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DEVELOPMENT OF RAINFALL INTENSITY-DURATION FREQUENCY MODELS FOR SELECTED LOCATIONS IN SOUTH EASTERN NIGERIA

BY

Emeka-Chris, C.C[x1], Ahaneku, I.E[1], Osodeke, V.E[2]., Ehimogue, P[3]., Obineche C.I[4]., DURUMBAH-OBIH, F. M[5]

[1, 2,3]Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture Umudike, Nigeria

[2]Department of Soil Science Technology, Federal College of Land Resources Technology Owerri, Imo State Nigeria

[4]Department of Agricultural Engineering Technology, Federal College of Land Resources Technology Owerri, Imo State Nigeria

[5]Department of Environmental Management Technology, Federal College of Land Resources Technology Owerri, Imo State Nigeria

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Abstract

The development of a rainfall intensity-duration-frequency (IDF) Models for selected locations in humid rainforest zones of Nigeria is the subject of concentration on this research. Thirty-two (32) years (1983-2014) daily rainfall data were collected for Umuahia and Owerri from Nigeria Meteorological Agency (NIMET) Oshodi, Lagos State for the study. The method of annual maximum series was used to select data sets for rainfall analysis. For the development of the models, the advanced storm, a pattern developed by United State Department of Agriculture (USDA) Soil Conservation service was used to break down daily rainfall into shorter durations. Gumbel and Log Pearson Type III distributions were used to compute the observed rainfall intensity values at durations of 10, 15, 20, 30, 60,120,180,240, 300, and 360 minutes for return periods of 2, 5, 10, 20,50, and 100 years. To obtain parameters for the IDF models for each location, the computed rainfall intensities were subjected to non-linear regression analysis using Microsoft Excel Optimization Technique Solver wizard for the respective durations and return periods. The performance of the models were analysed by determining the chi-square(χ^2), coefficient of determination(R^2), and Root Mean Square Error(RMSE) of the fitted distributions. Coefficient of determination values, R^2 obtained from the fitted IDF Models adopting Log Pearson Type 111 and Gumbel distributions gave perfect value of 1 for both regions. Also for the Log Pearson Type 111 distribution, RMSE values ranged from 1.57 ─ 15.33 and 0.46 – 11.69 for Umuahia and Owerri regions. Gumbel distribution and RMSE values ranged from 0.05 – 14.47 and 0.21 – 11.08 for Umuahia and Owerri regions. However, there was no significant difference amongst the predicted intensities of the various IDF models.

Keywords: *Gumbel distribution, Rainfall, intensity- duration –frequency (IDF), Log Pearson type III*

1. Introduction

Extreme rainfall events cause pollution of the quality of water, destruction of assets, and loss of lives due to flooding. Rainfall is an important component in the hydrologic cycle. Brian et al. (2006) posit that rainfall frequency analyses are needed in the development and designing of various water resources projects, this includes storm sewers, culverts, and other hydraulic structures. To design flood protection structures involving hydrologic flows, rainfall events statistics (that is, in relations to intensity, duration, and period of return) are required (Prodanovic and Simonovic, 2007). Graphically the quantity of precipitation that falls within a catchment area in a given period of time are represented by Rainfall – Intensity - Duration-Frequency (IDF) curves (Elsebaie, 2012). IDF curves are an important tool for the engineers when designing urban drainage works. The estimation, use of IDF curves rely on the proposition of rainfall sequence stationarity, that is, that intensities and frequencies of extreme hydrological events remain unchanged over time. Hence, it is expected that global warming will adjust rainfall extreme occurrence events.

The establishment of IDF relationships was started as early as 1932 (David et al., 2019). Since then, many sets of relationships have been constructed for several parts of the globe. However, such relationships have not been accurately constructed in many developing countries (Koutsoyiannis et al., 1998).

Koutsoyiannis (2003) opined that the IDF relationship is a mathematical relationship between the rainfall intensity (i), the duration (d), and the return period (T) (or, equivalently, the annual frequency of exceedance f, typically referred to as ‘frequency’ only). Indeed the IDF-curves allow for the estimation of the return period of an observed rainfall event or conversely of the rainfall amount corresponding to a given return period for different aggregation times.

A major challenge hydrologists and engineers encounter in the planning and design of water resources structure is that of unavailability of required long-term rainfall data. In South Eastern Nigeria, IDF curves and Models are not readily available (Okonkwo and Mbajiorgu, 2010). The few available IDF curves for some parts of the country are very costly and plotting of the curves were done manually (i.e fitting of lines were done by eye to the points). This manual method of developing IDF curves is prone to error. The general objective of this study is to develop Rainfall Intensity- Duration – Frequency (IDF) curves for some selected locations in Humid forest Zones of Nigeria.

2. Materials and Methods

South Eastern Nigeria covers about 29095 km2 which is about 3.19 % of the total area of Nigeria. It is located within latitudes 4° 47' 35" N and 7° 7' 44" N, and longitudes 7° 54' 26" E and 8° 27' 10" E(figure 1) of Nigeria and is made up of five (5) States namely; Abia, Anambra, Ebonyi, Enugu and Imo (Anejionu *et al*., 2013). The relative location is bounded in the northwest by Kogi and Benue States, in the northeast by Cross River State, in the South by Akwa Ibom and Rivers States, and finally in the West by Delta State. The mean minimum and maximum temperatures ranged from 21-30 °C in the coast and 29 - 33 °C in the interior or inlands (Chukwu, 2007). The rainfall of Southern Nigeria generally is heavy (very high) and usually above 1300 mm.

Table 2.1: Characteristics of the meteorological stations of the study cities

Location	State	Coordinate	Agro-ecological zones	Available Data Range
Owerri,	**Imo**	06^{o} 26’ 54’N, 07^{o} 30’E	Eastern Moist Forest	1983- 2014
Umuahia,	**Abia**	05^{o} 32’N, 07^{o} 29’E	Eastern Moist Forest	1983- 2014
Enugu,	**Enugu**	06^{o} 27’N, 07^{o} 30’E	Forest(Derived) Savanna Moist	1983 – 2014
Onitsha,	**Anambra**	06^{o} 10’N, 06^{o} 47’E	Eastern Moist Forest	1983- 2014

National Food Reserve Agency (NFRA), 2008

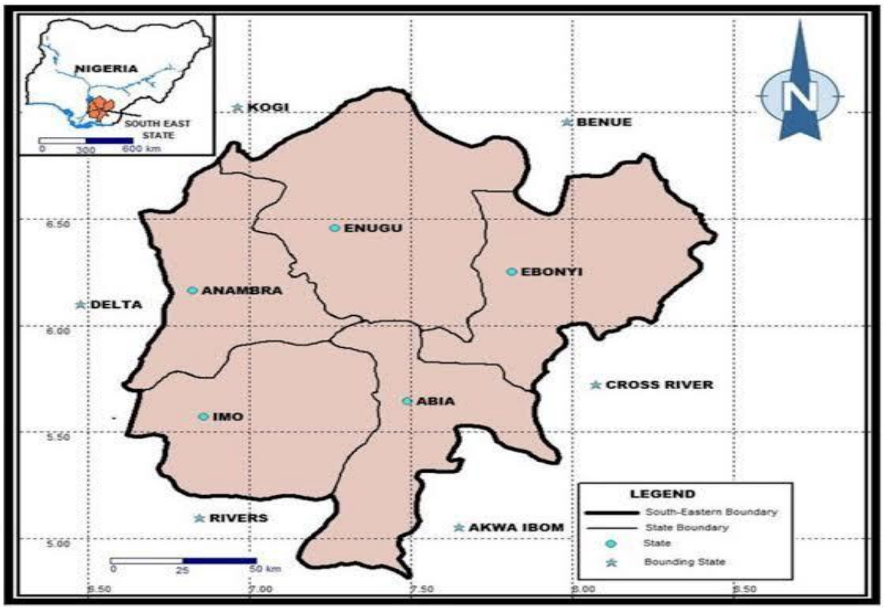

Figure2.1: Map of the southeast region of Nigeria showing the two-component states. (FDLAR, 1990)

2.2 Data Requirement and Collection for the Study

The data required in this study are rainfall depths for smaller durations namely, 5, 10, 15, 20, 30, 60, 120, 180, 240, 300, and 360 minutes. Daily rainfall data were collected from National Root Crop Research Institute (NRCRI) Umudike and the Nigeria Meteorological Agency, (NIMET) Lagos. The length of the records used for all the stations is same and is 32 years (from 1983 to 2014). A model was used to break down the 24-hour rainfall data into 0.25hour, 0.5 hour, 1 hour, 2 hours, 4 hours, and 6hrs durations.

2.3 Gumbel theory of distribution

Gumbel distribution methodology was used to perform the flood probability analysis; hence it is the most widely used distribution for IDF analysis owing to its suitability for modeling maxima (Elsebaie, 2012).

$P_T=P_{ave}+KS$ (1)

Where K is Gumbel frequency factor given by:

$K = \frac{\sqrt{6}}{\pi}\ [0.5772 + In[In\left[\frac{T}{T-1}(8)\right]]]$ (2)

Where P_{ave} is the average of the maximum precipitation corresponding to a specific duration.

In utilizing Gumbel's distribution, the arithmetic average in Eq. (3) was used:

$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P\,i$ (3)

Where Pi is the individual extreme value of rainfall and n is the number of events or years of record. The standard deviation, S of P data was calculated using Eq. (4)

$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}(Pi - Pave)^{2\frac{1}{2}}\right]$ (4)

The frequency factor (K), which is a function of the return period and sample size, was multiplied by the standard deviation to give the departure of a desired return period rainfall from the average.

Then the rainfall intensities, I (mm/h) for return period T were obtained from:

$I_T = \frac{P_T}{T_d}$ (5)

Where T_d is duration in hours,

From the raw data, the maximum precipitation (P) and the statistical variables (average and standard deviation) for each duration (0.25hr, 0.5hr, 1hr, 2hr, 4hr, 6hr) were computed.

2.4 Log Pearson type III

The LPT III probability model was used to calculate the rainfall intensity at different rainfall durations and return periods to form the historical IDF curves for the selected locations. The mean and the standard deviation were determined using the logarithmically transformed data. The simplified expression for this latter distribution is given as follows:

$P^{*} = \log(P_i)$ (6)

$P^*_T=P^*_{ave}+K_TS$ (7)

$P^*_{ave}=\frac{1}{n}\sum_{i=1}^{n} P*$ (8)

$S^* = [\frac{1}{n-1}\sum_{i=1}^{n}(P* - P*_{ave})^{2^{1/2}}]$ (9)

Where P^*_T, P^*_{ave} are as defined previously in Section 2.3, Based on the logarithmically transformed Pi values; i.e. P* of Eq. (6).

K_T is the Pearson frequency factor which depends on return period

(T) and skewness coefficient (Cs).

The skewness coefficient, Cs, is required to compute the frequency factor for this distribution. The skewness coefficient were computed using Eq. (1) (Chow, 1988) and Burke and Burke (2008).

$Cs = \frac{n\sum_i^{ni}(P^*i-P_{ave})^3}{(n-1)(n-2)(S^*)^3}$ (10)

The computed frequency precipitation P^*_T values and intensities (I_T) for six different durations and six return periods using LPT III methodology are given in a table.

2.5 Intensity-Duration –Frequency (IDF) Model Development

The Intensity-Duration-Frequency (IDF) formulae are the empirical equations representing a relationship between the variables. The variables used for the development of the appropriate mathematical models are the maximum rainfall intensity, the rainfall duration, and frequency. Several commonly used IDF equations relating the rainfall intensities, the frequencies, and durations are available in literature (Chow, 1988; Burke and Burke, 2008; Nhat et al., 2006 and Mohammad, 2016). The commonly used IDF equations are

Bernard equation $i=\frac{aT^b}{t^c}$ (11)

Talbot equation $i=\frac{aT^b}{t+d}$ (12)

Kimijima equation $i=\frac{aT^b}{(t^c+d)}$ (13)

Sherman equation $i=\frac{aT^b}{(t+d)^c}$ (14)

Where,

i = intensity of rainfall in mm/hr; t = duration of rainfall in minutes; T = return period of rainfall in years; a, b, c, and d are the regional IDF parameters to be determined.

Equation (14) which is the most general form of IDF equation has been used to develop the IDF equations by optimization method.

2.5.1 Application of Excel Solver Optimization Technique to estimate IDF Parameters

The excel solver methods are mainly the Generalized Reduced Gradient (GRG Solver) for optimization of nonlinear equations and the linear programming Solver (LP Solver) for linear equations. Due to the fact that IDF equations are nonlinear, the GRG Solver was used in this work to get the optimum of the parameters for the models.

2.5.2 Calibration of the Sherman (1932) Model

Sherman (1932) model as given in equation (14) was calibrated using GRG Solver optimization method to obtain optimum values for the regional parameters namely a, b, c, and d for the models.

Thus the objective function becomes:

$MinSSE= \sum_{i=1}^{n}(i_{obs} - i_{est})^2$ (15)

Where i_{obs} = observed intensity corresponding to any duration i_{est} = estimated intensity corresponding to any duration. Solving equation (15) produces the optimum values for the parameters a, b, c, and d achieved through an iterative process that produces the least squared error.

2.6 Model Performance Analysis

The performance of the Intensity Duration Frequency (IDF) models given by Gumbel distribution and Log Pearson Type 111 Distribution (LPT 111) were evaluated by obtaining empirical data from the models and then goodness of Fit test, Correlation Coefficient, and Root Mean Square Error (RMSE) analysis were carried out. To determine the best-fit distribution, the observed distributions were fitted to the theoretical distribution by comparing the frequencies observed in the data to the expected frequencies of the theoretical distribution. A Goodness-of-fit test between observed and expected frequencies is based on the chi-square quantity, which is expressed as:

$$\chi^2 = \sum_{i}^{k} = \frac{(Oi-Ei)^2}{Ei} \qquad (16)$$

Where,

χ^2 = random variable whose sampling distribution is approximated very closely by the chi-square distribution.

Oi and Ei = the observed and expected frequencies for the i-th class interval in the histogram. K = the number of class intervals.

Mohammad (2016) provided programmable formulae to obtain coefficient of determination (R^2) and Root Mean Square Error(RMSE) as follows:

$$R^2 = \frac{\sum_{i=1}^{n}(\text{Iobs}-\text{Iavg})^2 - \sum_{i=1}^{n}(\text{Iobs}-\text{Ipred})^2}{\sum_{i=1}^{n}(Iobs-Iavg)^2} \qquad (17)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}}\sum_{i=1}^{N}(Ii - \hat{I}*)^2 \qquad (18)$$

The theoretical description of Correlation Coefficient (CC) is as given in equation (19)

$$CC = \sum_{i=1}^{N}\left(\frac{(Ii-\hat{I})(I*i-\hat{I}*)}{\sqrt{\sum_{i=1}^{N}(Ii-\hat{I})^2 + \sum_{i=1}^{N}(I*i-\hat{I}*i)^2}}\right) \qquad (19)$$

Where Ii is the recorded rainfall intensity of ith event, I_{*i} is the estimated rainfall intensity of the ith event. $\hat{I}$ is the average recorded rainfall intensity and $\hat{I}_{*i}$ is the average of estimated rainfall intensity.

3. RESULTS AND DISCUSSION

3.1: Results of Intensity Duration Frequency (IDF) Curves by Gumbel and Log Pearson Type (LPT) 111 methods

The results of the computed rainfall intensities and frequency factors from observed frequency precipitation values for different durations and return periods using Gumbel and Log Pearson Type 111 (LPT 111) methods for the two regions studied are shown in appendices Tables 1 to 4.

Table 1: Computed Rainfall Intensities for different Durations and Return Periods using Gumbel Distribution for Umuahia

Return Period, T	Frequency Factor, K	Durations(minutes)									
		10	15	20	30	60	120	180	240	300	360
2	-0.164	105.616	84.520	80.874	82.176	54.174	36.975	29.347	24.651	21.365	19.564
5	0.719	147.837	118.112	113.694	114.828	77.035	51.673	41.011	34.447	29.856	27.340
10	1.305	175.862	140.404	135.477	136.498	92.206	61.427	48.752	40.949	35.491	32.501
25	2.044	211.202	168.512	162.945	163.828	111.339	73.727	58.515	49.148	42.597	39.009
50	2.592	237.403	189.360	183.315	184.092	125.527	82.849	65.754	55.228	47.867	43.835
100	3.137	263.466	210.092	203.571	204.246	139.637	91.920	72.953	61.275	53.107	48.635

Table 2: Computed Rainfall Intensities for different Durations and Return Periods using Log Pearson Type 111 Distribution for Umuahia

Return Period, T	Frequency Factor, K	Durations(minutes)									
		10	15	20	30	60	120	180	240	300	360
2	-0.224	98.922	79.444	76.835	77.452	53.456	34.433	26.356	20.699	19.908	18.191
5	0.706	134.677	108.16	104.607	105.446	72.778	46.878	35.882	28.18	27.104	24.766
10	1.337	166.066	133.372	128.991	130.026	89.943	57.806	44.246	34.749	33.422	30.539
25	2.126	215.419	173.004	167.324	168.666	116.413	74.984	57.396	45.076	43.354	39.614
50	2.703	260.784	209.44	202.562	204.188	140.929	90.776	69.483	54.568	52.484	47.957
100	3.266	314.257	252.384	244.093	246.054	169.824	109.388	83.73	65.757	63.246	57.79

Table 3: Computed Rainfall Intensities for different Durations and Return Periods using Gumbel Distribution For Owerri

Return Period, T	Frequency Factor, K	Durations(minutes)									
		10	15	20	30	60	120	180	240	300	360
2	-0.164	99.724	79.756	73.171	77.540	54.273	34.893	27.690	23.261	20.160	18.461
5	0.719	129.075	103.244	95.662	100.358	70.247	45.162	35.840	30.108	26.094	23.896
10	1.305	148.557	118.832	110.588	115.502	80.847	51.977	41.248	34.653	30.032	27.502
25	2.044	173.121	138.492	129.415	134.596	94.216	60.572	48.069	40.384	34.998	32.051
50	2.592	191.336	153.068	143.372	146.752	104.129	66.945	53.127	44.634	38.680	35.424
100	3.137	209.45	167.564	157.255	162.840	113.988	73.284	58.158	48.86	42.343	38.778

Table 4: Computed Rainfall Intensities for different Durations and Return Periods using Log Pearson Type 111 Distribution for Owerri

Return Period, T	Frequency Factor, K	Durations(minutes)									
		10	15	20	30	60	120	180	240	300	360
2	0.023	100.066	80.364	77.724	83.758	55.335	35.643	27.918	23.493	20,608	18.830
5	0.841	130.102	104.488	101.054	101.866	71.945	46.342	36.298	30.545	26.794	24.482
10	1.265	149.036	119.692	115.760	116.690	82.414	53.085	41.579	34.990	30.692	28.045
25	1.702	171.509	137.74	133.216	134.286	94.842	61.090	47.850	40.266	35.321	32.274
50	1.979	187.192	150.336	145.396	146.564	103.514	66.676	52.225	43.948	38.550	35.225
100	2.224	202.431	162.576	157.237	158.500	111.944	72.106	56.478	47.527	41.690	38.093

These are mainly results of descriptive statistics showing information on observed rainfall intensities and frequency factors for different durations and return periods. These results were used as input data for rainfall intensity transformation to derive the probability distribution function equivalent (i.e . Gumbel and Log Pearson Type 111) for fitting the IDF Curves.

3.1.1: Results of IDF curves by Gumbel and Log Pearson Type (LPT) 111 methods for Umuahia region

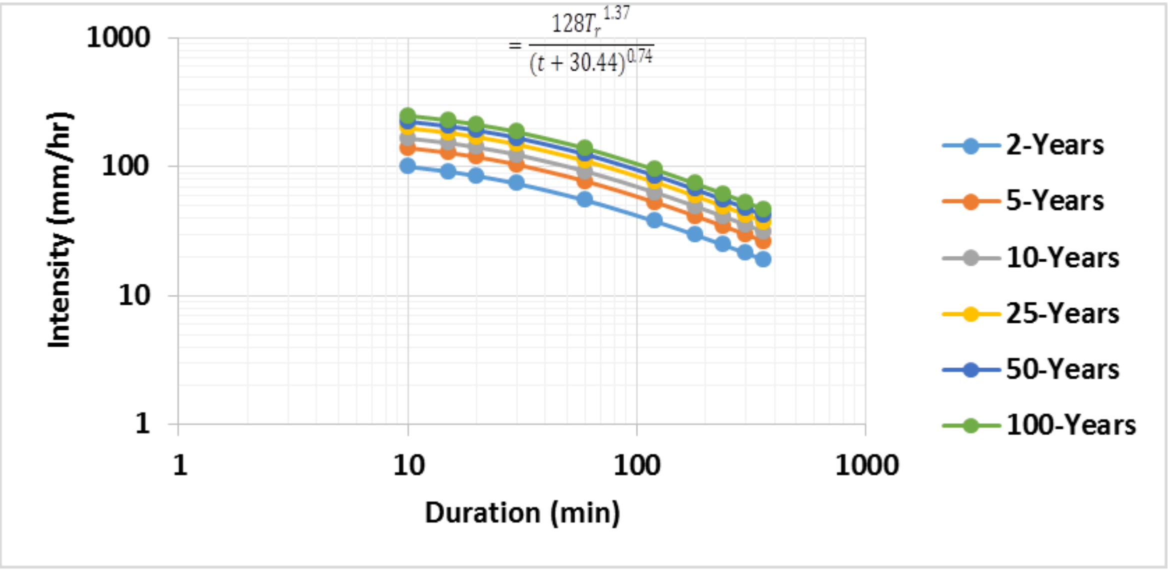

Figure 3.1.: IDF curves by Gumbel method at Umuahia (South-East Nigeria)

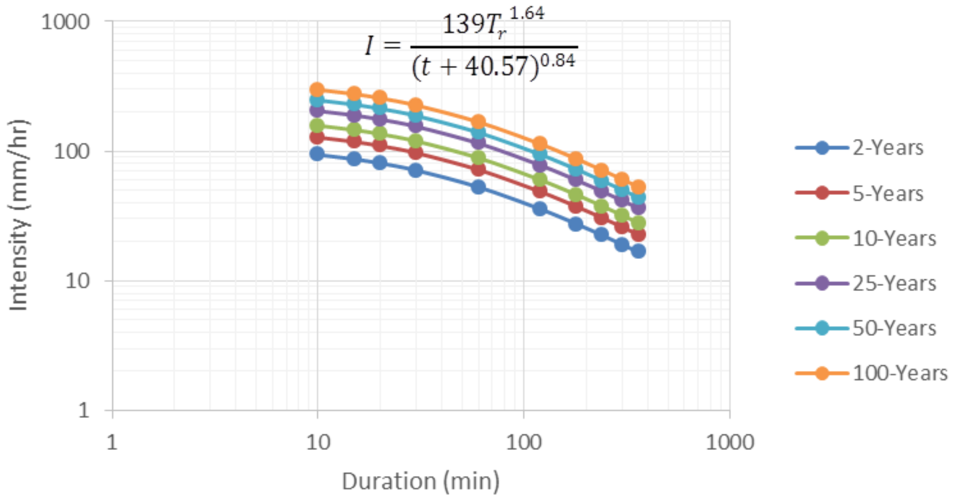

Figure 3.2: IDF curves by LPT III method at Umuahia (South-East Nigeria)

Figures 3.1 and 3.2 represents the IDF curves obtained by Gumbel and LPT 111 methods for Umuahia region. The trends of the curves from the two methods show good consistency. However, the rainfall intensities are increasing more at low return periods and durations in the IDF curves obtained using Gumbel distributions than in IDF curves obtained using Log Pearson Type 111 distributions. This shows that Gumbel method gave higher results in rainfall intensities than LPT 111 method.

3.1.2: Results of IDF curves by Gumbel and Log Pearson Type (LPT) 111 methods for Owerri region

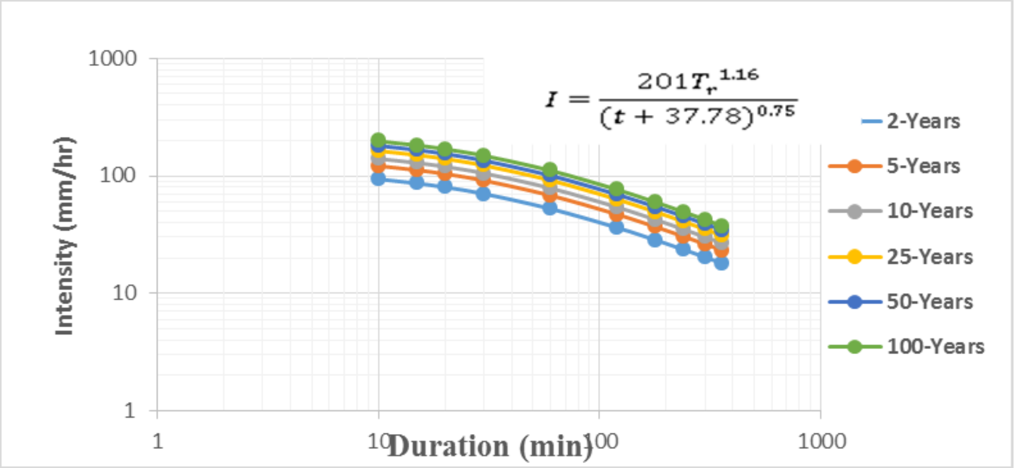

Figure3.3: IDF curves by Gumbel method at Owerri (South-East Nigeria)

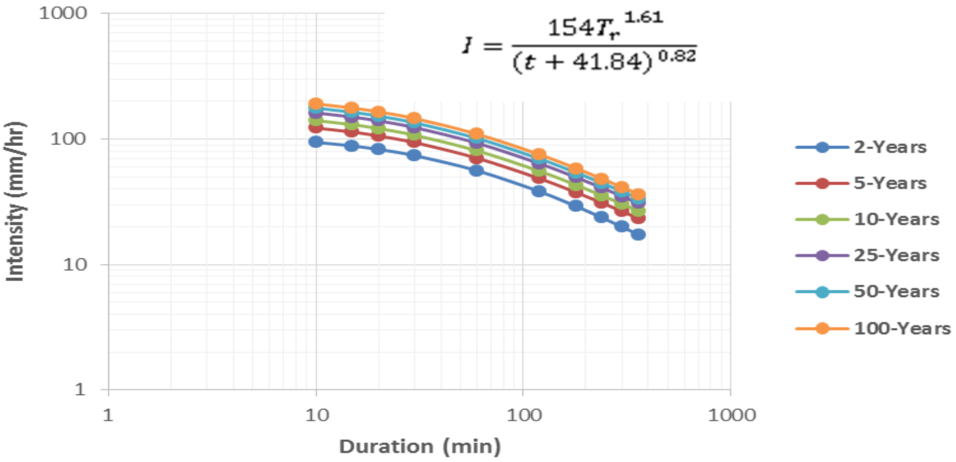

Figure 3.4: IDF curves by LPT III method at Owerri (South-East Nigeria)

*Corresponding Author: **Emeka-Chris, C.C**

Figures 3.3 and 3.4 show results of the IDF curves obtained by Gumbel and LPT 111 methods for the region. The trends of the curves from the two methods show good consistency. However, in the IDF curves obtained using Log Pearson Type 111, rainfall intensity values are higher for all the durations and return periods compared to Gumbel distribution.

3.2 Results of Rainfall Intensity Duration Frequency Models and their parameter values

The parameter values used in deriving the Gumbel and Log Pearson Type 111 models, including the models for each region are shown in table 5 below.

Table 5: Parameters values used in deriving models for rainfall intensity at different locations

S/No	Location	Distribution	Parameters				Models
			a	b	c	d	
1.	Umuahia	Gumbel	128	1.37	0.74	30.44	$I = \frac{128{T_r}^{1.37}}{(t+30.44)^{0.74}}$
		LPT III	139	1.64	0.84	40.57	$I = \frac{139{T_r}^{1.64}}{(t+40.57)^{0.84}}$
2.	Owerri	Gumbel	201	1.16	0.75	37.78	$I = \frac{201{T_r}^{1.16}}{(t+37.78)^{0.75}}$
		LPT III	154	1.61	0.82	41.84	$I = \frac{154{T_r}^{1.61}}{(t+41.84)^{0.82}}$

The Gumbel and Log Pearson Type 111 models, including the parameter values used in deriving the models for each region studied, are shown in table 5. The parameter values used in deriving the models are a, b, c, and d. For Umuahia region, the values of parameters a(139), b(1.64), c(0.84), and d(40.57) obtained using Log Pearson Type 111 method are higher than for Gumbel method. Also, values of parameters c(0.82) and d(46.35) using Log Pearson Type 111 method are higher than in Gumbel distribution for Owerri region. This accounts for the higher predicted rainfall intensities obtained using Log Pearson Type 111 method than Gumbel distribution, the model derived using Gumbel method for Owerri has the largest values of model parameters, compared to other models.

3.3 Model Performance/Validation

The results of the computed indicators of goodness of fit between Gumbel and Log Pearson Type 111 Models, namely Chi Square (χ^2), Root Mean Square Error (RMSE), Correlation Coefficient (R), and Coefficient of Determination (R^2) are given in table 3.2 and 3.3

3.3.1 Model Performance/Validation for IDF Umuahia Model

			Duration (min)									
Location	Distribution	Model validation	10	15	20	30	60	120	180	240	300	360
Umuahia	Gumbel	$\chi 2$	3.13	7.00	1.84	7.78	0.02	0.45	0.09	0.01	0	0.25
		RMSE	10.13	14.49	7.09	13.59	0.55	2.4	0.95	0.28	0.05	1.25
		R	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		P-value	0.68	0.22	0.87	0.17	1.00	0.99	1.00	1.00	1.00	1.00

Table 3.3: Model Performance/Validation for Umuahia IDF Model Obtained by Log Pearson Type 111 Method

Location	**Distribution**	**Model validation**	**Duration (min)**									
			10	15	20	30	60	120	180	240	300	360
Umuahia	Log Pearson Type III	$\chi 2$	3.48	7.13	2.1	7.24	0.12	0.51	0.43	1.5	0.5	1.81
		RMSE	11.13	15.33	8.02	13.98	1.57	2.63	2.13	3.57	1.89	3.38
		R	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

		P-value	0.63	0.21	0.83	0.2	1.00	0.99	0.99	0.91	0.99	0.87

Tables 3.2 and 3.3 show the model performance/validation of IDF Model obtained for Umuahia region using Gumbel and Log Pearson Type 111 distributions respectively. The results obtained revealed that in all cases the correlation coefficient (R) and coefficient of determination (R^2) obtained from the fitted IDF Models using both Gumbel and Log Pearson Type 111 distributions gave perfect value of 1. This indicates the goodness of the formulae to estimate IDF models in Umuahia region.

Results of chi-square goodness of fit test between the observed and predicted intensities for both Gumbel and LPT 111 method revealed that most of the data fit the distributions at level of significance of 5%. Only the data at 15 minutes and 30 minutes durations do not give good fit using both distributions.

The values of root mean square errors (RMSE) obtained using both Gumbel and LPT 111 distributions for Umuahia region are lower at higher durations from 60 minutes to 360 minutes, but higher at lower durations from 10 minutes to 30 minutes. This shows that the derived formulae can be used to estimate any frequency rainfall data for Umuahia region, especially at higher durations using both methods.

3.3.2 Model Performance/Validation for Owerri IDF Model

Tables 3.4 and 3.5 show the model performance/validation of IDF Model obtained for Owerri region using Gumbel and Log Pearson Type 111 distributions respectively.

Table 3.4 Model Performance/Validation for Owerri IDF Model Obtained by Gumbel Method

			Duration (min)									
Location	Distribution	Model performance	10	15	20	30	60	120	180	240	300	360
		X^2	3.47	4.91	4.13	6.32	0.48	0.51	0.14	0.03	0.01	0.16
		RMSE	9.51	10.92	9.47	11.08	2.63	2.27	1.04	0.43	0.21	0.9
Owerri	Gumbel	RMSE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Pvalue	0.63	0.43	0.53	0.28	0.99	0.99	1.00	1.00	1.00	1.00

Table 3.5: Model Performance/Validation for Owerri IDF Model Obtained by Log Pearson Type 111 Method

Location	Distribution	Model validation	Duration (min)									
			10	15	20	30	60	120	180	240	300	360
Owerri	Log Pearson Type III	$\chi 2$	2.97	5.74	1.92	5.81	0.22	0.7	0.29	0.03	0.05	0.55
		RMSE	8.76	11.69	6.47	10.44	1.82	2.6	1.5	0.47	0.46	1.58
		R	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		P-value	0.71	0.33	0.86	0.33	1.00	0.98	1.00	1.00	1.00	0.99

Tables 3.4 and 3.5 show the model performance/validation of IDF Model obtained for Owerri region using Gumbel and Log Pearson Type 111 distributions. The calculated chi-squared show that all the data gave good fit using both Gumbel and Log Pearson Type 111 distributions at 5% level of significance, except the data for 15 minutes and 30 minutes durations, which do not give good fit.

The correlation coefficient (R) and coefficient of determination (R^2) obtained from the fitted IDF Models adopting both Gumbel and Log Pearson Type 111 distributions have perfect value of 1. This shows that both Gumbel and Log Pearson Type 111 methods fit the models well. The values of root mean square errors (RMSE) obtained are lower for 20 minutes to 360 minutes durations, except for 10 minutes, 15 minutes, and 30 minutes durations for both Gumbel and Log Pearson Type 111 distributions.

4. CONCLUSION

This work shows the procedure for the development of rainfall intensity duration frequency models for selected locations in South Eastern Nigeria. The following conclusions were drawn from the study:

i) Annual maximum rainfall amount of shorter durations of 5, 10, 15, 20, 30, 60, 120, 180, 240, 300, and 360 minutes were estimated using the advanced pattern (storm type A) of generalized accumulated rainfall model developed by USDA Soil conservation service for downscaling of daily rainfall data.

ii) Gumbel and Log Pearson Type 111 distributions were used to estimate the frequency precipitation with durations of 5, 10, 15, 20, 30, 60, 120, 180, 240, 300, and 360 minutes for 2, 5 10, 25, 50 and 100 years return periods for each of the studied locations. Corresponding observed rainfall intensities were computed.

iii) Gumbel and Log Pearson Type 111 IDF models for each studied region were developed by subjecting the observed rainfall intensities to frequency analysis using the Microsoft excel optimization technique solver wizard to generate the regional parameters of each model.

iv) The coefficient of determination values, R^2 obtained from the fitted IDF Models adopting Log Pearson Type 111 and Gumbel distributions gave perfect value of 1

v) The Log Pearson Type 111 distribution, RMSE values ranged from 1.57-15.33 and 0.46 – 11.69 for Umuahia and Owerri regions respectively. Gumbel distribution and the RMSE values ranged from 0.05 – 14.47 and 0.21 – 11.08 for Umuahia and Owerri regions. This shows that the derived formulae can be used to estimate any frequency rainfall data for south-eastern region. Models have been developed for Gumbel and Log Pearson Type-3 distributions. These models are in agreement with PDF theory which shows higher intensity occurring at shorter duration and lower intensity at longer duration. The prediction of rainfall intensity with the Probability Distribution Functions showed a good match with observed intensity values. To achieve adequate climate forecasting capacity, the study, therefore, recommends that qualitative climatic data should be made available and accessible for easy analysis. The IDF Models are recommended for the prediction of rainfall intensities for the studied locations in South Eastern Nigeria to aid in designing of drainage systems and planning for water resources development, hence it can be adopted by any country with such terrain.

Declaration of Competing Interest

All authors declare that there is no conflict of interest related to this article.

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