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Developing Rainfall Intensity–Duration–Frequency Models for Calabar City, South-South, Nigeria.

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Abstract: - Rainfall Intensity – Duration – Frequency (IDF) models for Calabar city are presented based on 10 years (2000 - 2009) rainfall data. The statistical method of least squares was used and the models developed are categorized into two sets. The first set of models represents an inverse relationship between rainfall intensities and duration for specified frequencies which are called "INTENSITY – DURATION MODELS" and frequencies of 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2.2, 2.8, 3.7, 5.5, and 11 years are used; and very high and positive regression coefficient ranging from 0.9372 to 0.9930 and goodness of fit 0.8788 to 0.9851 were recorded. The second set of models represents rainfall intensities and frequencies for specified duration which are called "INTENSITY – FREQUENCY MODELS", and durations of 15, 30, 45, 60, 90, 120, 180, 300 and 420 minutes were used, and very high and positive regression coefficients ranging from 0.7908 to 0.9890 and goodness of fit 0.6263 to 0.9863 were obtained. The range of frequencies and durations used are based on assessment of the data obtained, which included all critical rainfalls of high intensities. A total of 20 models were developed; this includes 11 Intensity – Duration models and 9 Intensity – Frequency models. Their coefficient of correlation is estimated to show the degree of correctness. The two sets of models obtained from this research, will serve as an important tool for the prediction of the occurrence of any given rainfall amount in Calabar city as well as for use in the design of structures that control storm runoff and flooding in Calabar and cities of similar rainfall characteristics.

Keywords:- Correlation Coefficient, Least Squares, Rainfall Intensity, Intensity- Duration Model, Intensity-Frequency Model

I. INTRODUCTION

Models can be expressed mathematically to represent a system or sets of data; Models are also seen as mathematical representations of sets of relationships between variables or parameters (Nwaogazie, 2006; Nwadike, 2008). In this study, we shall be looking at Mathematical models as representing a set of variables which establishes relationships between these variables.

A major challenge any hydrologist or engineer will encounter in the planning and design of water resources structure is that of unavailability or limited required long-term rainfall data. The development of rainfall models requires long-term rainfall records with durations. Only a few meteorological stations in a developing country like Nigeria can boast of consistent 30 years rainfall data; some of these stations are in Lagos, Calabar, Benin, Port Harcourt, Kano, Owerri and Onitsha, with missing data in-between and some without the duration of the rainfall events. The remaining stations nation-wide have very short records of rainfall data (Nwaogazie and Duru, 2002).

Every design of a water resources structure needs an engineer to carry out a careful analysis on the existing rainfall data. In the analysis involving such rainfall event, randomness is present. Design of water resources structures become difficult to handle when the problem of inconsistency and unavailability of required long-term rainfall data exist. The engineer has to then adopt frequency analysis through which future probabilities are determined from the past rainfall events.

The design of hydraulic structures such as drainage structures is a problem when there are no measured values of rainfall history of such an environment. The quantity of water the drains should collect is assumed rather than calculated. Sometimes this assumption of rainfall quantity can cause temporary floods in such areas.

Hence, the need for the development of rainfall models for Calabar city, a major town and capital of Cross River State, Nigeria.

II. METHODOLOGY

2.1 Study Area and Data Collection

Calabar City lies within the South-South region of Nigeria. It is located at $4^0 57' 0''$ North and $8^0 19' 0''$ East of Nigeria. Calabar city falls under the mangrove region where rainfall is very high .The available rainfall data obtained from the region covered the period between the year 2000 and 2009 which includes the amounts and duration of rainfalls.

2.2 Model Development

The analysis of the Calabar ten (10) years rainfall involved sorting of the rainfall amounts against durations of 15, 30, 45, 60, 90, 120, 180, 300 and 420 minutes and converting the rainfall amounts to intensity value in millimeter per hour (mm/hr). The resulting rainfall intensity was assigned the rank of 1.The probabilities of the rainfall events were obtained using the Weibull's formula shown in equation (1) indicating a return period of one year longer than the period of record for the largest value (Chow, 1952). Tables 1 and 2 showed the rankings of the various rainfall durations and their calculated intensities.

$$P(X_m) = \frac{m}{n+1} \qquad (1)$$

Where,

$P(X_m)$ = Probability of exceedence of variate X_m
m = Rank of descending values, with largest equal to 1,
n = Number of years of record

Return periods (frequencies) of the rainfall events were calculated as the reciprocals of their corresponding probabilities as also shown in Table 1 and 2.

Table 1: Rainfall ranking and probability of event

S/NO.	15MINS INTENSITY (mm/hr)	30MINS INTENSITY (mm/hr)	45MINS INTENSITY (mm/hr)	60MINS INTENSITY (mm/hr)	90MINS INTENSITY (mm/hr)	RANKING	FREQUENCY
1	147	75.42857143	118.8	62.06896552	57.22105263	1	11
2	124.6153846	61.93548387	85.06666667	58.78125	39.68571429	2	5.5
3	107.4	60.54545455	51.84	52.24615385	39.53333333	3	3.7
4	100.8	53.4	38.26666667	46.8	34.75862069	4	2.8
5	99.81818182	43.09090909	33.75	35.79661017	33.38823529	5	2.2
6	91.2	40.32	32.26666667	35.54716981	33.20454545	6	1.8
7	78.5	36.24	31.59183673	28.125	32.21917808	7	1.6
8	74.76923077	33.6	30.57142857	24.70588235	29.92307692	8	1.4
9	49.89473684	33.08571429	27.06666667	22.4	26.85714286	9	1.2
10	48.6	31.15384615	25.22727273	22.19047619	25.44303797	10	1.1
11	46	30.18181818	22.95	20.94545455	21.97894737	11	1.0

Table 2: Rainfall ranking and probability of event in Calabar City

S/NO.	120MINS INTENSITY (mm/hr)	180MINS INTENSITY (mm/hr)	300MINS INTENSITY (mm/hr)	420 INTENSITY (mm/hr)	RANKING	FREQUENCY
1	112.324493	38.06896552	20.32807571	19.71818182	1	11
2	44.41935484	28.6	20.32807571	14.26666667	2	5.5
3	40.89473684	25.77777778	19.66956522	14.18734177	3	3.7
4	26.953125	24.32727273	19.66	13.91646192	4	2.8
5	26.03478261	24	19.464	11.6	5	2.2
6	24.04918033	23.78313253	19.10460251	10.77889447	6	1.8
7	23.73214286	20.78350515	18.775	10.4	7	1.6
8	21.73109244	20.0106383	17.57777778	9.383886256	8	1.4
9	21.19672131	19.60869565	16.53488372	8.8	9	1.2
10	20.86725664	19.05	14.67391304	8.313253012	10	1.1
11	20	18.29268293	14.55652174	8.171428571	11	1.0

The mathematical equation employed in developing a relationship between rainfall intensity and duration for a given recurrence period is given as equation (2)

$$i = \frac{A}{t+B} \qquad (2)$$

Where,

i = rainfall intensity in mm/hr

t = duration in minutes

A and B= regional constants

Equation (2) can be represented in a linear form as:

$$y = a_1 x + a_0 \qquad (3)$$

Where

$y = \frac{1}{i}$, $a_1 = \frac{1}{A}$ and $a_0 = \frac{B}{A}$.

The solution of Equation (3) was achieved with the aid of a computer program.

Table 3 showed all the intensity duration models developed, for frequencies of 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2.2, 2.8, 3.7, 5.5, 11 years. The rainfall intensity duration curves are linear in nature as shown in Figure 1

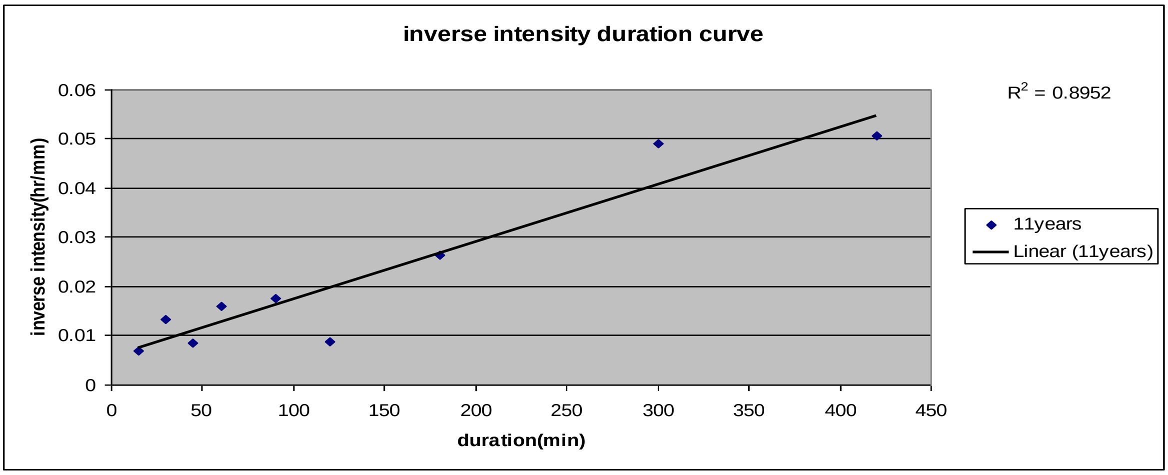

Figure 1: Rainfall intensity duration curve for 11 years frequency

Table 3:Summary of all intensity duration models developed

s/no	Frequency	Intensity duration model $i = \frac{A}{t+B}$	Checks
1.	11	$i = \frac{8576.33}{t+47.8216}$	CC = 0.9489 GF = 0.8952
2.	5.5	$i = \frac{6915.6293}{t+55.8645}$	CC = 0.9907 GF = 0.9851
3.	3.7	$i = \frac{7110.3527}{t+76.7918}$	CC = 0.9930 GF = 0.9815
4.	2.8	$i = \frac{7494.0048}{t+114.6583}$	CC = 0.9751 GF = 0.9505
5.	2.2	$i = \frac{6620.7627}{t+108.9115}$	CC = 0.9601 GF = 0.9218
6.	1.8	$i = \frac{6620.7627}{t+108.9115}$	CC = 0.9520 GF = 0.9061
7.	1.6	$i = \frac{6189.2678}{t+120.0718}$	CC = 0.9454 GF = 0.8933
8.	1.4	$i = \frac{5605.0670}{t+114.8478}$	CC = 0.9372 GF = 0.8788
9.	1.2	$i = \frac{5451.9682}{t+127.5761}$	CC = 0.9361 GF = 0.8782
10.	1.1	$i = \frac{5006.2578}{t+118.9487}$	CC = 0.9508 GF = 0.9041
11.	1.0	$i = \frac{5080.0101}{t+135.1283}$	CC = 0.9433 GF = 0.8896

± Rainfall intensity is given in mm/hr

- Regression parameter: GF = Goodness of fit and
  CC = Coefficient of Correlation

Another model employed to fit rainfall intensity values is the Power model. Its form is presented as equation (4)

$$í = aR^b \quad (4)$$

Where
i = Rainfall intensity (mm/hr)
R = Return period or frequency (yrs)
a and b are regional constants

Equation 4 can be represented by

$$y = a_1 x + a_0 \quad (5)$$

Where,

$$y = \log i$$

a_1 = b and $a_0 = \log a$

Equations can be used to fit rainfall data. Using the statistical method of least squares in regression, the constants *a* and *b* can be evaluated.
The solution of Equation (5) was also achieved with the aid of a computer program.

Table 4 shows all the intensity return period models developed, for durations of 15, 30, 45, 60, 90, 120, 180, 300, 420 minutes. The rainfall intensity return period curves are linear in nature as shown in Figure 2.

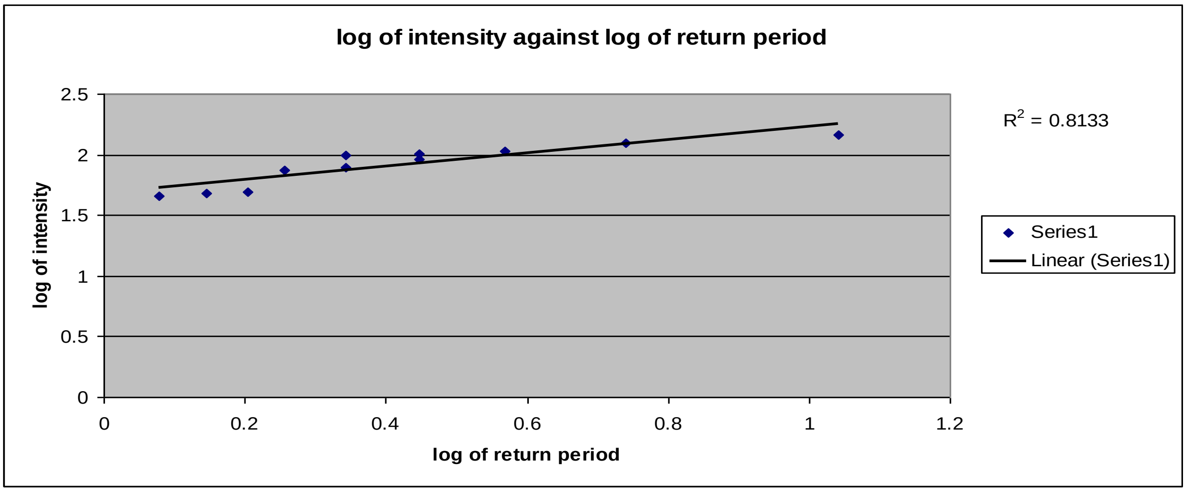

Figure 2: Rainfall intensity return period curve for 15 min duration

Table 4: Summary of all intensity return period models developed

s/no	Durations	Intensity return period models ($i = aR^b$)	Checks
1.	15	$i = 48.5176R^{0.5476}$	CC = 0.9890 GF = 0.8133
2.	30	$i = 27.68R^{0.4624}$	CC = 0.9435 GF = 0.9863
3.	45	$i = 18.3527R^{0.7844}$	CC = 0.9772 GF = 0.9549
4.	60	$i = 19.61R^{0.5845}$	CC = 0.9202 GF = 0.845
5.	90	$i = 22.7196R^{0.3857}$	CC = 0.9732 GF = 0.9459
6.	120	$i = 14.2659R^{0.7583}$	CC = 0.9567 GF = 0.9087
7.	180	$i = 17.005R^{0.3269}$	CC = 0.9851 GF = 0.9687
8.	300	$i = 15.6747R^{0.1503}$	CC = 0.7908 GF = 0.6263
9.	420	$i = 7.6542R^{0.4086}$	CC = 0.9555 GF = 0.9123

± Rainfall intensity is given in mm/hr

- Regression parameter: GF = Goodness of fit and
  CC = Coefficient of Correlation

III. DISCUSSION OF RESULTS

The first set of the models involved finding solution to Equation (3) using available rainfall intensity-duration data for specified frequencies of 1, 1.1, 1,2, 1.4, 1.6, 1.8, 2.2, 2.8, 3.7, 5.5 and 11 years. A total of eleven (11) rainfall models were developed with very high and positive values of goodness of fit, ranging from 0.8788 to 0.9851 and coefficients of correlation of 0.9372 to 0.9930. The plots of intensities against duration for the eleven (11) models provided a good basis for the predicted results.

The second set of the rainfall calibration involved solving Equation (5) using as input data, rainfall intensities and frequencies for specified durations of 15, 30, 45, 60, 90, 120, 180, 300, and 420 minutes. A total of nine (9) rainfall models were developed with positive values of goodness of fit of 0.6263 to 0.9863, and coefficient of correlation of 0.7908 to 0.9890, indicating a good correlation. Also the plots of the models provided a good basis for the predicted results. The following observations are characteristic of Calabar city rainfall pattern:

- The high intensity storms correspond to short durations, a common feature of tropical thunderstorms.
- The curves are linear in nature (see Figures 1 and 2)

These observations are in agreement with other literatures (Thunderstorm Rainfall, 1947; World Meteorological Organization, 1969, Viesma et al., 1977; Nwaogazie and Duru, 2002; Linsley and Franzini, 1979). In drainage design and construction, it is a common knowledge that the cost of drainage increases as the size of the gutter design capacity is increased. On account of the above, urban drainage design calculations as adopted in this research work were based on average rainfall intensity that has a return period of 10years. This is in keeping with the recommendations made in the Highway design manual, Part – 1 (FMW&H, 2006). This work has succeeded in presenting Calabar City as well as towns with similar climatic conditions in South-South region of Nigeria with set of well defined models that can serve very well in water works and hydraulic structures design.

IV. CONCLUSION

The rainfall intensity-frequency relationship is one of the most commonly used tools in Water Resources Engineering, either for planning, designing and operation of water resources projects, or for various engineering projects against floods. It is therefore, important in the determination of rainfall intensity for any desired period as a guide in the design of water related structures. The availability of Rainfall Intensity-Frequency Regimes will really make the design of some hydraulic structures easy for civil and water resources engineers, as well as other environmentalists carrying out works relating to rainfall around the study area.

For calabar city, the study simply developed models from past available records of rainfall events which gave high and positive coefficients of correlation using the regression data fitting approach. It provided the desired basic rainfall information required for the design of drains for Calabar city.

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