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Research Article

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Predictive Rainfall Models for Omoku in Rivers State, Nigeria

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Abstract This research work presents the rainfall intensity duration frequency (IDF) models for considered Omoku City in Ogba/Egbema/Ndoni Local Government of Rivers State in Nigeria which were developed by application of least square statistical technique of analysis. The rainfall information of Federal College of Education (Technical) metrological station Omoku was used in developing the models. It was sourced from the Port Harcourt office of Niger Delta Basin Development Authority. Seven rainfall (IDF) models were generated, seven models were generated using the Chow's type equation of power model for a durations of 10, 20, 30, 45, 60, 90, 120, 240, 300, 360 minutes and a frequency of 1.3, 1.5, 2.5, 3, 5, 7.5, 15 years were evaluated using Weilbull ranking method. The first seven models relates the rainfall intensities and durations for a given frequency (return periods). The coefficient of correlations obtained was positive and of high values, it ranged from 0.9153 to 0.8855, this indicates a good curve fitting. These models developed from this research work are very useful in predicting rainfall events and in designing other water resources engineering related works.

Keywords Predictive Rainfall, Weilbull ranking method, the Chow's type equation

1. Introduction

Model has been defined in various ways based on the area of study of various individuals. It could be seen as a process of representing an object physically before its construction as seen in building modelling, Model is also applied in conceptual and abstract view, in areas of Engineering, Management Sciences and applied sciences disciplines.

Mathematical model is defined as a description of phenomenon, theory, systems or data by mathematical and logical objects, like formulas, functions and relations. It often explains things by grouping variables into various sets. Therefore mathematical modelling could be seen as an act of representing a phenomenon or systems with mathematical equations.

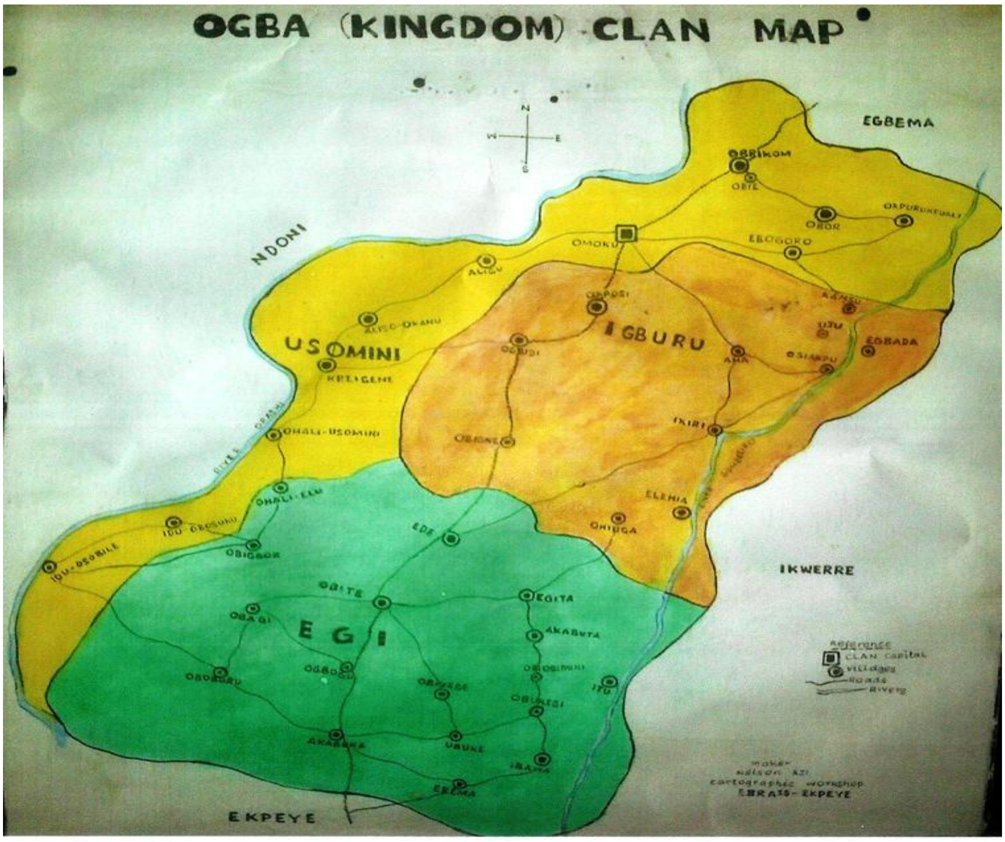
Hydrologists and engineers encounters a lot of difficulties in designing and planning process for construction of water structures in developing countries like Nigeria due to limited or in some cases unavailability of necessary long period rainfall information required. Nigeria as a developing country cannot provide 35 years consistent rainfall records while developed countries like America has rainfall information of more than 100 years frequency and rainfall duration. Only some meteorological stations like Onitsha, Makurdi, Kano, Lagos, Yola, Bida, Yelwa, Owerri, Lokoja, Port Harcourt and Benin can boast of above 35 years rainfall information, although some have missing data in between while others without rainfall duration. Other stations in Nigeria have short record, [1-4]. This research work presents information on developing rainfall intensity-duration-frequency functions for Omoku in Ogba/Egbema/Ndoni Local Government Area of Rivers State, Nigeria. The relationship derived from the return period and intensity duration for any location will be useful in various civil and water resources projects designs and planning. Such projects includes drainage works, highway and sewer systems. The precipitation pattern of design systems is usually created by applying relationships between frequency, intensity and duration of rainfall appropriate for the geographical location and the projects itself, [5-6]. The rainfall intensity frequency duration (IDF) curves are always available and are widely applied in designing water resources facilities, hence the need for this research work.

Regression modelling was used in this research to fit rainfall information from Omoku Meteorological Station for 14year duration. There are a lot rainfall models are obtainable in literature, these includes quotient model, power model and non-linear multiple regression models, these models were used in fitting rainfall data [1, 7-8]. The method was to use the initial data in calibrating the model and applying the correlation coefficient as parameter for evaluating curve fitting. The original data were then used in developing numerous sets of models.

2. Materials and Methods

2.1. Study Area

The study area for this research work is Omoku in Ogba/Egbema/Ndoni Local government area of Rivers State, Nigeria. Omoku lies within longitude 06.656'E and latitude 05.342'N. Rainfall records of Omoku meteorological station between January1987 to December 2000 were collected from the Niger Delta Basin Development Authority



2.2. Data Collection

The data for this research work was obtained from Niger Delta Basin Development Authority, Port Harcourt. It was carried out at Federal College of Education (Technical) Omoku, metrological station. The area of study is on a longitude 6.6560E and latitude 5.3420 N. The rainfall record of 1987 to year 2000 was used for these research works.

2.3. Data Analysis and Methods

The Omoku fourteen years rainfall information was analyzed by arranging the rainfall amounts against durations. The durations used in this research work includes 10, 20, 30, 45, 60, 90, 120, 180, 240, 300 and 360minutes. The annual highest rainfall values were then selected for various durations, the selected maximum rainfall amounts (mm) were then converted to rainfall intensities (mm/hr) by dividing the amount against corresponding duration. The rainfall intensities obtained are arranged in order of decreasing magnitude with rank of 1 assigned to rainfall intensity with the highest value.

The intensities were then related to their corresponding probabilities and recurrence intervals of the rainfall data using the Weibull's formula in Equation (1), the rainfall events probabilities were given as shown in Table 2, this shows a return period (frequency) of one year more than the record period for the highest value (Chow, 1952).

$$P(xm) = \frac{m}{n+1} \quad (1)$$

Where

$P(x_m)$ = Probability of exceedence of Variate x_m

m = Rank of descending values, with Largest equal to1

n = Number of years of record

The reciprocals of the probabilities of exceedence were computed to obtain the corresponding return period (frequency) of the rainfall events using Equation (2) as shown in Table 1. This approach was adopted by the United States Water Resources Council (1981).

$$T = \frac{n+1}{m} \quad (2)$$

From the computed frequencies, some return periods were then selected and used in the developing the rainfall intensity duration frequency models. The chosen return periods are 1.3, 1.5, 2.5, 3, 5, 7.5, 15 years. Power model approach was used in developing rainfall intensity duration frequency models for Omoku City.

2.4. Rainfall Intensity against Return Period: Power Models

For the purposes of models development, the power model were used to fit the rainfall data so as to develop another set of rainfall intensity duration frequency models. The power model equation is given as;

$$I = aR^b \quad (3)$$

The solution of Equation (3) is obtained using regression model, and tabulated in Table 3.

Table 1: Return Period Versus Rainfall Intensity

RETURN PERIOD, R (YR)	INTENSITIES, i (mm/hr)									
	10 mins	**20 mins**	**30 mins**	**45 mins**	**60 mins**	**90 mins**	**120 mins**	**240 mins**	**300 mins**	**360 mins**
1.3	8.32	19.30	23.44	23.60	15.60	16.24	12.68	13.20	10.21	5.63
1.5	8.80	32.41	28.30	25.30	23.60	19.80	15.47	14.50	11.03	7.68
2.5	33.20	60.80	45.10	40.82	27.82	30.05	18.32	18.85	13.32	9.93
3	38.60	64.40	45.68	42.36	33.32	30.11	19.50	20.51	16.44	13.40
5	48.36	82.12	53.00	46.37	36.30	48.42	22.18	22.38	18.62	15.68
7.5	195.32	98.28	54.86	58.65	43.20	53.90	26.47	25.46	20.36	22.42
15	196.20	138.31	236.05	63.68	44.20	54.68	27.38	33.60	21.64	22.48

Table 2: Calculation for probability of excedence (P) and frequency interval (R) of the rainfall intensity of various duration using, Weibull ranking method (n=14) rainfall intensity (mm/hr) for the duration of years

	MAXIMUM RAINFALL INTENSITIES (mm/hr) FOR DURATIONS										
YEAR m	10 min	20 min	30 min	45 min	60 min	90 min	120 min	240 min	300 min	360 min	$P=\frac{m}{n+1}$	$T=\frac{1}{P}$
1	196.20	138.31	236.05	63.68	44.20	54.68	27.38	33.60	21.64	22.48	0.067	15
2	195.32	98.28	54.86	58.65	43.20	53.90	26.47	25.46	20.36	22.42	0.133	7.5
3	48.36	82.12	53.00	46.37	36.30	48.42	22.18	22.38	18.62	15.68	0.20	5
4	46.20	80.50	52.46	43.82	35.62	35.40	20.13	21.50	16.62	14.26	0.267	3.75
5	38.60	64.40	45.68	42.36	33.32	30.11	19.50	20.51	16.44	13.40	0.333	3
6	33.20	60.80	45.10	40.82	27.82	30.05	18.32	18.85	13.32	9.93	0.40	2.5
7	25.86	43.64	35.00	37.68	26.70	28.16	18.30	18.36	12.48	9.75	0.467	2.14
8	26.30	36.40	34.62	35.16	25.30	26.32	16.38	17.82	12.40	8.95	0.533	1.88
9	19.20	33.48	34.60	29.34	25.20	21.48	15.50	14.62	11.53	8.20	0.60	1.67

10	8.80	32.41	28.30	25.30	23.60	19.80	15.47	14.50	11.03	7.68	0.67	1.5
11	8.46	21.48	23.67	25.01	16.20	18.42	14.12	13.60	10.60	7.10	0.733	1.36
12	8.32	19.30	23.44	23.60	15.60	16.24	12.68	13.20	10.21	5.63	0.80	1.3
13	8.20	18.70	18.37	10.27	13.60	15.86	12.50	9.40	8.94	5.12	0.867	1.15
14	5.28	18.50	16.30	9.27	13.48	4.38	12.33	8.05	5.46	3.26	0.933	1.07

3. Results and Discussion

Table 3: Predictive Rainfall IDF Models for various Return Periods for Omoku City

Duration (Minutes)	**Rainfall Models $i = aR^b$**	**Regression Parameters GF = Goodness of fit CC = Coefficient of correlation**
10	$i = 6.6845R^{1.3958}$	GF = 0.9182 CC = 0.9582
20	$i = 23.764R^{0.7165}$	GF = 0.8814 CC = 0.9388
30	$i = 18.819R^{0.779}$	GF = 0.8473 CC = 0.9205
45	$i = 23.852R^{0.4111}$	GF = 0.8985 CC = 0.9479
60	$i = 18.602R^{0.3798}$	GF = 0.8181 CC = 0.9045
90	$i = 16.793R^{0.5216}$	GF = 0.8894 CC = 0.9431
120	$i = 13.276R^{0.304}$	GF = 0.9196 CC = 0.9590
240	$i = 12.762R^{0.3601}$	GF = 0.9751 CC = 0.9875
300	$i = 10.132R^{0.3234}$	GF = 0.9089 CC = 0.9534
360	$i = 5.9602R^{0.5698}$	GF = 0.9056 CC = 0.9516

3.1. Application of Developed Model

One of the practical applications of these models calibrated are drains and culverts design. This calibrated models helps the Engineers to determine maximum design discharge. From rational method we have:

$$Q = CIA \tag{4}$$

Where I= rainfall intensity, A= Surface rainfall area and C = runoff coefficient

A hydraulic drain design was used to demonstrate the practical applications of these models calibrated, is presented as follows:-

Frequency (Return Period), R = 15years

Duration of Rainfall, t = 2.0hr (120mins)

Transverse slope, s = 0.005

Area of Runoff, A = $0.52km^2 (520x10^3 m^2)$

Rational Formula Coefficient, C = 0.5

Substituting design parameter into the model equation for 120 minutes rainfall duration and return period of 15 years.

$$I = 13.276\ R^{0.304}$$

The Rainfall Intensity is given as;

$$i = 13.276\ (15)^{0.304} = 30.24mm/hr\ (8.40\ x10^{-6} m/s)$$

Solving to evaluate discharge generated using Equation (4) becomes:

$$Q = 0.50(8.40X10^{-6})\frac{m}{s}\ x\ 520x10^3\ m^2$$

$$Q = 2.184\ \frac{m^3}{s}$$

Using Manning's Equation, we obtain

$$Q = \frac{AR^{1/2}S^{1/2}}{n} \tag{5}$$

For Best hydraulic section for rectangular channels, the hydraulic radius is given as, R_{max}:

$$R_{max} = \frac{y}{2} \tag{6}$$

Substituting hydraulic radius, R_{max} into Manning's equation,

Where b=2y, $A=2y^2$ and A= yb gives:

$$Q = \frac{S^{\frac{1}{2}} 2y^2 y^{\frac{2}{3}} \frac{1}{2}^{2/3}}{n}$$

$$= \frac{S^{\frac{1}{2}} 2y^{\frac{8}{3}} y^{\frac{2}{3}} \frac{1}{2}^{2/3}}{n}$$

$$= \frac{1.2599 y^{\frac{8}{3}} s^{\frac{1}{2}}}{n}$$

Solving for y:

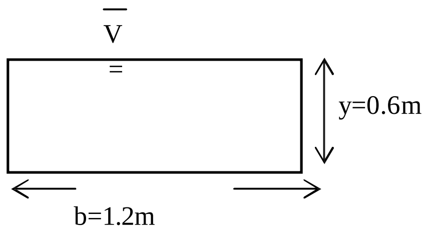
$$y = \frac{Qn}{1.2599 S^{\frac{1}{2}}}$$

$$y = \frac{2.184 \times 0.0016}{1.2599 \times 0.005^{\frac{1}{2}}}$$

= 0.6m (Depth of flow)

And

b= 2y =1.2m (Width of flow).



Application of the developed models in designing a drain in Omoku City gives the following section: Breath(b) = 1.2m and depth(d) = 0.6m respectively.

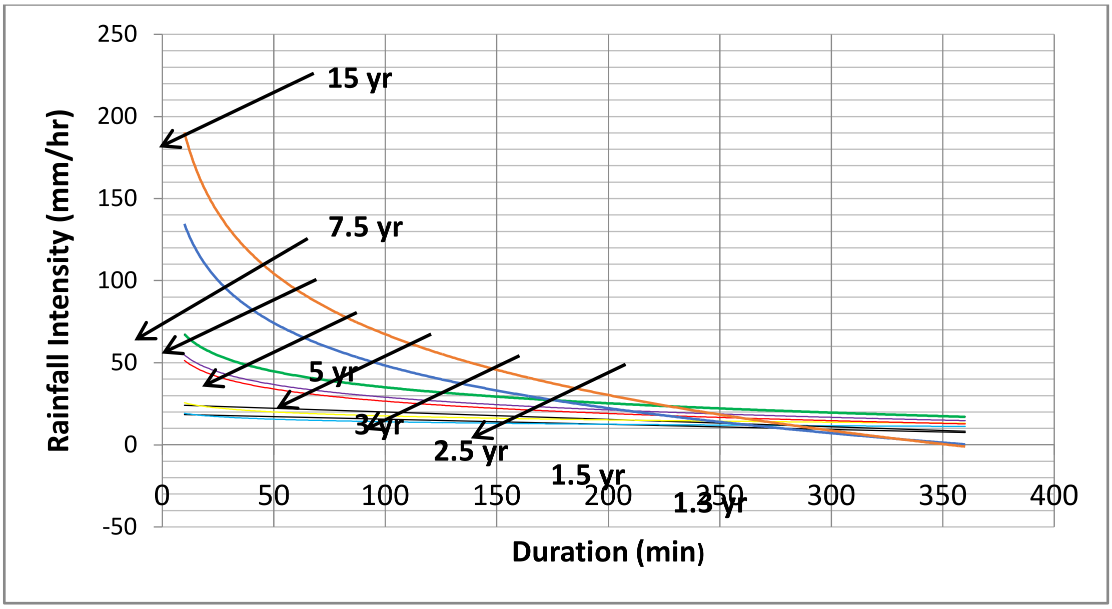


Figure 2: Rainfall Intensity Frequency Curve for Omoku

Also using the power model a total of ten rainfall IDF models was developed. The developed IDF models, the goodness of fit (GF) and the coefficient of correlation (CC) were later tabulated and presented in Table 3. The goodness of fit and coefficient of correlation gave a positive and high values which ranged from 0.9751 – 0.8181 and 0.9875 – 0.9045 respectively.

Comparing the actual data obtained from the field with the results predicted from the plots of the rainfall intensities against return periods for given durations, the following were observed:

- Nonlinear curves were obtained
- Intensities with very high storm correspond to rainfall with short duration.
- It was observed that curves of short duration of rainfall lie above curves of longer duration of rainfall.

4. Conclusion

The following conclusions can be deduced from the rainfall studies of Omoku:

- The power model Equation (3) was used in developing the rainfall intensity duration model for the Omoku City by fitting the field data into regression model. The developed models generate using power model gives rainfall intensity against frequency for specified durations.
- Ten rainfall intensity duration frequency models were obtained from the power models with very high and positive values of coefficient of correlation ranging from 0.9875 to 0.9045 were obtained.

The plots of these power models conforms to the field data which equally agree with the literature that the rainfall intensity duration frequency curves are non-linear, and that high intensity storms correspond to short durations

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