12 and 24 *hrs*. The length of periods in years enlisted for various locations of study are presented in **Table 1**. The weather recording stations for, which these data were obtained include: Ibadan, Ondo, Ikeja, Umudike, Enugu, Warri, Sokoto, Benin, Port-Harcourt and Calabar. The data obtained for these various stations were then used throughout this study. The data available for each of the rainfall stations were suitably arranged to form a series consisting of maximum annual values (Annual

Maximum Series). The annual maximum series was then subjected to basic statistical analysis after fitting to Gumbel's Extreme Value Type 1 Distribution.

2.1 Frequency Analysis

The distribution of the n_1 extreme values taken from n_1 samples, with each sample having n_2 observations, depends on the distribution of the n_1n_2 total observations. Gumbel was the first to employ extreme value theory for analysis of flood frequencies and it has been widely used for rainfall depth-duration-frequency studies. Chow (1964) has demonstrated that the Gumbel distribution is essentially a log-normal with constant skewness. The Cumulative Distribution Function (CDF) of this density function is given as in Eq.1

$$P(X \leq x) = F(x) = exp\{-exp[-\alpha(x-u)]\} \quad (1)$$

This is a convenient form to evaluate the function. Parameters α and *u* are given as functions of the mean and standard deviation.

The general equation proposed by Chow (1988) for hydrologic frequency analysis is given by Eq. 2

$$x = \bar{x} + Ks \quad (2)$$

where *K* is the frequency factor and *s* is the standard deviation. *K* is a function of *T*, the recurrent interval and varies with the coefficient of skewness in skewed distributions and can be affected greatly by the number of years of record.

Equation (1) can be solved for the recurrence interval *T* and for the variate *x*, as follows:

$$\frac{1}{T} = 1 - F(x) = 1 - exp\{-exp[-\alpha(x-u)]\} \quad (3)$$

$$x = u - \frac{1}{\alpha} ln[ln\,T - ln(T-1)] \quad (4)$$

On substituting the values of *u* and α into Eq. 2, the general frequency equation, with u and α defined as follows as in Eqs 5 and 6:

$$u = \varepsilon + 0.5772\alpha \quad (5)$$

$$\sigma^2 = \frac{\pi^2\alpha^2}{6} \approx 1.645\alpha^2 \quad (6)$$

The frequency factor for the extreme value distribution becomes

$$K = -\frac{\sqrt{6}}{\pi}\left(0.5772 + ln\,ln\frac{T}{T-1}\right) \quad (7)$$

T is the recurrence interval or return period. This frequency factor *K*, for the Gumbel extreme value distribution was then used throughout this study for calculating the values of *x* for different return periods *T*.

2.2 Regression Analysis

Regression technique can also be used for identification of the mathematical dependence among observed values of physically related variables, which account for the additional information contained in correlated sequences of events. Sampling errors are reduced and the reliability of estimates is improved. The fitting technique is the method of least squares, which minimizes the sum of the residuals squared. The Residual is taken as the vertical difference between any value of *y* predicted by the line and the value observed for the same corresponding value of *x*. The line to be fitted is

$$y_i = \alpha + \beta x_i \quad (8)$$

The best estimates of $\alpha\ and\ \beta$ were designated as in Eqs. 9 and 10

$$\alpha = \frac{\sum y_i}{n} - \frac{\beta \sum x_i}{n} = \bar{y} - \beta\bar{x} \quad (9)$$

$$\beta = \frac{\sum x_i y_i - \sum x_i \sum y_i/n}{\sum x_i{}^2 - (\sum x_i)^2/n} \quad (10)$$

where x_i represents the different time durations of rainfall (t) and y_i represents the reciprocals of the corresponding rainfall intensities $\left(\frac{1}{i}\right)$

Regression analysis is often used to fit intensity-duration-frequency curves. The rainfall formula used to fit the IDF curves in this study is of the form

$$i = {}^{A}\!/_{(t+B)} \quad (11)$$

where ***i*** is the rainfall intensity derived using the IDF constants *A* and *B*. The constants *A* and *B* are determined from the regression equation $y_i = \alpha + \beta x_i$.

$$\alpha = \frac{B}{A} \quad (12)$$

$$\beta = \frac{1}{A} \quad (13)$$

The values of the rainfall intensities (*i*) obtained by using the above rainfall formula are then used in plotting the graph of intensity against duration, which is also known as IDF curves.

3.0 RESULTS AND DISCUSSION

3.1 Results

With the use of Microsoft Excel Spreadsheets, frequency analysis was performed on the rainfall data obtained from the 10 stations considered using the Gumbel Distribution, after which tables of IDF relationships for different return periods and Intensity Duration Frequency (IDF) Curves were generated for each of the stations and these are presented in **Tables 1-11 and Figures 2-5**.

Table 1: Identities of the Stations Considered

S/N	Station Name	State	Longitude	Latitude	Elevation (m)	Mean Annual Rainfall (mm)	Periods (Years)	Length Of Record (Years)
1	Calabar	Cross River	8^0 21'E	4^0 58'N	63	2,800	1956-1962, 1971-1976	13
2	Enugu	Enugu	7^0 40'E	6^0 28'N	142	1,800	1956-1978	23
3	Ibadan	Oyo	3^0 59'E	7^0 22'N	221	1,300	1960-1972	13
4	Ikeja	Lagos	3^0 20'E	6^0 35'N	38	1,400	1937-1965	29
5	Benin	Edo	5^0 36'E	6^0 20'N	86	2,025	1956-1965, 1967-1968, 1970-1975	18
6	Oshogbo	Osun	4^0 33'E	7^0 47'N	319	1,241	1956-1974	19
7	Ondo	Ondo	4^0 50'E	7^0 6'N	287	1,700	1959-1975	16
8	Port-Harcourt	Rivers	7^0 1'E	4^0 51'N	18	2,400	1951-1966, 1969-1978	26
9	UMUDIKE	ABIA	07°29′ E	05°31′ N	152	1,800	1956-1963	8
10	WARRI	DELTA	5^0 44'E	5^0 31'N	4	2,700	1956-1975	20

Table 2: IDF relationships for different return periods for Ondo

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		12837	85.7	$i = \frac{12837}{t+85.7}$
2	50	$i = \frac{A}{t+B}$	11539	82.9	$i = \frac{11539}{t+82.9}$
3	25		10233	79.6	$i = \frac{10233}{t+79.6}$
4	10	I = Rainfall Intensity (mmhr^{-1})	8477	74.2	$i = \frac{8477}{t+74.2}$
5	5		7092	68.9	$i = \frac{7092}{t+68.9}$
6	2	t= Rainfall Duration (hrs.)	5009	57.6	$i = \frac{5009}{t+57.6}$
7	1		1570	11.0	$i = \frac{1570}{t+11.0}$

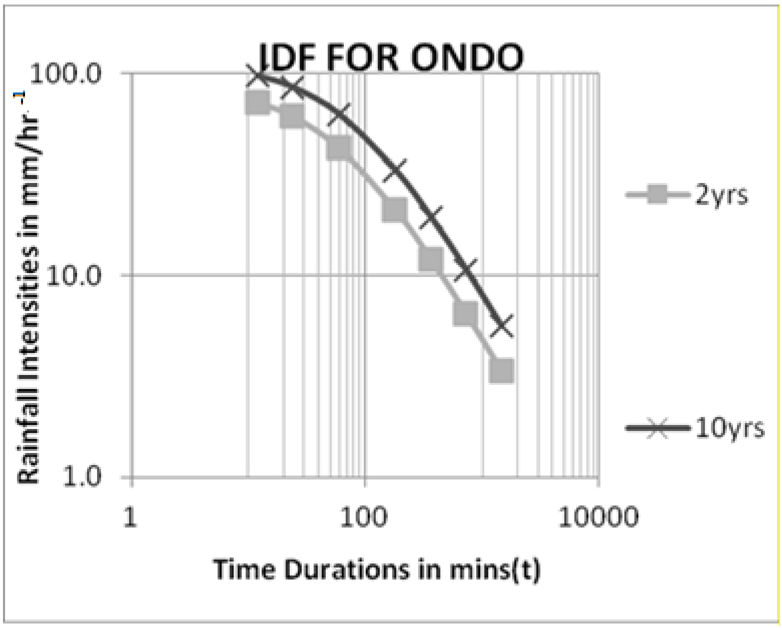

Figure 2: IDF curve for Ondo

Table 3: IDF relationships for different return periods for Ibadan

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		7200	29.4	$i = \frac{7200}{t+29.4}$
2	50	$i = \frac{A}{t+B}$	6622	29.0	$i = \frac{6622}{t+29.0}$
3	25		6041	28.5	$i = \frac{6041}{t+28.5}$
4	10	I = Rainfall Intensity (mmhr^{-1})	5257	27.8	$i = \frac{5257}{t+27.8}$
5	5		4637	27.1	$i = \frac{4637}{t+27.1}$
6	2	t= Rainfall Duration (hrs.)	3701	26.0	$i = \frac{3701}{t+26.0}$
7	1		2140	23.5	$i = \frac{2140}{t+23.5}$

Table 4: IDF relationships for different return periods for Warri

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		14985	203.7	$i = \frac{14985}{t+203.7}$
2	50	$i = \frac{A}{t+B}$	13881	203.1	$i = \frac{13881}{t+203.1}$
3	25		12770	202.5	$i = \frac{12770}{t+202.5}$
4	10	I = Rainfall Intensity (mmhr^{-1})	11271	201.6	$i = \frac{11271}{t+201.6}$
5	5		10086	200.7	$i = \frac{10086}{t+200.7}$
6	2	t= Rainfall Duration (hrs.)	8296	199.3	$i = \frac{8296}{t+199.3}$
7	1		5306	197.0	$i = \frac{5306}{t+197.0}$

Table 5: IDF relationships for different return periods for Benin

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		130	4.3	$i = \frac{130}{t+4.3}$
2	50	$i = \frac{A}{t+B}$	267	61.5	$i = \frac{267}{t+61.5}$
3	25		350	82.0	$i = \frac{350}{t+82.0}$
4	10	I = Rainfall Intensity (mmhr^{-1})	405	92.6	$i = \frac{405}{t+92.6}$
5	5		475	103.6	$i = \frac{475}{t+103.6}$
6	2	t= Rainfall Duration (hrs.)	527	110.5	$i = \frac{527}{t+110.5}$
7	1		579	116.5	$i = \frac{579}{t+116.5}$

Table 6: IDF relationships for different return periods for Oshogbo

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		1972	8.9	$i = \frac{1972}{t+8.9}$
2	50	$i = \frac{A}{t+B}$	4235	28.5	$i = \frac{4235}{t+28.5}$
3	25		5596	39.3	$i = \frac{5596}{t+39.3}$
4	10	I = Rainfall Intensity (mmhr^{-1})	6498	44.5	$i = \frac{6498}{t+44.5}$
5	5		7640	49.6	$i = \frac{7640}{t+49.6}$
6	2	t= Rainfall Duration (hrs)	8488	52.7	$i = \frac{8488}{t+52.7}$
7	1		9330	55.3	$i = \frac{9330}{t+55.3}$

Table 7: IDF relationships for different return periods for Umudike

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		9219	4.7	$i = \frac{9219}{t+4.7}$
2	50	$i = \frac{A}{t+B}$	8563	6.3	$i = \frac{8563}{t+6.3}$
3	25		7901	8.4	$i = \frac{7901}{t+8.4}$
4	10	I = Rainfall Intensity (mmhr^{-1})	7008	11.9	$i = \frac{7008}{t+11.9}$
5	5		6301	15.6	$i = \frac{6301}{t+15.6}$
6	2	t= Rainfall Duration (hrs.)	5230	24.0	$i = \frac{5230}{t+24.0}$
7	1		3415	57.2	$i = \frac{3415}{t+57.2}$

Table 8: IDF relationships for different return periods for Ikeja

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		11636	72.9	$i = \frac{11636}{t+72.9}$
2	50	$i = \frac{A}{t+B}$	10635	70.6	$i = \frac{10635}{t+70.6}$
3	25		9626	67.8	$i = \frac{9626}{t+67.8}$
4	10	I = Rainfall Intensity (mmhr^{-1})	8266	63.1	$i = \frac{8266}{t+63.1}$
5	5		7190	58.4	$i = \frac{7190}{t+58.4}$
6	2	t= Rainfall Duration (hrs.)	5563	48.4	$i = \frac{5563}{t+48.4}$
7	1		2837	14.4	$i = \frac{2837}{t+14.4}$

Table 9: IDF relationships for different return periods for Calabar

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		14017	60.9	$i = \frac{14017}{t+60.9}$
2	50	$i = \frac{A}{t+B}$	12794	59.1	$i = \frac{12794}{t+59.1}$
3	25		11564	57.1	$i = \frac{11564}{t+57.1}$
4	10	I = Rainfall Intensity (mmhr^{-1})	9909	54.1	$i = \frac{9909}{t+54.1}$
5	5		8603	51.5	$i = \frac{8603}{t+51.5}$
6	2	t= Rainfall Duration (hrs.)	6639	47.0	$i = \frac{6639}{t+47.0}$
7	1		3387	41.8	$i = \frac{3387}{t+41.8}$

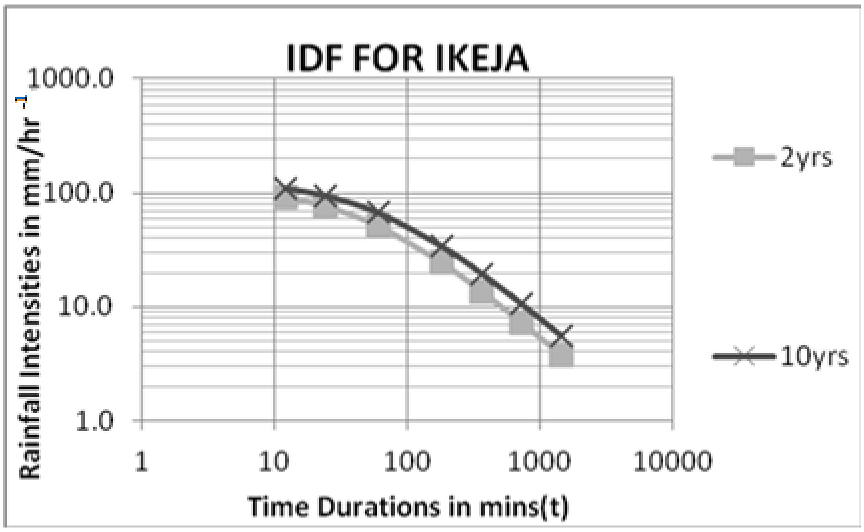

Figure 3: IDF curve for Ikeja

Table 10: IDF relationships for different return periods for Port Harcourt

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr^{-1})*
1	100		11064	24.2	$i = \frac{11064}{t+24.2}$
2	50	$i = \frac{A}{t+B}$	10358	26.3	$i = \frac{10358}{t+26.3}$
3	25		9647	28.8	$i = \frac{9647}{t+28.8}$
4	10	I = Rainfall Intensity (mmhr^{-1})	8690	32.9	$i = \frac{8690}{t+32.9}$
5	5		7934	37.2	$i = \frac{7934}{t+37.2}$
6	2		6796	46.4	$i = \frac{6796}{t+46.4}$
7	1	t= Rainfall Duration (hrs.)	4923	80.3	$i = \frac{4923}{t+80.3}$

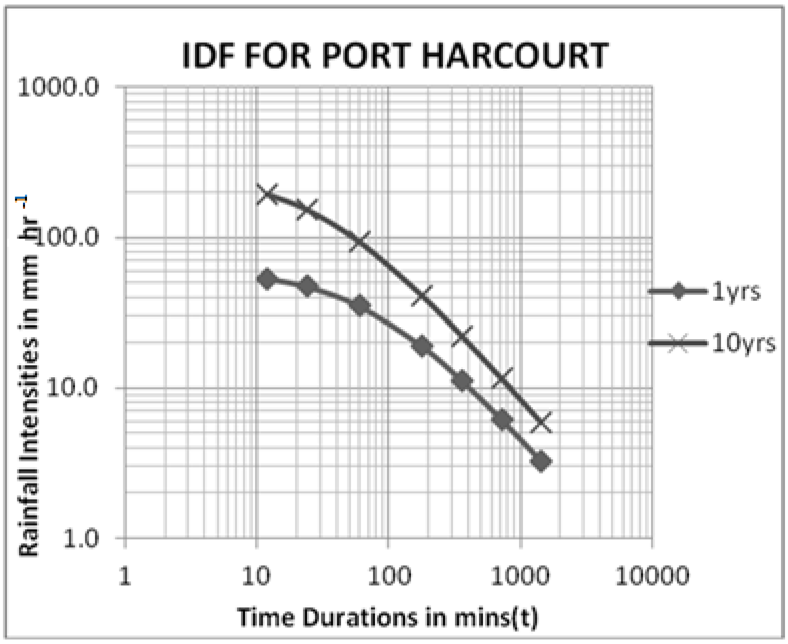

Figure 4: IDF curve for Port Harcourt

Table 11: IDF relationships for different return periods for Enugu

S/N	RETURN PERIOD T (Years)	IDF CURVE EQN	*A*	*B*	*I (mmhr⁻¹)*
1	100		9748	33.8	$i = \frac{9748}{t+33.8}$
2	50	$i = \frac{A}{t+B}$	8953	33.8	$i = \frac{8953}{t+33.8}$
3	25		8153	33.9	$i = \frac{8153}{t+33.9}$
4	10	I = Rainfall Intensity (mmhr^{-1})	7075	34.0	$i = \frac{7075}{t+ 34.0}$
5	5		6221	34.1	$i = \frac{6221}{t+34.1}$
6	2	t= Rainfall Duration (hrs.)	4932	34.8	$i = \frac{4932}{t+34.8}$
7	1		2779	41.1	$i = \frac{2779}{t+41.1}$

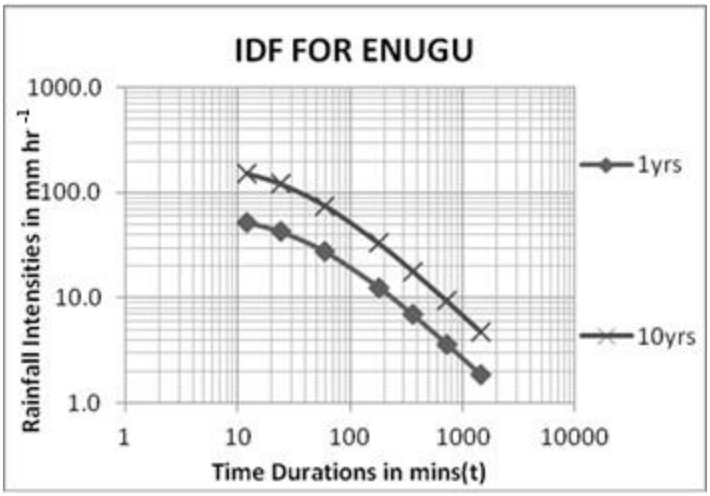

Figure 5: IDF curve for Enugu

3.2 Discussion

For Ikeja, Lagos State:

The IDF relationship for a 10 yr storm for Ikeja is $i = \frac{8266}{t+63.1}$.

Substituting the value of t= 9 minutes, the rainfall intensity to be designed for is i = **114.65 mmhr^{-1}**

For Port-Harcourt, Rivers State:

The IDF relationship for a 10 yr storm for Port-Harcourt is $i = \frac{8690}{t+32.9}$. Substituting the value of t= 9 minutes, the rainfall intensity to be designed for is i = **207.40 mmhr^{-1}.**

For Enugu, Enugu State:

The IDF relationship for a 10 yr storm for Enugu is $i = \frac{7075}{t+34.0}$. Substituting the value of t= 9 minutes, the rainfall intensity to be designed for is i = **164.53 mmhr^{-1}.**

From the results obtained for the three stations above, it was observed that Port-Harcourt had the highest rainfall intensity, followed by Enugu and then Ikeja. Thus, from this analysis between these three stations, rain falls with highest intensity is at Port-Harcourt, followed by Enugu and then Ikeja.

4.0 CONCLUSION

It can be concluded from the analysis of the results generated using the excel spreadsheet program that the program works satisfactorily. It will be of immense help in developing a database for the continuous (or long term) analysis of rainfall in Nigeria and generation of IDF curves. This may then be uploaded to websites of Meteorological Agencies for ready use in the hydraulic design of structures and other related purposes.
The IDF relationships for the three different stations, for a storm of 10 yr return period with time duration of 9 minutes, indicate that Port-Harcourt had the highest rainfall intensity, followed by Enugu and then Ikeja. This will serve as a tool for the engineers in estimating storm water runoff for the design of storm sewer systems in these locations.

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