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Development of Intensity Duration Frequency Curves for Calabar Metropolis, South- South, 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. The IDF relationship is a mathematical relationship between the rainfall intensity, the duration and the return period.Rainfall data collected from the Nigerian Meteological Agency (NIMET) at the Margaret Ekpo International Airport, Calabar, Cross River State, Nigeria, were used to developed rainfall models for the Calabar catchment area. The afore-mentioned data were obtained on the basis of daily recordings. Twenty three years peak rainstorm intensity values with their corresponding durations were extracted and analysed using statistical methods of least square using Microsoft Excel software. The IDF curves were developed for return periods between 2 years and 100 years using the Extreme Value Type 1 (Gumbel) distribution for rainfall intensity values for durations of 2, 5, 10, 15, 30, 60, 120, 240 and 320 minutes. The IDF curves are recommended for the prediction of rainfall intensities for Calabar.

Keywords: Rainfall intensity, rainfall duration, intensity-duration-frequency curves, IDF

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I. Introduction

The Intensity Duration Frequency (IDF) relationship is a mathematical relationship between the rainfall intensity, the duration and the return period. The rainfall Intensity Duration Frequency (IDF) relationship is one of the most commonly used tools for the design of hydraulic and water resources engineering control structures. The establishment of such relationship was done as early as 1932 (Bernard, 1932). The rainfall intensity-duration-frequency (IDF) relationship is commonly required for planning and designing of various water resource projects (El-sayed, 2011). This relationship is determined through statistical analysis of data of meteorological stations. Quantification of rainfall is generally done using isopluvial maps and intensity-duration-frequency (IDF) curves (Chow et al., 1988). The IDF formulae are the empirical equations representing a relationship among maximum rainfall intensity (as dependant variable) and other parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used functions found in the literature of hydrology applications (Chow *et al.*, 1988).All functions have been widely applied in hydrology. The IDF relation is mathematically as follows:

$$i = f(T, d) \quad \text{.......(1)}$$

Where T is the return period (years) and d duration(minutes)
The typical generalized IDF relationship for a specific return period is as given in equation (2)

$$i = \frac{a}{(d^v + b)^e} \quad \text{.......(2)}$$

where *a*, *b*, *e* and v are non-negative coefficients. Thus, the equation that is more general: with v=1 and *e*=1 it will be Talbot equation; v=1 and *b*=0 is Sherman; *e*=1 is Kimijima equation and v=1 is Sherman. This expression is an empirical formula that summarizes the experience from several studies. There has been considerable attention and research on the IDF relationship: Hershfield (1961) developed various rainfall contour maps to provide the design rain depths for various return periods and durations. Bell (1969) proposed a generalized IDF formula using the one hour, 10 years rainfall depths; P_1^{10}, as an index. Chen (1983) further developed a generalized IDF formula for any location in the United States using three base rainfall depths: P_1^{10}, P_{24}^{10}, P_1^{100}, which describe the geographical variation of rainfall. Kothyari and Garde (1992) presented a relationship between rainfall intensity and P_{24}^{2} for India. The engineering application of rainfall intensity is mainly in the estimation of design discharge for flood control structures. This has become imperative with the recent devastations caused by flood in various regions of Nigeria; perhaps being due to the lack of rainfall data and the subsequent design of most drainage structures without appropriate rainfall intensity values.

This paper proposes the approach to the formulation and construction of IDF curves using data from recording station by using empirical equations.

To this end the specific objective is:

a. Develop IDF curves for the estimation of the maximum intensity of 320 minutes rainfall for different return periods for Calabar.

II. Materials And Methods

Description of Area of Study

Calabar Metropolis lies between latitudes 04° 45' 30" North and 05° 08'30" North of the Equator and longitudes 8° 11' 21" and 8°30'00" East of the Meridian. The town is flanked on its eastern and western borders by two large perennial streams viz: the Great Kwa River and the Calabar River respectively. The Calabar River is about 7.58 metres deep at its two major bands (Tesko-Kotz, 1983). The city lies in a peninsular between the two rivers, 56km up the Calabar River away from the sea. Calabar has been described as an inter-fluvial settlement (Ugbong, 1998).

The area is drained by the two main perennial channels, the Calabar and the Great Kwa Rivers. The rivers are fed by the numerous ephemeral and intermittent channels, gullies and rills which are inundated during the slightest storm events. Surface water is also carried by the sloping terrain, the roadside ditches and sandy soils which are pervious to water. The major ephemeral channel is the one truncating the city from the MCC/WAPI junction axis down to the Cross River University of Technology staff quarters on the south, and empting roughly and abruptly into the Great Kwa River. This ephemeral channel is also called channel 1 in the metropolis (Ekeng, 1998). Precipitation is characterized by a double maxima rainfall which starts from April and ends in October, reaching its peak in June and September. The average annual rainfall is about 1830mm with some variations within the metropolis (NAA Weather Report, 1995). In some wet years (1976, 1978, 19 80, 19 95, 1996, 1997, 1999, 2001, 2005, 2007 and 2008), rainfall reading have been observed to go up to over 3000mm (NIMET, 2010; Antigha, 2012). On the average over 80% of the total annual rainfall falls over a period of seven months (from April to October). June has an average rainfall of 530mm (Antigha, 2012).

2.1 Data Collection

The major material used for this work is rainfall data comprising of rainfall durations and intensities in Calabar. The Twenty three (23) years rainfall data included data ranging from 1983 to 2010. The data were obtained from Nigeria Meteorological Centre (NIMET) office of the Margaret Ekpo International Airport in Calabar, Cross River State, Nigeria. This office is undoubtedly the data base for most climatic parameters in Calabar and its environ. The data arrangement involved sorting the data according to years, rainfall intensities and durations. The rainfall intensities selected are the maximum values for each month for all the years analysed.

2.2 Data Analysis

Various approaches can be used for the analysis of data to be employed in IDF plots. For this study, the graphical method basically was employed. Rainfall durations were abstracted from the rainfall event data obtained from the data source. The intensity was obtained by dividing the depth (amount) of rain by the duration as given by the expression;

$$I=\frac{R}{t} \quad \text{...}(3)$$

Where I, is the rainfall intensity in mm/hr, R, is the amount of rainfall in mm, and t is the duration of the rainfall in hours. The monthly maximum intensities from data were collated and arranged in descending order of magnitude (Kruskal Wallis approach). This maximum rainfall intensity values for Calabar for the period analysed are as shown in Table 1.

Table 1: Annual Maximum Rainfall Intensity (mm/hr) at Calabar

YEAR	DEPTH (mm)	DURATION (hr)	INTENSITY (mm/hr)	DURATION (minutes)	RANK	RETURN PERIOD (T)(yr)	PROBABILITY(1/T)
2009	9.33	0.03	311	1.8	1	24.00	0.04
2001	5.04	0.02	252	1.2	2	12.50	0.08
1986	16.92	0.09	188	5.4	3	8.67	0.12
1985	10.92	0.06	182	3.6	4	6.75	0.15
2002	39.96	0.27	148	16.2	5	5.60	0.18
2006	10.29	0.07	147	4.2	6	4.83	0.21
1989	18.08	0.16	113	9.6	7	4.29	0.23
1990	11.22	0.11	102	6.6	8	3.88	0.26
1994	14.76	0.15	98.4	9	9	3.56	0.28
1996	54.38	0.57	95.4	34.2	10	3.30	0.30
1983	11.28	0.14	80.6	8.2	11	3.09	0.32
1988	45.06	0.59	76.8	35.2	12	2.92	0.34
2005	68.71	0.91	75.5	54.6	13	2.77	0.36
2003	13.25	0.18	73.6	10.8	14	2.64	0.38
1995	94.80	1.37	69.2	82.2	15	2.53	0.39
1992	75.68	1.1	68.8	66	16	2.44	0.41
1997	106.83	1.76	60.7	105.6	17	2.35	0.43
2004	19.79	0.34	58.2	20.4	18	2.28	0.44
2000	64.98	1.24	52.4	74.4	19	2.21	0.45
2010	19.72	0.4	49.3	2.4	20	2.15	0.47
2007	15.91	0.36	44.2	21.6	21	2.10	0.48
1991	100.10	2.56	39.1	153.6	22	2.05	0.49
2008	64.96	1.77	36.7	106.7	23	2.00	0.50

Intensity Duration Frequency Curves Development

Steps used in developing the IDF curves are as follows:

- The values are ranked in decreasing order with the highest intensity taking the value of 1 in the rank. The return periods or recurrence intervals are calculated by the Weibull's formula stated below:

$$T = \frac{n+1}{m} \quad \text{.....(4)}$$

Where, T is the recurrence interval in years;
n is the highest rank; and
m is the rank value of each rainfall intensity.
The probability was obtained using the following relationship:

$$P = \frac{1}{T} \quad \text{.....(5)}$$

Where P is the probability and T is the return period (recurrence interval)

- Rainfall data intensity was regressed against duration for each year
- After fitting the regression, rainfall intensities for 2minutes, 5 minutes, 10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes, 240 minute and 320 minutes were estimated. Hence, means and standard deviations of the data for different durations were calculated.
- Then, K_T which is the frequency factor for return period, was computed for corresponding return periods using Gumbel's distribution as given by the expression;

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

Where T is the return period

- Chow (1951) has shown that most frequency functions can be generalized to eq. (7). Rainfall intensities were calculated for corresponding return period

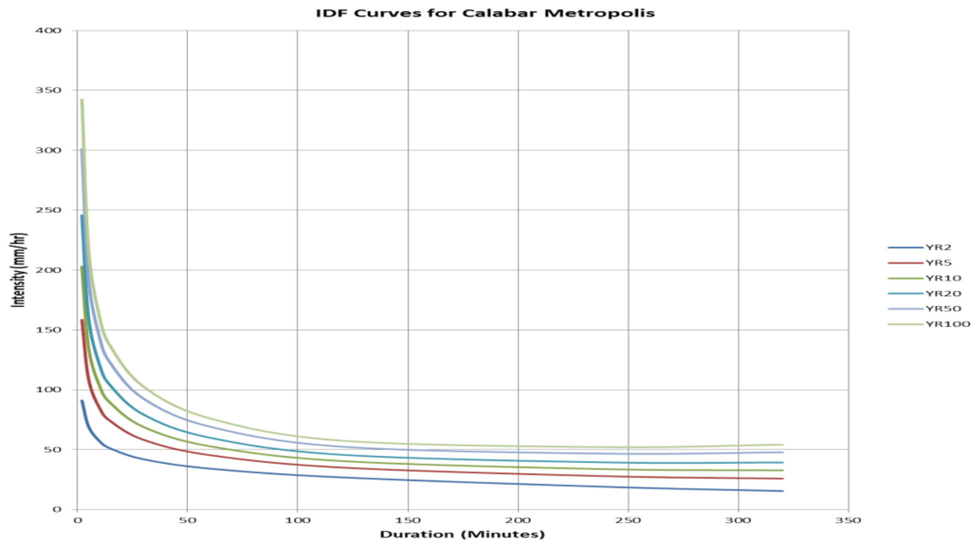
$$X_T = \overline{X} + K_T s \quad \text{.....(7)}$$

Where k_T is the rainfall intensities for each return period,
s is the standard deviation of rainfall intensities and
$\overline{X}$ is the mean rainfall intensities
X_T is the rainfall intensity for a given return period

Hence, the plot of rainfall intensities against duration was obtained for corresponding return period.

III. Results

The intensity duration frequency curves are obtained by plotting the rainfall intensity values against corresponding durations for different return periods. The IDF curve for Calabar is shown in Figure 2.



IV. Conclusion

Intensity-duration-frequency data are needed by hydrologists and engineers involved in planning and design of water resources projects. Historical rainfall records obtained from the Nigerian Metrological Agency were used to generate the IDF curves for Calabar. The maximum intensity of any rainstorm over any return period in Calabar can be obtained from the aforementioned IDF curve. The estimated rainstorm intensity can be used to evaluate the quantity of discharge hence, the design of hydraulic structures.

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