ESTABLISHMENT OF AN EMPIRICAL MODEL THAT CORRELATES RAINFALL- INTENSITY- DURATION-FREQUENCY FOR MAKURDI AREA, NIGERIA

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ABSTRACT

Rainfall records for 30 years (1979-2009) were used to establish an emperical model that correlates rainfall-intensity-duration-frequency for Makurdi area. They were analyzed by sorting out the maximum monthly rainfall depths with their corresponding durations and ranked in descending order of magnitude and their return periods were computed. All ranked rainfall depths for each return period were converted to rainfall intensities. The Sherman's mathematical method was first employed to develop station constants and IDF curves for Makurdi. The station constants for Makurdi area were found to be c = 21.429, m = 0.6905, b = 0.2129. Values of durations of rainfall were substituted in each regression equation to compute corresponding rainfall intensity for each return period. Graphs of rainfall intensities and corresponding durations for each return period were plotted with the subsequent derivation of IDF empirical equations for Makurdi. They were used to develop the IDF curves for 2yrs, 5yrs, 10yrs, 25yrs, 50yrs and 100yrs return periods. It was observed that for a given return period, the IDF curves decreased with increasing time interval. Rainfall Intensity -Durations -Frequency (IDF) data was produced and a model expressing the relationship between the rainfall intensity, the duration and frequency was developed for Makurdi area.These will be useful for construction of hydrologic structures such as dams and other drainage systems in Makurdi metropolis.

KEYWORDS: (IDF) formula, Station constants, Makurdi, Nigeria.

I. INTRODUCTION

Rainfall Intensity-Duration-Frequency Curves (IDF Curves) are graphical representations of the amount of rain that falls within a given period of time. These curves are used to help predict when an area will be flooded, or to pinpoint when a certain rainfall rate or a specific volume of flow of runoff will reoccur in the future [1].

The first step in designing a flood control structure is to determine the probable recurrence of storms of different intensities and durations so that an economic size of a structure can be provided. For most purposes it is not feasible to provide a structure that will withstand the greatest rainfall that has ever occurred. It is more economical to have a periodic failure than to design for a very intense storm. But where human life is endangered, however, the design should handle runoff from storms even greater than have been recorded. For these purposes, data providing return periods of storms of various intensities and durations are essential [2]. Precipitation in the form of rainfall, though useful to life (i.e life supporting), is not without problems. Too little of it causes drought and desertification in an environment and too much of it causes flood disaster with devastating consequences that might lead to loss of lives and properties. Efforts are continually being made by scientists and engineers using different irrigation and flood mitigation techniques towards ameliorating such problems. Rainfall intensity-duration-frequency (IDF) curves are used for the estimation of peak discharge of runoff in a catchment area, by the rational method, for subsequent sizing of hydraulic channels and other water ways. For selected storm duration and frequency, the design rainfall intensity is normally estimated from a set of statistically derived rainfall intensity –duration frequency or IDF curves appropriate to that region [3]. The extreme value type1 (Gumbel) method was applied by [4] to the annual extreme rainfall data sets generated by eleven rainfall zones to estimate the parameters and hence the intensity-duration-frequency (IDF) curves for Nigeria.

In an effort to develop IDF curves for some parts of Nigeria and the country as a whole, [4] divided the country into ten principal rainfall zones. He applied the extreme value type1 (Gumbel) method to develop the intensity-duration-frequency (IDF) curves from the historic rainfall records of 1951 to 1978 for Nigeria. Using the same rainfall records, [5] carried out the first comprehensive non-empirical IDF studies for Nigeria with a return period of 50 or more years. [6]developed a new technique for the analysis of extreme rainfall applicable to Lagos metropolis. The new technique developed by [6] was applied by [7] for the analysis of extreme rainfall for Nigeria. [8] presented IDF curves for Kano and Oshogbo for rainfall records of the periods 1951-1954 and 1956-1964 respectively.

The lapses observed with the works carried out by [4,5,6,7] were in their use of the same rainfall data for the period 1951-1978. Data used were very old compared to the current global climatic and environmental changes that are adversely affected by global warming and man’s activities. Any attempt to use such IDF curves produced to design any hydrological structure for current use may lead to inappropriate design which can cause failure of the structure. An empirical equation for the IDF curves of Imo River Basin and environ in Imo State of Nigeria was developed by [9].

The daily rainfall data used in the study were collected from the Nigerian Meteorological Department at Oshodi for the following stations: Enugu (1916-1965), Onitsha (1906-1966), Awka (1942-1965) and Adani (1948-1965). These rainfall records also look very old and using the developed empirical equation to design hydrological structures may lead to failures.

The IDF relationships can be used in conjunction with the rational method to determine peak discharge from a catchment area for design of hydrological structures. The quantity of storm runoff or discharge may be computed based on the correlation between rainfall intensity and surface flow using the expression in equation 1 equation below.

$$q = CiA \tag{1}$$

Where q = the design peak runoff rate in m^3/s,

C = the runoff coefficient,

i = rainfall intensity in mm/hr for the design return period and for a duration equal to the “time of concentration” of the water shed,

A = the watershed area m^2.

Previous IDF curves were developed based on past rainfall data up to 1978. Some researchers or designers of hydraulic structures might have used such curves to design culverts and other channels to contain runoff with a return period of 30 years or less. Certainly new IDF curves from most recent rainfall data are needed for use in designing current hydraulic structures that are expected to have higher capacity than those designed using the the very old data based IDF curves.

Experiences have shown that some hydraulic structures like open channels, culverts and small dams that were constructed some 20-30 years back now have far less capacity due to siltation and increased in runoff to contain much more runoff produced in the watershed. The excessive runoff tends to over-run the banks with the subsequent collapse of such structures. Also some areas might have been affected by erosion menace that would require new set of hydraulic structures to control such erosion. That calls for the use of the most current and improved IDF curves.

With the observed lapses, an up to date daily rainfall records for the period of 30 years (1979-2009) were used to develop IDF curves and empirical formulae for use in designing hydraulic modern structures such as channels, culverts dams and bridges and the control of soil erosion by water in Makurdi area. The objectives of this study are; To develop empirical equations, station constants and IDF curves for Makurdi area.

II. MATERIALS AND METHOD

2.1 Study Area

Markurdi is characterized by undulating rolling plain with irregular river valleys and ridges with steep slopes. It lies within the humid zone with little seasonal temperature variation throughout the year. There are two main seasons, the rainy season (April-October), and the dry season (November-March). The average annual temperature is 31.5^{o}C, and the relative humidity ranges between 65-69%. The rainfall varies between 1000mm to 2500mm [10]. Makurdi is located in the North-Central zone of Nigeria between latitude 7^0 45' - 7^0 52' N and longitude 8^0 35' – $8^0$41' E

2.2 Data Acquisition

Maximum weekly rainfall records with their corresponding durations and for a period of 30 years (1979-2009) were collected from Makurdi metrological station (Airforce Base) for statistical analysis. The essence of collecting 30 years or more of rainfall records was to be able to get as much as possible the most severe or extreme rainfall events that could be handled by hydraulic structures for a certain design period of time (Return period).

The maximum rainfall depth for each month and year corresponding to specified durations were sorted out. All rainfall depths that fell under each of the stated durations were ranked in descending order of magnitude to determine the return period for each duration. The return periods (recurrence intervals) of the ranked rainfall depths were computed using Weibull's equation method as shown in equation 2.

$$T = \frac{n+1}{m} \tag{2}$$

Setting rainfall intensity (*i*) as dependent variable (y) and duration (t) as independent variable (x), the rainfall intensities (i) with their corresponding durations (t) for each return period was subjected to regression analysis. The regression method correlates means of two variables y (dependent) and x (independent) variables by plotting them on x and y axes. The regression line equation (3) is given by [11] as:

$$\bar{y} = a + b\bar{x} \tag{3}$$

Where $\bar{y} = \frac{\sum y}{n}$ and $\bar{x} = \frac{\sum x}{n}$

$$a = \bar{y} - b\bar{x}$$

$$b = \frac{\sum xy - \left(\sum x\right)\left(\sum y\right)/n}{\sum x^2 - \left(\sum x\right)^2/n} = \frac{S_{xy}}{S_{xx}}$$

The IDF data was generated by substituting values of rainfall durations of 5 – 1440 (24hrs) and return periods of 2, 5, 10, 25, 50 and 100yrs into the developed empirical equation to obtain their corresponding rainfall intensities (mm/hr).

III. RESULTS

The empirical equation for the development of IDF curves for Makurdi area was found to be (equation 4):

$$i = \frac{21.429T^{0.6905}}{t^{0.2129}} \tag{4}$$

The station constants were found to be; c = 21.429, m = 0.6905 and b = 0.2129. This shows that rainfall intensity (i) is directly proportional to return period (T) and inversely proportional to the duration of rainfall (t). Table 1 shows the IDF data while fig 1 shows the IDF curve for Makurdi area.

Table 1. Results of Generated Final IDF Data

Time(min)	RETURN PERIODS (years) 2	5	10	25	50	100
	Rainfall intensities (mm/hr)					
5	24.55	46.22	74.59	140.43	226.64	365.76
10	21.18	39.88	64.36	121.17	195.54	315.57
15	19.43	36.58	59.04	111.14	179.37	289.48
20	18.28	34.41	55.53	104.54	168.71	272.28
25	17.43	32.81	52.95	99.69	160.89	259.65
30	16.76	31.56	50.94	95.90	154.76	249.76
35	16.22	30.54	49.29	92.80	149.76	241.70
40	15.77	29.69	47.91	90.20	145.57	234.92
45	15.38	28.95	46.72	87.97	141.96	229.10
50	15.04	28.31	45.69	86.01	138.81	224.02
55	14.73	27.74	44.77	84.29	136.02	219.52
60	14.46	27.23	43.95	82.74	133.53	215.49
90	13.27	24.98	40.31	75.90	122.48	197.67
120	12.48	23.50	37.92	71.39	115.21	185.93
150	11.90	22.41	36.16	68.08	109.86	177.30
180	11.45	21.55	34.78	65.48	105.68	170.55
210	11.08	20.86	33.66	63.37	102.27	165.04
240	10.77	20.27	32.72	61.59	99.40	160.42
270	10.50	19.77	31.91	60.07	96.94	156.45
300	10.27	19.33	31.20	58.74	94.79	152.98
330	10.06	18.94	30.57	57.56	92.89	149.90
360	9.88	18.60	30.01	56.50	91.18	147.15
420	9.56	17.99	29.04	54.68	88.24	142.40
780	8.38	15.77	25.46	47.92	77.34	124.82
840	8.25	15.53	25.06	47.17	76.13	122.86
900	8.13	15.30	24.69	46.49	75.02	121.07
960	8.02	15.09	24.35	45.85	74.00	119.42
1020	7.91	14.90	24.04	45.26	73.05	117.89
1080	7.82	14.72	23.75	44.72	72.16	116.46
1140	7.73	14.55	23.48	44.20	71.34	115.13
1200	7.64	14.39	23.22	43.72	70.56	113.88
1260	7.56	14.24	22.98	43.27	69.83	112.70
1320	7.49	14.10	22.76	42.85	69.15	111.59
1380	7.42	13.97	22.54	42.44	68.50	110.54
1440	7.35	13.84	22.34	42.06	67.88	109.54

Source: [12]

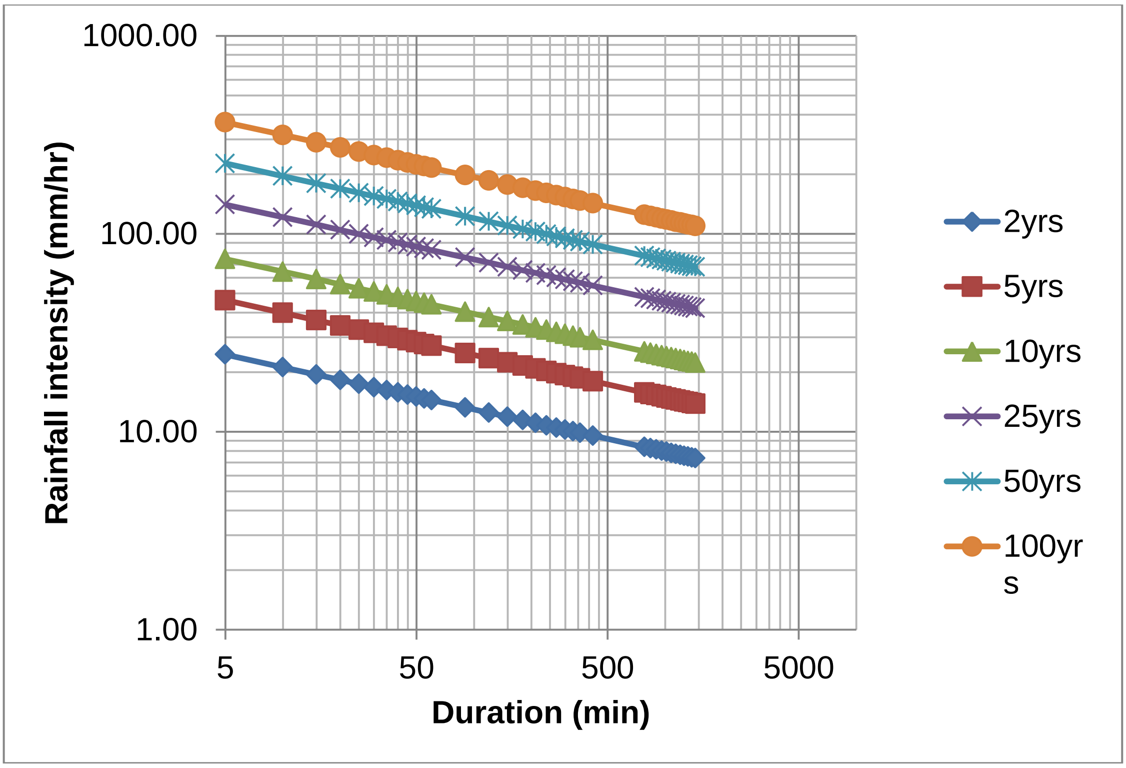

Fig 1. IDF curves for Makurdi area based on 1979 to 2009 rainfall records.

Figure 2 shows a flow chart of steps used to develop the IDF curves for Makurdi area:

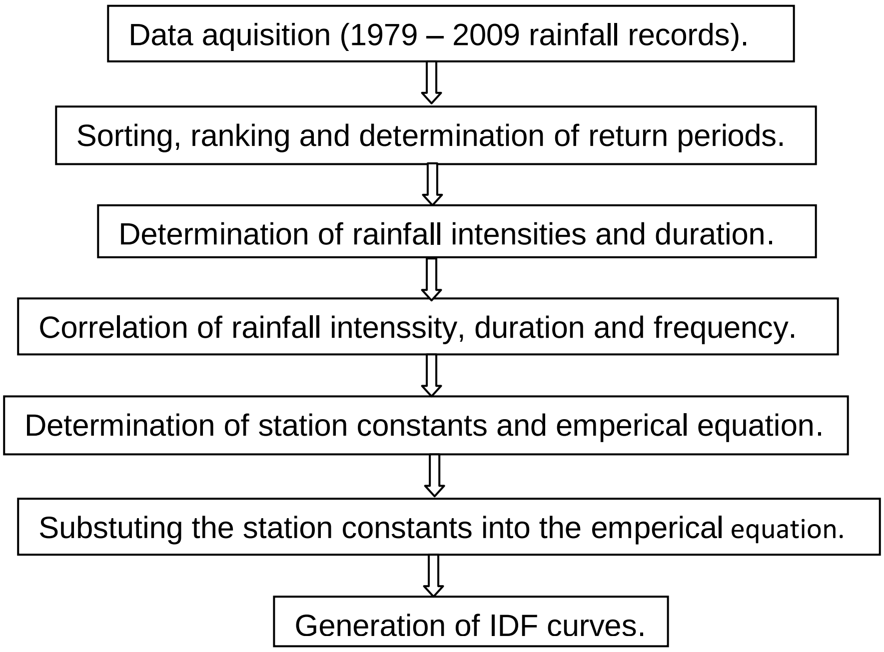

Fig 2: Flow chart of steps used to develop the IDF curves for Makurdi area:

IV. Discussion

The IDF curves produced have non-uniform negative slopes. The trend line regression equations for the various return periods by least square method also have non-uniform negative slopes. This shows that the rainfall intensities generally decrease with increase in duration for a giving return period. The empirical equation for Makurdi area compares favourably with that for Imo River Basin and environs

for Nigeria except for difference in station constants. This implies that station constants vary from one geographical region to the other. The empirical equation is used directly to compute the rainfall intensity (i) which when substituted into the rational method will lead to the computation of peak discharge of storm water for which hydrological structures can be designed for.
It could be deduced from figure 1 that for a given duration, the rainfall intensities increase with increase in return periods. This explains why larger hydrological structures such as dams and bridges are designed for higher return periods while small hydrological structures such as culverts and drainage gutters are designed for low return periods. Also, for a given return period, rainfall intensities decrease with increase in duration. This implies that high intensive rainfall of short durations could have high devastating consequences of runoff to the environment. Figure 3 gives the flow chart of usage of IDF curves in design of hydrological structures.

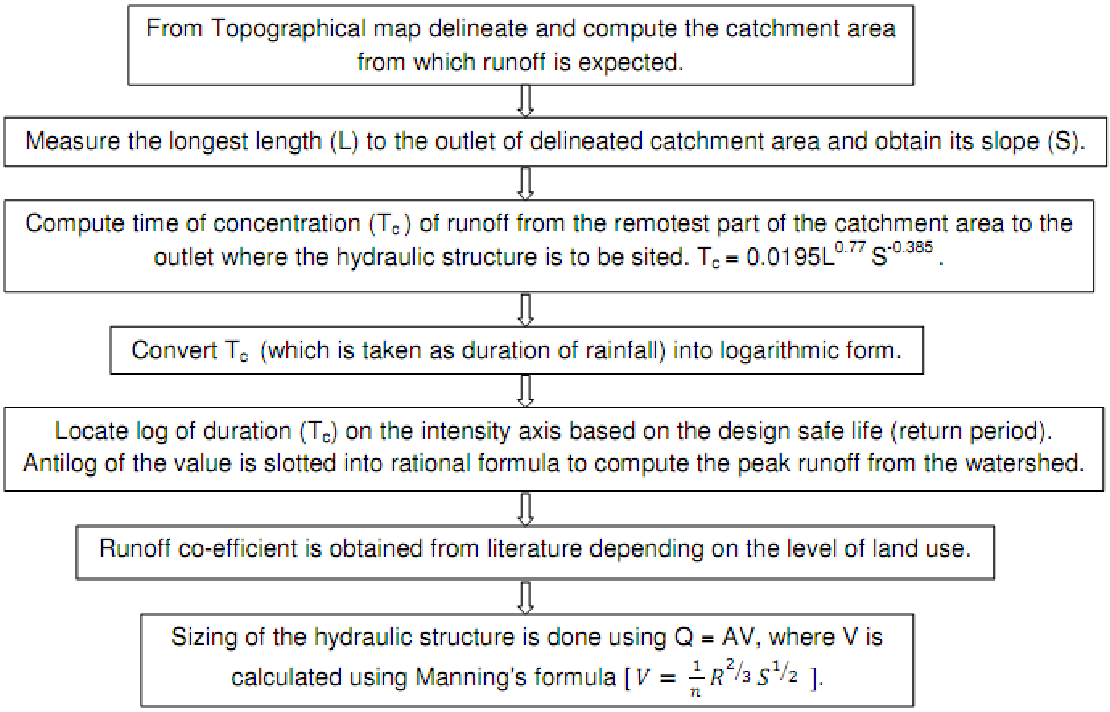

Fig 3: Flow chart to use the IDF curves to design hydrological structures

V. CONCLUSION

The graphical fitting method was first employed in the analysis of rainfall in an attempt to develop IDF curves for Makurdi area. Graphs of logarithms rainfall intensities were plotted against the logarithms of rainfall durations. The least square method was used with a view to bringing the scattered points close to each other. The empirical equations developed by the least square method agreed with earlier researchers empirical equations. The station constants for Makurdi area were found to be; c = 21.429, m = 0.6905 and b = 0.2129. It was concluded there was linear relationship between the rainfall amounts and their corresponding durations. Statistically, there was no significant difference between both rainfall amount and rainfall intensities.

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