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Synthesis of Isopluvial Maps for Nigeria Using IDF Equations Derived from Daily Rainfall Data

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Abstract A major challenge in water resources planning, design and operation in developing countries such as Nigeria is the paucity of relevant and accurate hydrological and meteorological data. The estimation of design storm for example depends on availabilty of rainfall quantities and their durations. Meteorological data collected at several synoptic stations in Nigeria show that daily records are available for rainfall. These records do not contain the durations of storms with their corresponding depths which are needed to generate intensity- duration –frequency (IDF) relations for storm drainage designs. The study generated annual series of daily maximum rainfall at seven synoptic station in central Nigeria. The series were fitted with Gumbel Extreme Value Type I distribution and rainfall depths at various return periods (2, 5, 10, 20, 50, 100, 200 years) were obtained. Proportionate depths of ranfall at short times scale (15, 30, 45, 60, 90 120 and 240 minutes) were obtained using USDA generalised accumulated rainfall curve for storm type A. After calculating the intensities, IDF equations were fitted for each station. These were then converted to isopluvial maps. The maps can be used to obtain rainfall depth at short durations (15, 30, 60 minutes) and frequencies when needed for design of storm drainage in agricultural lands and urban systems.

Keywords Isopluvial Maps, IDF Equations, Rainfall Data

Introduction

Rainfall as an environmental phenomenon is of immense importance to mankind. Hence the significance of studies to understand the rainfall process cannot be overemphasized. Floods, droughts, rainstorms, and high winds are extreme environmental events which have severe consequences on human society. Planning for these weather-related emergencies, design of engineering structures, reservoir management, pollution control, and insurance risk calculations, all rely on knowledge of the frequency of these extreme events [1].

The rainfall intensity-duration-frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or the protection of various engineering projects (e.g. highways, etc.) against floods. They describe the relationship between mean precipitation intensity and frequency of occurrence (the inverse of the return period) for different time intervals of a given duration. Nigerian hydrologists face a major challenge in planning and design of water resources structure due to the limited and / or unavailability of the required long term rainfall data. While daily rainfall record of over one hundred years duration and rainfall frequency atlas are commonly available in developed countries such as America, Australia and so on, Nigeria as an underdeveloped nation cannot boast of a consistent 30 years rainfall record [2].

Prodanovic and Simonovic (2007) [3] developed Rainfall Intensity-Duration-Frequency curves for the city of London, Ontario under changing climate by analyzing short duration high intensity rainfall for under the conditions of the changed climate. Predicted future climate change impacts for Southwestern Ontario included higher temperatures and increases in precipitation, leading to an intensification of the hydrologic cycle. The expected consequence of change in climate was an increase in the magnitude and frequency of extreme events (e.g. high intensity rainfall, flash flooding, severe droughts, etc.). Changes in extreme events are of particular importance to the design, operation and maintenance of municipal water management infrastructure.

Desramaut (2008) [4] carried out a study on the estimation of Intensity-Duration-Frequency curves for current and future climates. He proposed a statistical downscaling approach, based on the scale invariance concept, to incorporate GCM outputs in the derivation of Intensity- Duration-Frequency (IDF) curves and the estimation of urban design storms for current and future climates under different climate change scenarios. The estimated design storms were then used in the estimations of runoff peaks and volumes for urban watersheds of different shapes and different levels of surface imperviousness using the popular Storm Water Management Model (SWMM). Daniell and Tabios (2008) [5] compiled a report for the IHP regional steering committee for south East Asia and the Pacific. A Rainfall-Intensity-Frequency analysis was carried out for 9 countries; Australia, People's republic of China, Indonesia, Japan, Malaysia, New Zealand, Republic of Korea, Philippines and Vietnam. In the results obtained, it was concluded that the rainfall pattern follows a simple scaling process with two different scaling regimes: 10 minute to 1hour and 1hour to 24hours. Results obtained from the scaling process were found to be very similar to the observed data.

In Nigeria, Oyebande (1982) [6] applied Type 1 extreme value distribution (Gumbel) to the annual extreme rainfall data sets in the derivation of Rainfall Intensity-Duration-Frequency relationships and estimates for regions with inadequate data. These rainfall data sets were generated from 11 rainfall zones. Chi-Square test was used to confirm the appropriateness of the fitted distribution. Gumbel graphical plots and the computed confidence limits also showed that the Gumbel EV-1 functions fit well into the empirical distribution. Okonkwo and Mbajiorgu (2010) [7] observed that in Southeastern Nigeria, IDF curves are not readily available. So Generalized accumulated rainfall patterns developed by USDA Soil Conservation Service were matched with rainfall data for the locations of study, and the advanced pattern had the best fit with the observed characteristics and was used to break down recorded daily totals into shorter duration rainfall data. Akpan and Okoro (2013) [8] developed Rainfall Intensity – Duration – Frequency (IDF) models for Calabar city based on 10 years (2000 -2009) rainfall data. The statistical method of least squares was used and the models developed were categorized into two sets: "intensity – duration models" and "intensity – frequency models". The first set used an inverse relationship between rainfall intensities and duration 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. The second set of models represented rainfall intensities and frequencies for specified durations of 15, 30, 45, 60, 90, 120, 180, 300 and 420 minutes. The first set had a very high and positive regression coefficient ranging from 0.9372 to 0.9930 and goodness of fit of 0.8788 to 0.9851 while the second set had very high and positive regression coefficients ranging from 0.7908 to 0.9890 and goodness of fit of 0.6263 to 0.9863.

Antigha and Ogarekpe (2013) [9] also developed Intensity Duration Frequency Curves for Calabar Metropolis, South- South, Nigeria. Twenty three years peak rainstorm intensity values with their corresponding durations were extracted and analyzed using statistical methods of least square and 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.

Nwadike (2008) [2] developed 23 rainfall models for Enugu city based on the statistical method of least squares. The rainfall models are developed were grouped into 2 sets. The first set contained 4 rainfall models which represent an inverse relationship between rainfall intensities and durations for specified return periods of 1.1, 2.2, 5.5 and 11 years. High and positive values of coefficients of correlations of 0.9735 to 0.9885 were obtained; an indication of good curve fitting. The second set of rainfall models related rainfall intensities to return period for specified durations of 15, 30, 45, 60, 90, 120 and 180 minutes. Seven models were generated in this set with coefficients of correlations between 0.886 – 0.9466. Partial series analysis were made with view of comparing the resulting models with those developed using the annual series. Though, rainfall models of the partial series exhibited good correlation, their prediction differed significantly with the corresponding models of original data sets and thus not adequate for field application. The two sets of models obtained from research (excluding the partial series models) were intended to be useful for predicting rainfall events and in turn flood prediction and erosion control works.

In the special publication of the Nigerian Association of Hydrological Sciences on Hydrology for Disaster Management (2012), the Maximum Annual Precipitation series was obtained at Benin, Owerri, Onitsha and Calabar stations for different durations and fitted to one of the statistical distributions; General Extreme value (GEV). The distribution selected was based on fitting comparison criteria of RRI map. Then, this distribution was used to find 24-hr intensity-duration-frequency values at 2, 5, 10, 25, 50 and 100 years. These 24-hr IDF values were spatially interpolated using ArcView GIS model to obtain RRI maps for all durations and return periods and hence the plotting of IDF curves of selected catchments in Eastern Nigeria. Accordingly the IDF curves were constructed for ungauged sites to estimate rainfall intensity for various return periods and rainfall durations.

Rainfall data can be analyzed using Probability distribution models (PDMs) such as Normal Distribution, Exponential distribution, Log-Normal distribution, Pearson III distribution, Gumbel distribution, Log-Gumbel distribution, Exponential Distribution and Gamma Distribution. In developing rainfall intensity–duration–

frequency relationship for two regions in Saudi Arabia, Ibrahim (2012) [10] used Gumbel distribution and LPT III distribution as formula or as graphical approaches. However, according to Vivekanandan and Roy (2013) [11], a theoretical analysis of extreme hydrologic phenomena has led researchers to identify Gumbel distribution as a standard distribution for frequency analysis of recorded extreme hydrologic events, such as rainfall, flood, temperature, evaporation, etc. and hence used in the present study.

Study Area

Nigeria lies between 4^0 and 14^0N latitude and longitude 4^0 to 14^0 E. It is bounded on the north by the Republic of Niger, east by Cameroon and west by Benin Republic while the southern boundary is Gulf of Guinea which is an arm of the Atlantic Ocean. Nigeria is geographically located downstream river Niger and Benue that takes their sources from Guinea and Cameroun respectively. Nigeria has a total landmass of approximately 925,796 km^2. The climate of Nigeria varies more than any other country in West Africa due to its great length from the south to the north (1100 km). This results in virtually all of the climatic belts of West Africa being included within Nigeria's borders. Climatic data on Nigeria is kept by the Nigeria Meteorological Service. It operates and maintains synoptic weather stations throughout Nigeria. Figure 1 shows locations of synoptic weather stations in Nigeria.

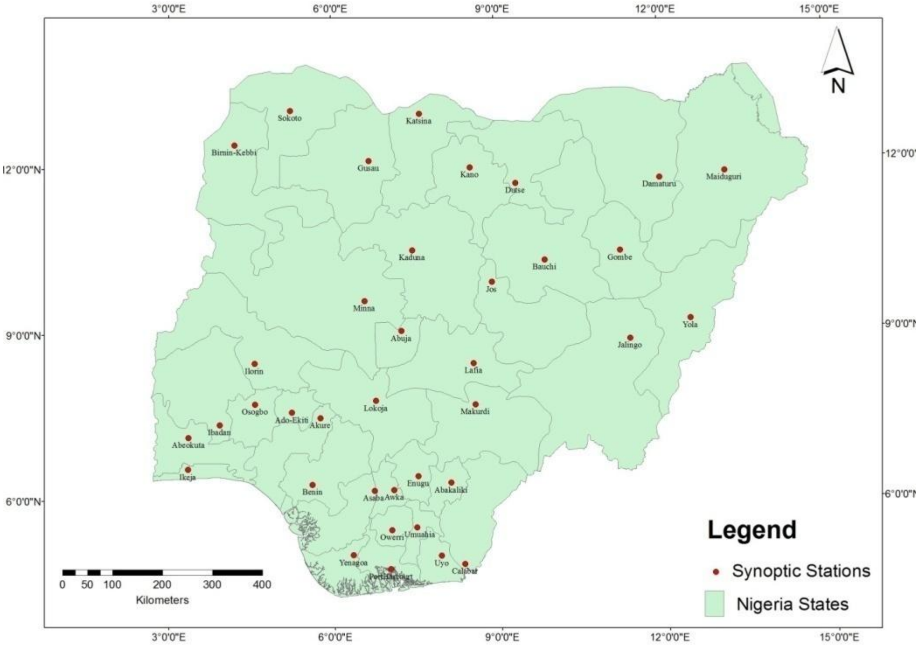
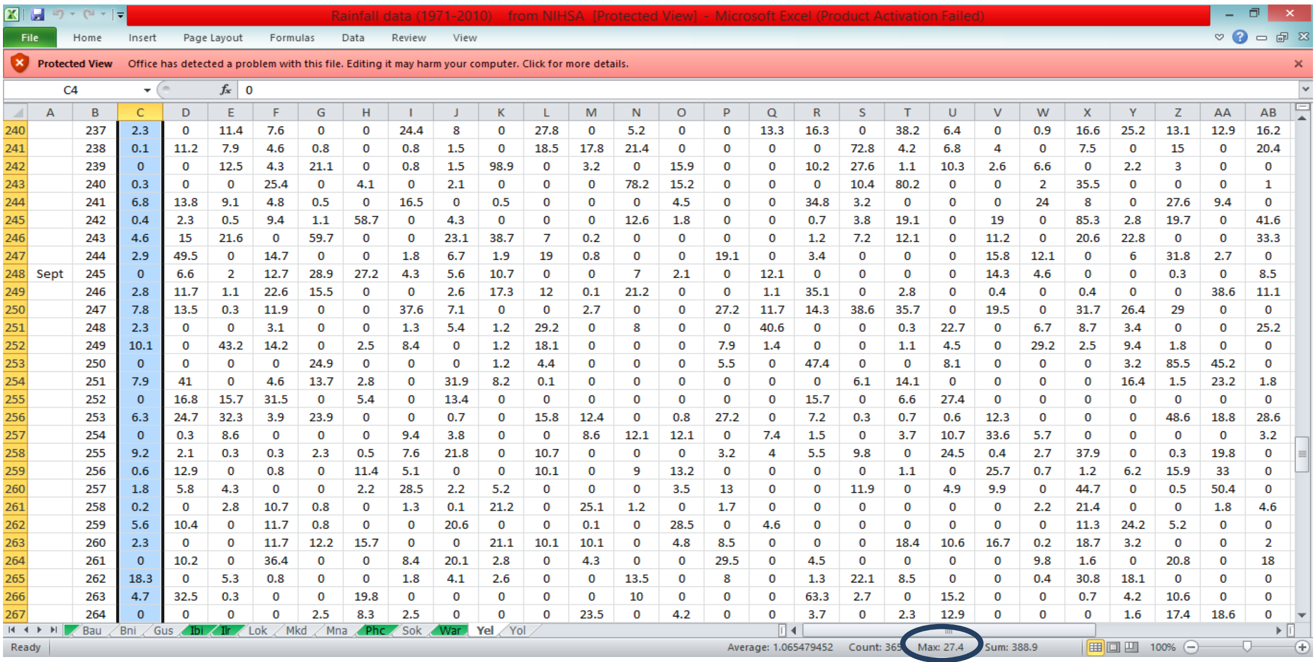


Figure 1: Map of Nigeria showing the location of various Synoptic Stations

Methodology

Data Collection and Analysis

Daily rainfall data from different synoptic stations in Nigeria was obtained from the Nigerian Meteorological Agency (NIMET) and Nigeria Hydrological Services Agency (NIHSA). The stations for which data was obtained were Bauchi, Benin City, Calabar, Gusau, Ibi, Ilorin, Lokoja, Makurdi, Minna, Port Harcourt, Sokoto, Warri, Yelwa and Yola. Daily rainfall depth (mm) was obtained on a Microsoft Excel Spreadsheet. The duration of the data for all the stations was 40 years (1971-2010) with the exception of Makurdi (1981-2010) which only had a 30 year record. The available rainfall data was analyzed to determine the peak rainfall for each year. This was done by highlighting the data set for each year for each station and checking the maximum value at the base of the Excel sheet. Figure 2 shows a typical worksheet containing daily rainfall depths at one of the stations analyzed. The process produced the annual daily maximum series which contained the largest value observed in each year. This approach is preferred because of its simple structure and its wider popularity when compared to the peak over threshold method otherwise known as partial duration series. The peak daily rainfall for each year was analyzed to obtain the following parameters: mean, standard deviation, maximum, minimum, skew coefficient, coefficient of variation and so on. These parameters are needed for fitting probability distribution function to the data.



Rainfall data (1971-2010) from NIHSA [Protected View] - Microsoft Excel (Product Activation Failed)

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
240		237	2.3	0	11.4	7.6	0	0	24.4	8	0	27.8	0	5.2	0	0	13.3	16.3	0	38.2	6.4	0	0.9	16.6	25.2	13.1	12.9	16.2
241		238	0.1	11.2	7.9	4.6	0.8	0	0.8	1.5	0	18.5	17.8	21.4	0	0	0	0	72.8	4.2	6.8	4	0	7.5	0	15	0	20.4
242		239	0	0	12.5	4.3	21.1	0	0.8	1.5	98.9	0	3.2	0	15.9	0	0	10.2	27.6	1.1	10.3	2.6	6.6	0	2.2	3	0	0
243		240	0.3	0	0	25.4	0	4.1	0	2.1	0	0	0	78.2	15.2	0	0	0	10.4	80.2	0	0	2	35.5	0	0	0	1
244		241	6.8	13.8	9.1	4.8	0.5	0	16.5	0	0.5	0	0	0	4.5	0	0	34.8	3.2	0	0	0	24	8	0	27.6	9.4	0
245		242	0.4	2.3	0.5	9.4	1.1	58.7	0	4.3	0	0	0	12.6	1.8	0	0	0.7	3.8	19.1	0	19	0	85.3	2.8	19.7	0	41.6
246		243	4.6	15	21.6	0	59.7	0	0	23.1	38.7	7	0.2	0	0	0	0	1.2	7.2	12.1	0	11.2	0	20.6	22.8	0	0	33.3
247		244	2.9	49.5	0	14.7	0	0	1.8	6.7	1.9	19	0.8	0	0	19.1	0	3.4	0	0	0	15.8	12.1	0	6	31.8	2.7	0
248	Sept	245	0	6.6	2	12.7	28.9	27.2	4.3	5.6	10.7	0	0	7	2.1	0	12.1	0	0	0	0	14.3	4.6	0	0	0.3	0	8.5
249		246	2.8	11.7	1.1	22.6	15.5	0	0	2.6	17.3	12	0.1	21.2	0	0	1.1	35.1	0	2.8	0	0.4	0	0.4	0	0	38.6	11.1
250		247	7.8	13.5	0.3	11.9	0	0	37.6	7.1	0	0	2.7	0	0	27.2	11.7	14.3	38.6	35.7	0	19.5	0	31.7	26.4	29	0	0
251		248	2.3	0	0	3.1	0	0	1.3	5.4	1.2	29.2	0	8	0	0	40.6	0	0	0.3	22.7	0	6.7	8.7	3.4	0	0	25.2
252		249	10.1	0	43.2	14.2	0	2.5	8.4	0	1.2	18.1	0	0	0	7.9	1.4	0	0	1.1	4.5	0	29.2	2.5	9.4	1.8	0	0
253		250	0	0	0	0	24.9	0	0	0	1.2	4.4	0	0	0	5.5	0	47.4	0	0	8.1	0	0	0	3.2	85.5	45.2	0
254		251	7.9	41	0	4.6	13.7	2.8	0	31.9	8.2	0.1	0	0	0	0	0	0	6.1	14.1	0	0	0	0	16.4	1.5	23.2	1.8
255		252	0	16.8	15.7	31.5	0	5.4	0	13.4	0	0	0	0	0	0	0	15.7	0	6.6	27.4	0	0	0	0	0	0	0
256		253	6.3	24.7	32.3	3.9	23.9	0	0	0.7	0	15.8	12.4	0	0.8	27.2	0	7.2	0.3	0.7	0.6	12.3	0	0	0	48.6	18.8	28.6
257		254	0	0.3	8.6	0	0	0	9.4	3.8	0	0	8.6	12.1	12.1	0	7.4	1.5	0	3.7	10.7	33.6	5.7	0	0	0	0	3.2
258		255	9.2	2.1	0.3	0.3	2.3	0.5	7.6	21.8	0	10.7	0	0	0	3.2	4	5.5	9.8	0	24.5	0.4	2.7	37.9	0	0.3	19.8	0
259		256	0.6	12.9	0	0.8	0	11.4	5.1	0	0	10.1	0	9	13.2	0	0	0	0	1.1	0	25.7	0.7	1.2	6.2	15.9	33	0
260		257	1.8	5.8	4.3	0	0	2.2	28.5	2.2	5.2	0	0	0	3.5	13	0	0	11.9	0	4.9	9.9	0	44.7	0	0.5	50.4	0
261		258	0.2	0	2.8	10.7	0.8	0	1.3	0.1	21.2	0	25.1	1.2	0	1.7	0	0	0	0	0	0	2.2	21.4	0	0	1.8	4.6
262		259	5.6	10.4	0	11.7	0.8	0	0	20.6	0	0	0.1	0	28.5	0	4.6	0	0	0	0	0	0	11.3	24.2	5.2	0	0
263		260	2.3	0	0	11.7	12.2	15.7	0	0	21.1	10.1	10.1	0	4.8	8.5	0	0	0	18.4	10.6	16.7	0.2	18.7	3.2	0	0	2
264		261	0	10.2	0	36.4	0	0	8.4	20.1	2.8	0	4.3	0	0	29.5	0	4.5	0	0	0	0	9.8	1.6	0	20.8	0	18
265		262	18.3	0	5.3	0.8	0	0	1.8	4.1	2.6	0	0	13.5	0	8	0	1.3	22.1	8.5	0	0	0.4	30.8	18.1	0	0	0
266		263	4.7	32.5	0.3	0	0	19.8	0	0	0	0	0	10	0	0	0	63.3	2.7	0	15.2	0	0	0.7	4.2	10.6	0	0
267		264	0	0	0	0	2.5	8.3	2.5	0	0	0	23.5	0	4.2	0	0	3.7	0	2.3	12.9	0	0	0	1.6	17.4	18.6	0

Average: 1.065479452 Count: 365 Max: 27.4 Sum: 388.9

Figure 2: An Excel Spreadsheet showing how to obtain Annual Maximum daily rainfall from a set of data

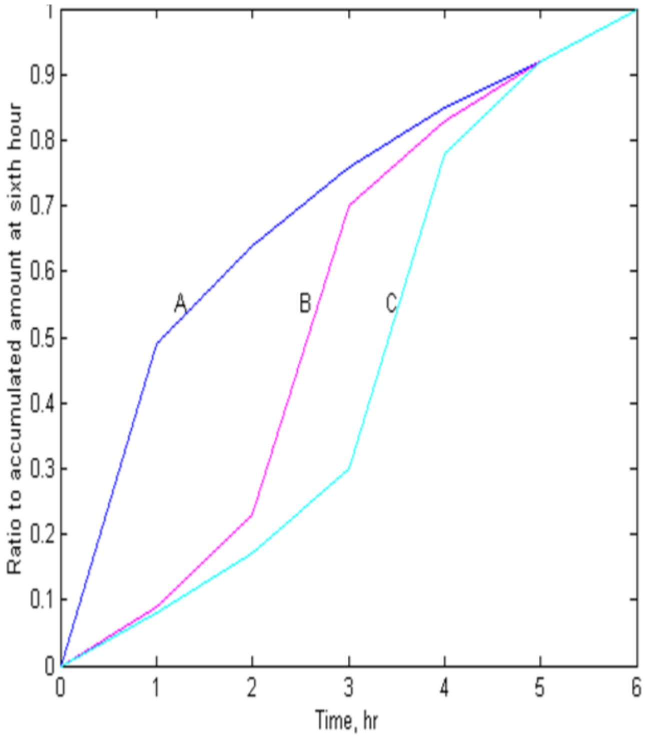

Figure 3: Generalized accumulated rainfall curves for A (advanced), B (intermediate), and C (retarded) types of storms. (USDA SCS, 1955)

Rainfall Intensity Estimation

Rainfall intensity is time rate of precipitation, that is, depth per unit time (mm/hr or in/hr). The average intensity is commonly used and can be expressed as

$$i = \frac{P}{t} \tag{1}$$

Where P is the rainfall depth (mm or in) and t is the duration, usually in hours. The data required for computation of intensities are storm depths at various durations, say 15minutes (0.25hour), 30minutes (0.5hour), 45minutes (0.75hour), 60minutes (1 hour), 90 minutes(1.5hours), 120minutes (2hours), 180minutes (3hours), 240minutes (4hours), 300minutes (5 hours) and 360minutes (6 hours). Unfortunately, only data on daily rainfall totals were available for all the stations. Estimates of rainfall depths of shorter durations than daily were obtained using the Generalized Accumulated rainfall curves for A, B and C storm types [7]. Curve A is for advanced type of storm in which the greatest intensity occurs in the early part of the storm; Curve B is for intermediate storm type with highest intensity occurring in the middle of the storm; and Curve C is for the retarded storm type with high intensity occurring late in the storm duration (Figure 3). Curve A was chosen as it represented the storm pattern of rainfall in most part of Nigeria.

The intensities were obtained by first fitting the Gumbel Extreme Value Type I Probabilty distribution to the depth P_T estimated with Figure 2 and the annual series data such that precipitation P_T (in mm) at each duration t and specified return period T (in years) is given by the following equation:

$$P_T = P_{av} + KS \tag{2}$$

where K is Gumbel frequency factor calculated as

$$K = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left[\ln\left[\frac{T}{T-1}\right]\right]\right] \tag{3}$$

P_{av} and S are the average and standard deviation of the maximum precipitation series or annual series for a specific duration (15, 30, 45, 60, 60, 90, 120, 180, 240 min). The intensities were then calculated with equation 1.

Development of IDF Relationships

The IDF relationship is mathematically stated as follows:

$$i = \frac{aT^b}{(t+c)^d} \tag{4}$$

Where i = Intensity (mm/hr), T is the return period (years) which is the average length of time between precipitation events that equal or exceed the design magnitude; and t is duration (minutes or hours) while a, b, c and d are non-negative coefficients. Since intensity varies inversely with the duration for any given return period, then an equation of the form

$$i = \frac{A}{(t+c)^d} \tag{5}$$

can be assumed between i and t. The values of A, c, and d called locality constants were determined by regression analysis. First assuming a value for say c Eqn (5) becomes

$$i = \frac{A}{(F)^d} \tag{6}$$

Taking logarithms on both sides of Eqn 6 gives the linear form as

$$\log i = \log A - d\log F \tag{7}$$

This is a simple linear regression which was solved for A and d for several trial values of c. The best values of A, c and d were taken as those for which the sum of squared deviations (SSD) is minimum. That is

$$SSD = \sum (i - \hat{i})^2 \tag{8}$$

This procedure is then carried out for all frequencies to obtain new values of c, A, and d. Now from equation 5 we have

$$A = aT^b \tag{9}$$

$$\log A = \log a + b\log T \tag{10}$$

The values of a and b were next obtained from the plot of log A against log T.

Results and Discussion

The values of the locality constants a, b, c, d for the 14 stations are shown in Table 2.

A comparison of results obtained for Calabar was made with that of the work done by Akpan and Okoro (2013) [8] on the same station. The Intensity-Duration and Intensity-Return Period models were employed by Akpan and Okoro (2013) [8] in their IDF analysis of Calabar. Another comparison of IDF analysis results was also made between those obtained in this study and those obtained in an earlier work done by Mbajiorgu and Okonkwo (2010) [7] for Port Harcourt.

Table 1 : Values of IDF equation constants for the 14 stations

Station	a	b	c	d
Bauchi	2208.5	0.17	6	2.2
Benin	3315.8	0.18	6	2.2
Calabar	3684.7	0.16	6	2.2
Gusau	1019.7	0.21	6	2.2
Ibi	1307.9	0.17	6	2.2
Ilorin	2480.3	0.16	6	2.2
Lokoja	2375.5	0.16	6	2.2
Makurdi	2392.4	0.18	6	2.2
Minna	2324.1	0.14	6	2.2
Port Harcourt	3238.7	0.16	6	2.2
Sokoto	1860.5	0.21	6	2.2
Warri	3575.3	0.15	6	2.2
Yelwa	2048.9	0.17	6	2.2
Yola	2040.4	0.15	6	2.2

The equation based on the Gumbel Distribution method for Calabar in this study is:

$$i = \frac{3684.7T^{0.16}}{(t+6)^{2.2}} \tag{11}$$

The equation from Intensity-Duration model [8] for Calabar was

$$i = \frac{A}{(t+B)} \tag{12}$$

Where, i = rainfall intensity in mm/hr, t = duration in minutes and A and B= regional constants. Considering an 11 year return period, Akpan and Okoro (2013) obtained A =8576.33 and B = 47.8216.0.

The equation for Intensity-return period models (Akpan and Okoro, 2013) for Calabar was

$$i = aT^{b} \tag{13}$$

Where i = Rainfall intensity (mm/hr), T = Return period or frequency (yrs), a and b are regional constants. Akpan and Okoro (2013) [8] obtained that at 15 minutes (a=48.5176, b= 0.5476), 30 minutes (a= 27.68, b= 0.4624), 45 minutes (a=18.3527, b= 0.7844), 60 minutes (a= 19.61, b= 0.5845), 90 minutes (a= 22.7196, b= 0.3857), 120 minutes (a=14.2659, b=0.7583), 180 minutes (a=17.005, b=0.3269), 300 minutes (a=15.6747, b=0.1503) and 420 minutes (a=7.6542, b=0.4086). The results shown in Tables 4 indicate a high degree of agreement between the intensity-return period equation of Akpan and Okoro (2013) [8] with the Gumbel method considered in this study at durations of 0.75 hour and above. The results for Port Harcourt are also similar for the three methods. However the IDF equation generated for Port Harcourt in this study gave lower estimates of storm depths compared to the models of Mbajiorgu & Okonkwo (2010) [7].

Table 2: Comparison of intensities for 11 year return period at Calabar

Duration (hr)	**Gumbel method (This study) (mm/hr)**	**Intensity-Duration model [8] (mm/hr)**	**Intensity-Return Period model [8] (mm/hr)**
0.25	96.14	178.41	180.37
0.5	88.19	177.48	120.38
0.75	81.17	176.57	83.89
1	74.92	175.67	79.65
1.5	64.37	173.89	57.29
2	55.85	172.14	87.90
3	43.10	168.75	37.24
5	27.72	162.36	22.48
6	22.89	159.35	20.39

Table 3: Comparison with results for Port Harcourt as obtained by Mbajiorgu&Okonkwo (2010)

Method	**10 year -15 min**	**2 year – 30 min**	**5 year – 1 hr**	**25 year – 1 hr**	**100 year – 6 hr**
Graphical method [7] (mm)	34.3	35.4	64.3	92.7	238.8
Statistical method [7] (mm)	30.6	35.8	62.8	82.5	206.4
Gumbel Method (this study)(mm)	20.6	29.4	57.7	74.2	169.1

Construction of Isopluvial Maps

Rainfall depths (in mm) were generated for different return periods at different durations of 5, 10, 15, 30, 60, 120, 180 and 240 minutes for the 14 stations. The results for some selected stations are shown in Tables 4-7 .

Table 4: Rainfall Depths (mm) generated from IDF Analysis for Bauchi

Duration (minutes)	**Return Period (years)**						
	2	**5**	**10**	**25**	**50**	**100**	**200**
5	11.03	12.89	14.51	16.96	19.08	21.47	24.17
10	20.23	23.65	26.61	31.11	35.01	39.40	44.34
15	27.93	32.65	36.74	42.95	48.34	54.40	61.22
30	34.38	40.19	45.23	52.87	59.50	66.95	75.35
60	44.31	51.79	58.29	68.14	76.68	86.29	97.11
120	51.26	59.92	67.43	78.82	88.71	99.83	112.34
180	59.34	69.36	78.06	91.25	102.69	115.56	130.05
240	62.75	73.35	82.55	96.50	108.59	122.21	137.53

Table 5: Rainfall Depths (mm) generated from IDF Analysis for Benin

Duration (minutes)	**Return Period**						
	2	**5**	**10**	**25**	**50**	**100**	**200**
5	17.18	19.99	23.45	30.74	33.97	39.86	46.76
10	33.34	36.68	43.03	59.65	62.33	73.12	85.78
15	48.56	50.63	59.40	86.88	86.05	100.94	118.42
30	59.40	62.32	73.10	106.27	105.91	124.24	145.75
60	75.69	80.31	94.21	135.42	136.49	160.12	187.84
120	75.23	92.91	108.99	134.60	157.90	185.23	217.30
180	87.09	107.55	126.17	155.81	182.79	214.43	251.54
240	92.09	113.73	133.42	164.77	193.29	226.751	266.00

Table 6: Rainfall Depths (mm) generated from IDF Analysis for Calabar

Duration (minutes)	**Return Period**						
	2	**5**	**10**	**25**	**50**	**100**	**200**
5	21.90	24.79	27.23	30.83	33.87	37.20	40.86
10	42.50	48.11	52.85	59.83	65.71	72.18	79.29
15	61.90	70.08	76.97	87.14	95.72	105.14	115.48
30	75.71	85.71	94.15	106.59	117.07	128.60	141.25
60	96.48	109.23	119.98	135.83	149.19	163.87	180
120	95.90	108.57	119.25	135.00	148.29	162.88	178.91
180	111.01	125.68	138.04	156.28	171.66	188.55	207.10
240	117.39	132.90	145.98	165.26	181.52	199.39	219.01

Table 7: Rainfall Depths (mm) generated from IDF Analysis for Gusau

Duration (minutes)	**Return Period**						
	2	**5**	**10**	**25**	**50**	**100**	**200**
5	8.57	11.92	15.29	21.27	27.29	35.03	44.95
10	16.63	23.12	29.67	41.27	52.96	67.97	87.23
15	24.22	33.68	43.22	60.11	77.14	99.00	127.05
30	29.62	41.19	52.86	73.52	94.35	121.08	155.40
60	37.74	52.49	67.37	93.69	120.23	154.30	198.03
120	37.52	52.17	66.96	93.12	119.50	153.37	196.83
180	43.43	60.39	77.51	107.79	138.34	177.54	227.84
240	45.92	63.87	81.96	113.99	146.29	187.74	240.94

Thereafter, isopluvial maps were constructed using computer software known as Surfer 12. Surfer is a mapping program owned by Golden Software Inc. that quickly converts data into outstanding contours, surface, wireframe, vector, image, shaded relief and post maps. With these maps, the rainfall depth for any location in Nigeria can be estimated far more easily and faster without necessarily going through the probability distribution fitting procedure. The maps are very useful for design and planning purposes. Some of the precipitation maps generated for Nigeria are presented in Figures 4 to 7. The maps show isopluvial lines for 2-year and 50-year return periods with durations of 15 minutes, 30 minutes, 1hour and 2 hours. The 14 stations used were those at Bauchi, Benin City, Calabar, Gusau, Ibi, Ilorin, Lokoja, Makurdi, Minna, Port Harcourt, Sokoto, Warri, Yelwa and Yola.

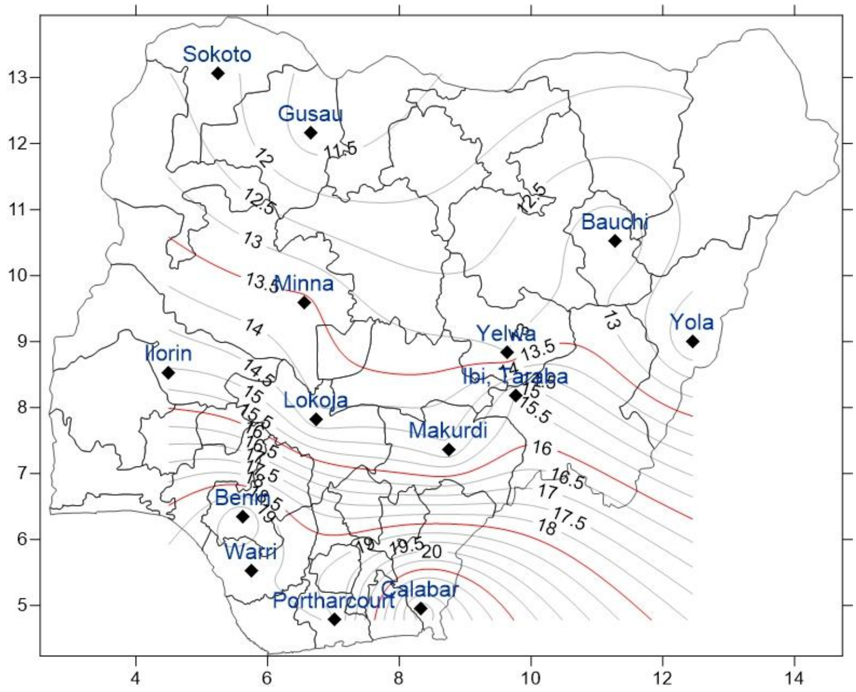

Figure 4: Isopluvial maps for Nigeria (5 yr, 15 min)

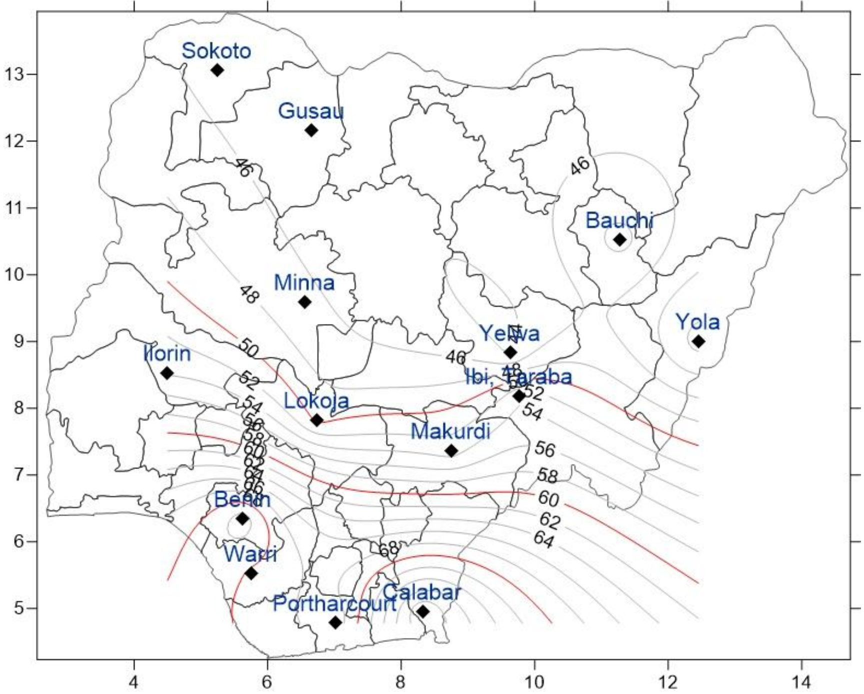

Figure 5: Isopluvial maps of Nigeria (10 yr, 60 min)

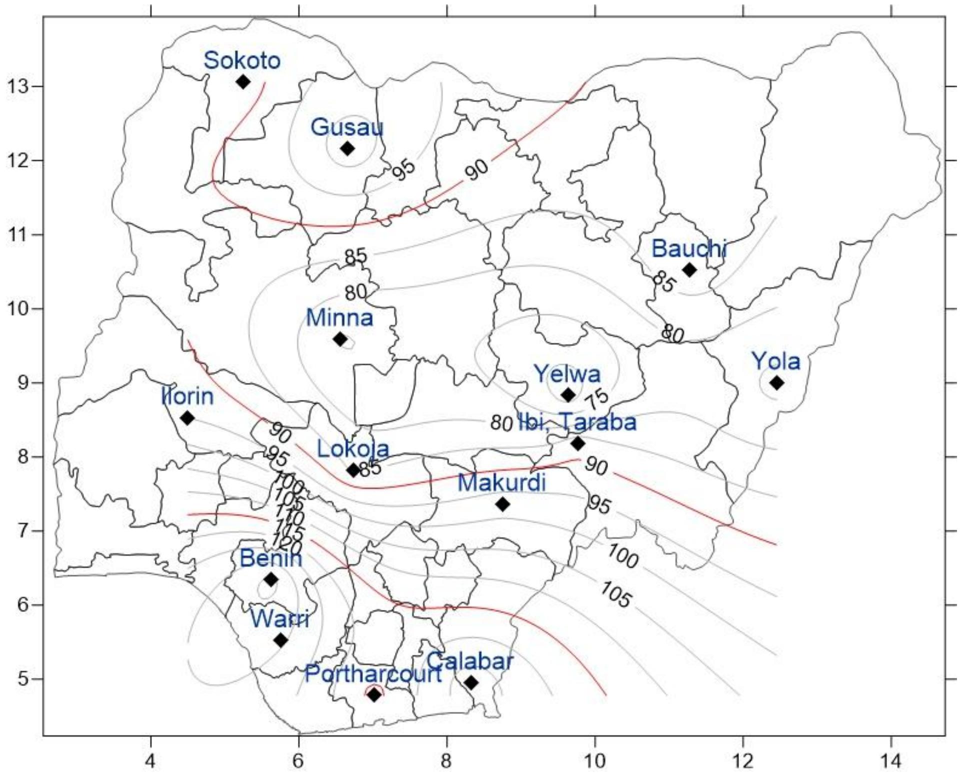

Figure 6: Isopluvial Maps of Nigeria (50 yr, 90 min)

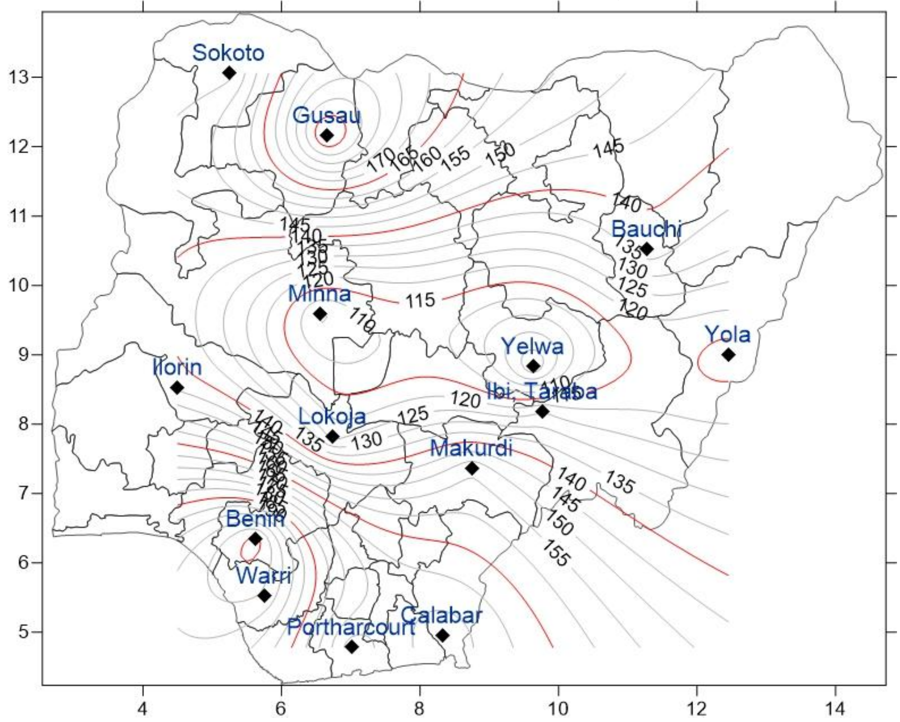

Figure 7: Isopluvial Maps of Nigeria (200 yr, 120 min)

Conclusion

Hydrologists and engineers require Intensity-duration-frequency data in the planning and design of water resources projects. Historical rainfall records are needed to obtain design estimates for both small and large projects. This study has attempted to provide much needed and useful design charts for water resources planning and development in Nigeria. The results from the IDF analysis showed that the Gumbel Extreme Value Type distribution method was successfully used to derive the rainfall intensity, duration and frequency at each of the 14 selected synoptic stations in Nigeria. Isopluvial maps were also produced for Nigeria for various duration and frequencies. The results obtained should serve to meet the need for rainfall intensity-duration-frequency relationships and estimates in various parts of Nigeria, both for short and longer recurrence intervals. The use of the results of this study to calculate design floods could be done with greater easy for most parts of Nigeria. It is hoped that as more precipitation data at required time scale are available the analysis could also be refined and applied to individual station series to obtain improved estimates of the IDF parameters and more precise maps.

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