Development of Rainfall Intensity-Duration-Frequency Curves for South Western Nigeria

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***Abstract*—One of the major challenges faced by engineer and hydrologist is inadequate or non-availability of hydrological and meteorological data to properly design, operate and plan water resources against extreme rainfall event. Such data would be needed for the development of Rainfall Intensity-Duration-Frequency (IDF) curves for design of storm drainage in urban systems. This study analysed the daily rainfall data collected from Nigeria Meteorological Agency (NIMET) Oshodi, Lagos for eight major towns in five state in South Western Nigeria over a period of twenty nine (1984-2012) years. The data was processed and analysed using Microsoft Excel spread sheet to generate series of peak annual rainfall. The record of duration of rainfall data was not available and as a result a USDA generalised accumulated rainfall curve for storm type A was adopted for short duration interval. The rainfall intensity values were calculated for duration of (15, 30, 45, 60, 90, 120 and 240 minutes) to estimate returns period of (2, 5, 10, 20, 50, 100 and 200 years) using Gumbel Extreme Value Type 1 distribution. The non-parametric Kolmogorv-Smirvov test and the Chi-Square test were used to confirm the appropriateness of the fitted distributions for the locations. The IDF curves were developed for the towns and recommended for the design of storm drainage.**

***Index Terms*—Rainfall intensity, return period, gumbel distribution, intensity-duration-frequency-curve.**

I. Introduction

The importance of precipitation in the field of Civil Engineering cannot be over-emphasized due to its diverse uses. The quantification and occurrence of extreme precipitation is required by hydraulic engineers and hydrologists in the water resources planning, design, and operation. A rainfall intensity-duration-frequency (IDF) relationship is the most commonly used method for designing and planning of various water resource projects [1]. The rainfall characteristics are often required to design water structures, reviewing and updating rainfall characteristics (i.e. Intensity-Duration –Frequency (IDF)) curves for future climate scenarios therefore, becomes very necessary [2]. The evaluation of rainfall is a major issue in hydrologic risk analysis and design.

Reference [3] shows developed Rainfall-Intensity-Duration-Frequency curves for the Colombo region using annual peak rainfall values. The values were fitted to Log Pearson type III (LP3) and Gumbel Extreme Value (EV1). LP3 distribution was found to be the best fitted distribution for 1, 4, 6, and 24 hour's duration of annual peak precipitation while, EVI was the most appropriate distribution for other durations such as 2 and 12hours. Reference [4] shows analysed daily rainfall data series of three different cities: Addis Ababa (Ethiopia), DarEs Salaam (Tanzania) and Douala (Cameroon) using two different models of disaggregation to obtain durations shorter than 24hours. The intensity duration frequency curves were obtained using the probability distribution of Gumbel and the procedure was applied to the climate simulation over the time period 2010-2050. The results of the climate model projection suggest that future rainfall intensity could be subjected to decrease or increase depending on the different area considered, but with an increase in terms of frequency. Projections from climate models suggest that the probability of occurrence of intense rainfall in future will be increase due to increase in greenhouse gas emissions [5].

Reference [6] shows work done on revision of the rainfall-intensity duration frequency curves for the city of Kumasi-Ghana using annual maximum rainfall depths of various durations, over twenty -two years. The data set was then subjected to frequency analysis using the Gumbel distribution whose parameters were computed by fixing the statistics to the data. The Chi-square test and the Kolmogorov-Smirvov test proved the appropriateness of the fitting. The IDF estimates from the work were compared with the existing IDF curves prepared by [7] and found that at shorter durations (12mins and 24mins.), the new IDF give higher intensities for the same period while for longer durations (42mins, 1hr, 2hr, 3hr, 6hr, 12hr and 24hrs, the new IDF curves give lower intensities for the same return period.

Reference [8] used Type 1 extreme value distribution (Gumbel) to the annual maximum extreme rainfall data series from eleven (11) rainfall zones in the development of Rainfall- Intensity - Duration - Frequency relationships and estimates for regions with inadequate data. 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 EV1 functions fit well into the empirical distribution. Reference [9] shows analysed peak daily rainfall for 12 major towns in Nigeria over a period of 33yrs and used the statistical

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parameters derived to compute the locality omission constant (a, b, and c) in Sherma equation. The values for the constants were used to develop the rainfall intensity function for each town and subsequently used to estimate intensities for various recurrence intervals (T) and rainfall durations (t). The estimated average rainfall intensities for various frequency and durations were plotted on log-log graph to develop the rainfall intensity charts. Reference [10] observed that in South-Eastern Nigeria, Intensity-Duration-Frequency 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 the recorded daily totals into shorter duration rainfall data.

Reference [11] shows estimated twenty three years peak rainstorm intensity values with their corresponding durations from the historical rainfall records and used the data to develop Intensity - Duration - Frequency Curves for Calabar Metropolis, South-South, Nigeria 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. Reference [12] produced isopluvial maps for Nigeria for various durations and frequencies from generated annual series of daily maximum rainfall at seven synoptic stations in central Nigeria. The series were fitted with Gumbel Extreme Value Type 1 duration and rainfall depths at various return periods (2, 5, 10, 20, 50, 100 and 200) were obtained proportionate depths of rainfall 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.

In the South-western part of Nigeria, Intensity- Duration-Frequency curves are not readily available for many towns. The methods employed for a few IDF curves for the region found in the literature, [8], [9], [13] were too simplistic and lacking rigorous analyses. This work attempts to address these short-comings and develop IDF for eight major towns in the region.

II. The Study Area

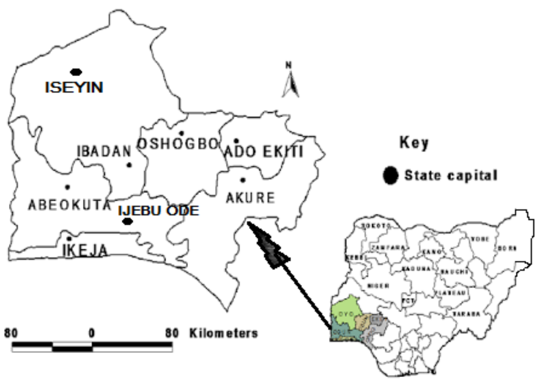

Fig. 1. Map of Nigeria showing the selected towns of the south-western states.

A map of Nigeria showing the South Western geographical region is shown in Fig. 1;

The selected towns lie within the South-Western part of Nigeria. Southwest Nigeria covers a total land area of 142, 114 square kilometres with several large rivers and streams. The selected areas are located within the longitudes, latitudes and elevations above sea level as recorded below in Table I.

TABLE I: Table Showing the Longitude and Latitude of Selected Towns

S/N	Towns	Longitude	Latitude	Elevation Above Sea Level (m)	Years of Rainfall Data (1984-2012)
1	Ikeja	03^0 20′00′′	06^0 35′00′′	39	29
2	Akure	05^0 11′35′′	07^0 15′09′′	353	29
3	Osogbo	07^0 33′25′′	07^0 46′15′′	336	29
4	Iseyin	03^0 35′29′′	07^0 58′35′′	321.18	29
5	Ondo	04^0 50′00′′	07^0 6′00′′	287	29
6	Abeokuta	03^0 20′42′′	07^0 09′20′′	64	29
7	Ijebu–Ode	06^0 82′00′′	06^0 32′00′′	68	29
8	Ibadan	03^0 54′21′′	07^0 22′21′′	181	29

The weather conditions vary between the two distinct seasons in Nigeria; The rainy season (March -November) and the dry season (November - February). The dry season is also the bringer of the Harmattan dust; cold dry winds from the northern deserts blow into the southern regions.

III. Methodology

A. Data Requirement, Collection and Analysis of Data

The data required for the computation of intensities are rainfall depths for short durations say 15mins, 30mins, 45mins, 1hr, 2hrs and 4hrs. Unfortunately, only data on daily rainfall are available in all the stations. Computation of rainfall depths of shorter duration other than daily were obtained using the generalised accumulated rainfall curves for A, B, and C storm types [12]. Curve A is for intermediate storm type with highest intensity occurring in the middle of the storm; and Curve B is for the retarded storm type with high intensity occurring late in the storm duration (Fig. 2). Curve A was chosen as it represented the storm pattern of rainfall in most part of Nigeria.

Daily rainfall data for eight major towns in five states in the South-Western, Nigeria was collected from the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos, Nigeria. NIMET is the agency responsible for the measurement, control and storage of rainfall data of the areas in Nigeria.

The data was collected for a period of twenty nine years (1984-2012) and daily rainfall depth (mm) was obtained on a Microsoft Excel Spread sheet. The daily data was analysed and annual maximum rainfall for each year was extracted for the determination of the following parameters; mean, standard deviation, skew coefficient, coefficient of variation, maximum and minimum rainfall values. The summary of the statistic for maximum annual rainfall for the towns is presented in Table III. These parameters would be required for fitting probability distribution function to the data.

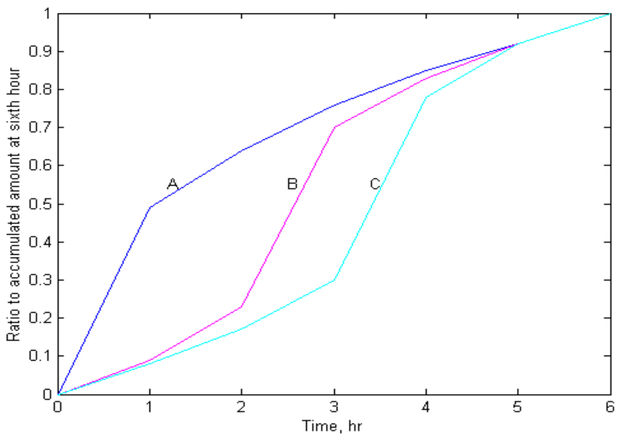

Fig. 2. Generalised accumulated rainfall curves for A (advanced), B (intermediate and C (retarded) types of storms [14].

TABLE II: SUMMARY OF THE STATISTIC ANNUAL MAXIMUM RAINFALL (1984-2012)

Selected Towns	Parameters					
	Mean $\bar{x}$ (mm)	Stand. Dev. (mm)	Skew Coeff. (G)	Coeff. Of Var. (Cv)	Max. (mm)	Min. (mm)
Ikeja	116.69	51.05	0.98	0.44	237.3	53.8
Akure	83.08	23.27	1.82	0.28	150.1	57.2
Osogbo	72.59	17.37	0.76	0.24	116	48.6
Iseyin	81.38	23.83	0.97	0.29	140	45
Ondo	85.86	37.23	3.11	0.43	246.3	51.9
Abeokuta	78.29	24.80	0.72	0.32	134.2	42.3
Ijebu-Ode	100.86	28.18	1.56	0.28	174.8	67.3
Ibadan	83.82	24.63	2.59	0.29	183.4	52.2

B. *Intensity-Duration-Frequency Curve Development*

The step taken to develop intensity-duration-frequency curve is as follows:

1) *Preparation of annual maximum data series*

The annual maximum rainfall depths for the different durations (0.25-hour, 0.5-hour, 0.75-hour, 1-hour, 1.5-hour, 2- hour, and 4-hour) were calculated.

2) *Rainfall intensity determination*

Rainfall intensity is the rate of precipitation, depth of precipitation per unit time. The average intensity is commonly used

$$i = \frac{p}{t_d} \quad (1)$$

where; p is the rainfall depth,

t_d is the duration of rainfall.

The intensities were computed for each year and then ranked in descending order with the highest value taking the value of 1 in the rank. The intensity values data was subjected to statistical analysis to determine the mean ($\bar{x}$) and standard deviation (S).

3) *Fittings the probability distribution*

There are a number of probability distribution functions that can be used to describe extreme value data such as annual maxima. These include log-normal (two Parameters), Normal, Type I Extreme value (Gumbel), Type III Extreme value, Log-Pearson Type III, and Gamma distribution. The Gumbel's Extreme Value distribution was fitted to each selected duration data series to obtain the design rainfall depth for 0.25hr, 0.5hr, 0.75hr, 1hr, 2hr, and 4hr return period. The primary reason why Gumbel was chosen over the others was that Gumbel has a fixed value of skew. The Kolmogorov-smirnov and chi-square goodness of fit test were used to evaluate the accuracy of the fittings of a distribution. From the result the test statistic never exceeded the limiting 95 percent values.

4) *Determination the rainfall depth*

The frequency factors or the CDF of the distribution (by inverting the CDF) are the two commonly available methods that can be used to determine rainfall depth. The frequency factor was used for the data and the rainfall depth for a given return period was calculated as;

$$X_T = \bar{x} + K_T S \quad (2)$$

where,

X_T = design rainfall intensity

$\bar{x}$ = Mean

S = Standard deviation, and

K_T = frequency factor for return period (T)

The K_T is the Gumbel frequency factor is calculated as

$$K = -\frac{\sqrt{6}}{\pi}\,[\,0.5772 + \ln\{\ln(\frac{T}{T-1})\}] \quad (3)$$

The IDF curves were then developed by plotting the design rainfall intensity values X_T against corresponding durations t_d for the different return period.

IV. RESULTS AND DISCUSSIONS

The results of the design rainfall intensities for different return period were computed and shown in Table III to IV.

TABLE III: THE INTENSITIES (MM/HR) AND DURATIONS FOR DIFFERENT RETURN PERIODS FOR FOUR (4) TOWNS IN OYO AND ONDO STATES

Station	Duration	Returns Period (T)						
	(Hours)	2YEAR	5YEAR	10YEAR	20YEAR	50YEAR	100YEAR	200YEAR
Akure	0.25H	114.1333	143.7243	163.3623	182.1625	206.4922	224.7562	242.9196
	0.5H	63.40738	79.84684	90.75684	101.2014	114.7179	124.8645	134.9553
	0.75H	46.49875	58.55435	66.55501	74.21435	84.12644	91.56733	98.96726
	1H	38.04443	47.90811	54.4541	60.72083	68.83072	74.91872	80.97321
	1.5H	29.59011	37.26186	42.35319	47.22732	53.535	58.27012	62.97916
	2H	25.36295	31.93874	36.30274	40.48056	45.88715	49.94581	53.98214
	4H	16.84259	21.20932	24.10729	26.88162	30.47193	33.16714	35.84751
Ondo	0.25H	114.8488	162.1893	193.6067	223.6838	262.607	291.8262	320.8846
	0.5H	63.80489	90.10518	107.5593	124.2688	145.8928	162.1257	178.2692
	0.75H	46.79025	66.07713	78.87681	91.13042	106.988	118.8922	130.7308
	1H	38.28293	54.06311	64.53557	74.56125	87.53566	97.27541	106.9615
	1.5H	29.77562	42.04908	50.19433	57.99208	68.08329	75.65865	83.19231
	2H	25.52196	36.04207	43.02371	49.7075	58.35711	64.85027	71.30769
	4H	16.94817	23.93419	28.57043	33.00889	38.75277	43.06463	47.35277
Ibadan	0.25H	114.882	146.1948	166.9755	186.8696	212.615	231.9417	251.162
	0.5H	63.82331	81.21934	92.76416	103.8165	118.1194	128.8565	139.5345
	0.75H	46.80376	59.56085	68.02705	76.13207	86.62091	94.49476	102.3253
	1H	38.29399	48.73161	55.6585	62.28987	70.87165	77.3139	83.72068
	1.5H	29.78421	37.90236	43.28994	48.44768	55.1224	60.13303	65.11609
	2H	25.52933	32.48774	37.10567	41.52658	47.24777	51.5426	55.81379
	4H	16.95307	21.57389	24.64048	27.57625	31.37547	34.22751	37.06384
Iseyin	0.25H	111.5532	141.8554	161.9654	181.2175	206.1319	224.8349	243.4349
	0.5H	61.97399	78.80858	89.98079	100.6764	114.5177	124.9083	135.2416
	0.75H	45.4476	57.79296	65.98591	73.82934	83.97966	91.59939	99.17718
	1H	37.1844	47.28515	53.98848	60.40583	68.71063	74.94496	81.14497
	1.5H	28.9212	36.77734	41.99104	46.98231	53.4416	58.29052	63.11275
	2H	24.7896	31.52343	35.99232	40.27055	45.80709	49.96331	54.09664
	4H	16.46184	20.93353	23.90115	26.74216	30.41877	33.17876	35.92355

TABLE IV: THE INTENSITIES (MM/HR) AND DURATIONS FOR DIFFERENT RETURN PERIODS FOR TWO (2) TOWNS IN OGUN STATE

Station	Duration	Returns Period (T)						
	(Hours)	2YEAR	5YEAR	10YEAR	20YEAR	50YEAR	100YEAR	200YEAR
Abeokuta	0.25H	106.8847	138.4218	159.3513	179.3879	205.3177	224.7828	244.1409
	0.5H	59.38037	76.901	88.52851	99.65996	114.0654	124.8794	135.6338
	0.75H	43.5456	56.39407	64.92091	73.08397	83.64794	91.57819	99.46479
	1H	35.62822	46.1406	53.1171	59.79598	68.43922	74.92761	81.38028
	1.5H	27.71084	35.88713	41.3133	46.50798	53.23051	58.27703	63.29578
	2H	23.75215	30.7604	35.4114	39.86399	45.62615	49.95174	54.25352
	4H	15.77291	20.42683	23.51538	26.47218	30.29862	33.17108	36.02773
Ijebu Ode	0.25H	138.5859	174.42	198.2013	220.9679	250.4307	272.548	294.5436
	0.5H	76.99216	96.90002	110.1118	122.76	139.1281	151.4156	163.6353

	0.75H	56.46092	71.06002	80.74866	90.02397	102.0273	111.0381	119.9992
	1H	46.19529	58.14001	66.06709	73.65597	83.47689	90.84934	98.1812
	1.5H	35.92967	45.22001	51.38551	57.28798	64.92647	70.66059	76.36316
	2H	30.79686	38.76001	44.04472	49.10398	55.65126	60.56622	65.45413
	4H	20.45104	25.73907	29.24845	32.60811	36.95591	40.21976	43.46564

TABLE V: THE INTENSITIES (MM/HR) AND DURATIONS FOR DIFFERENT RETURN PERIODS FOR TWO (2) TOWNS IN OSUN AND LAGOS STATES

Station	Duration (Hours)	Returns Period (T)						
		2YEAR	5YEAR	10YEAR	20YEAR	50YEAR	100YEAR	200YEAR
Osogbo	0.25H	100.4231	122.5035	137.1571	151.1855	169.34	182.9683	196.5216
	0.5H	55.79063	68.05752	76.1984	83.99197	94.07776	101.6491	109.1787
	0.75H	40.91313	49.90885	55.87882	61.59411	68.99036	74.54264	80.06436
	1H	33.47438	40.83451	45.71904	50.39518	56.44666	60.98943	65.50721
	1.5H	26.03563	31.76017	35.55925	39.19625	43.90296	47.43623	50.95005
	2H	22.31625	27.22301	30.47936	33.59679	37.63111	40.65962	43.67147
	4H	14.81939	18.07778	20.2402	22.31037	24.98941	27.00053	29.00059
Ikeja	0.25H	155.9716	220.8859	263.966	305.2083	358.5806	398.6467	438.4921
	0.5H	86.65087	122.7144	146.6478	169.5602	199.2115	221.4704	243.6067
	0.75H	63.54397	89.99054	107.5417	124.3441	146.0884	162.4116	178.6449
	1H	51.99052	73.62863	87.98868	101.7361	119.5269	132.8822	146.164
	1.5H	40.43707	57.26671	68.43564	79.12808	92.96535	103.3528	113.6831
	2H	34.66035	49.08575	58.65912	67.82407	79.68459	88.58815	97.4427
	4H	23.01664	32.59601	38.95332	45.03942	52.91555	58.82807	64.70804

The IDF curves were obtained by plotting the rainfall intensity against the corresponding durations for different return periods. The IDF curves generated for the selected towns are shown in Fig. 3-10.

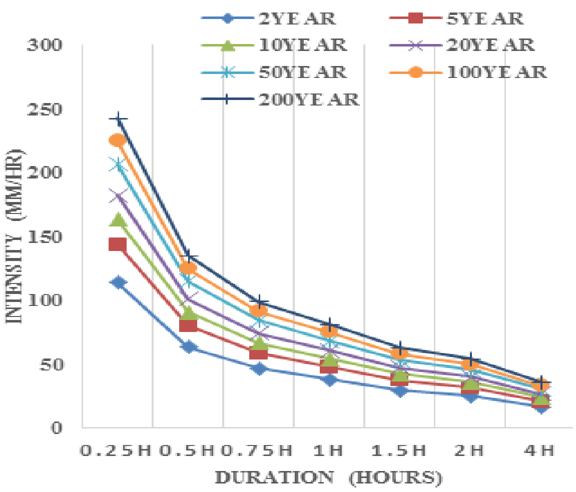

Fig. 3 .IDF curve for Akure.

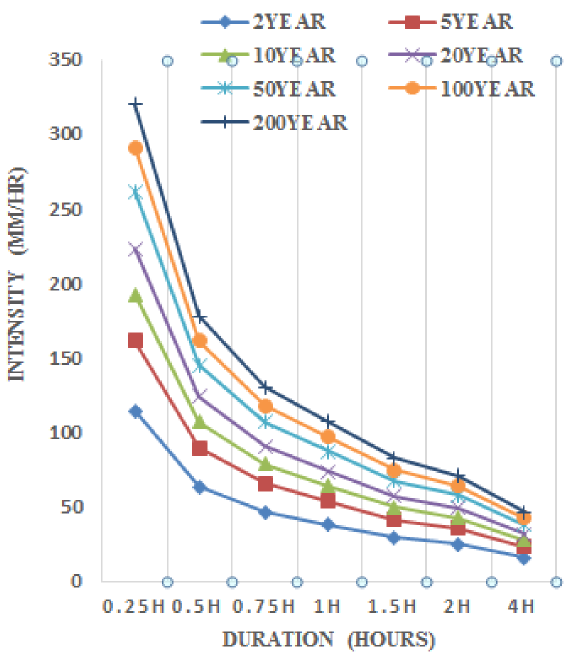

Fig. 4. IDF curve for Ondo.

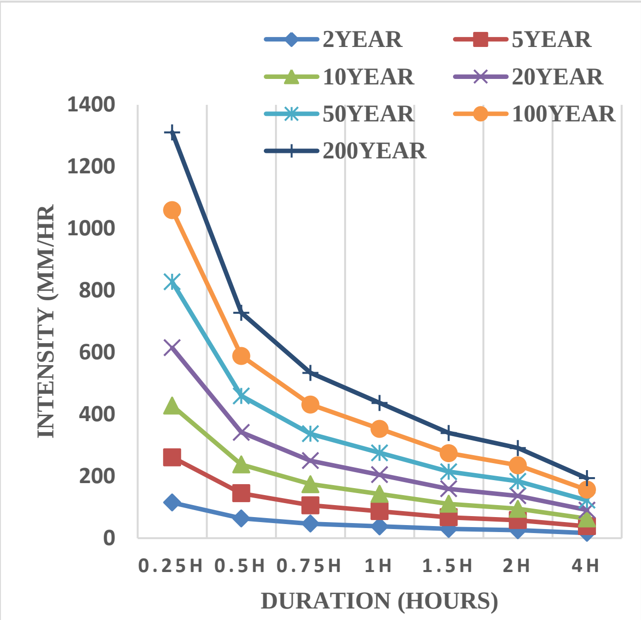

Fig. 5. IDF curve for Ibadan.

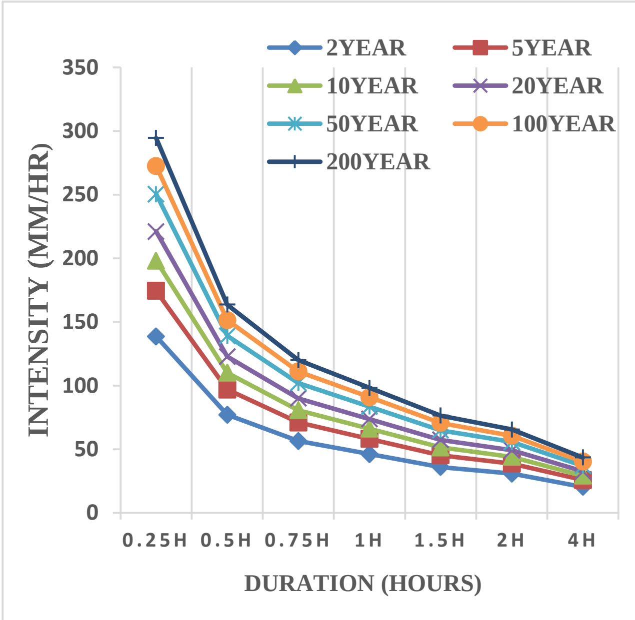

Fig. 8. IDF curve for Ijebu - Ode.

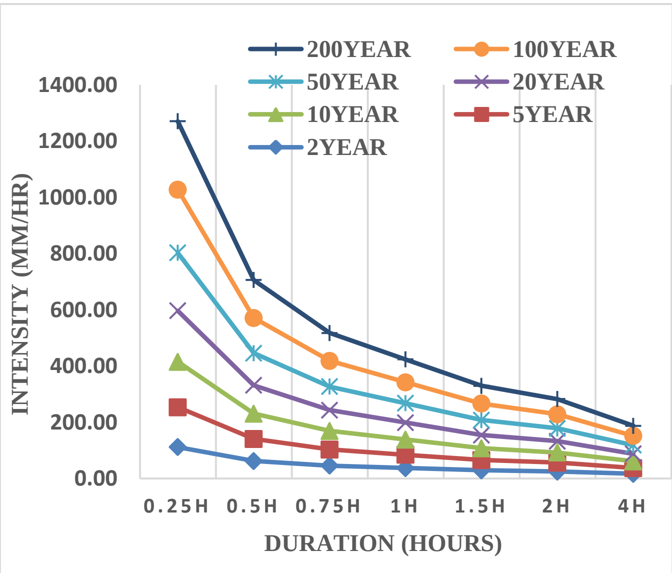

Fig. 6. IDF curve for Iseyin.

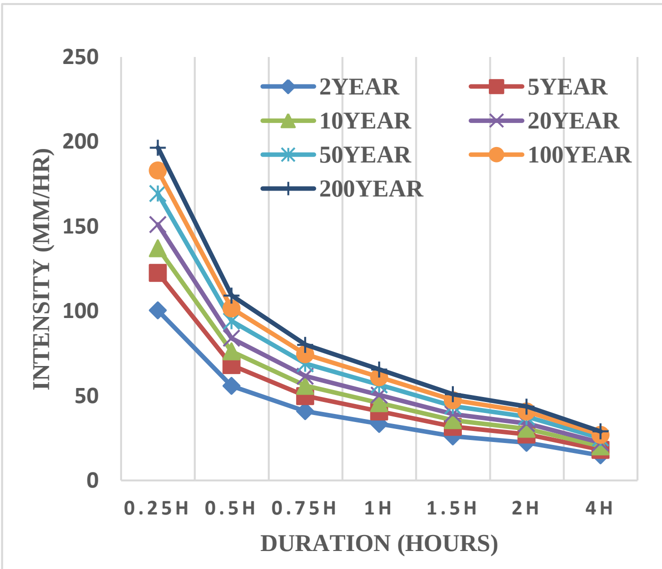

Fig. 9. IDF curve for Osogbo.

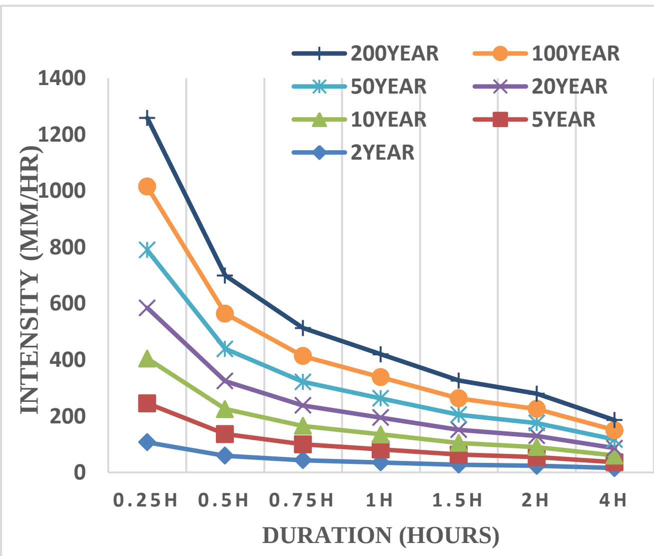

Fig. 7. IDF curve for Abeokuta.

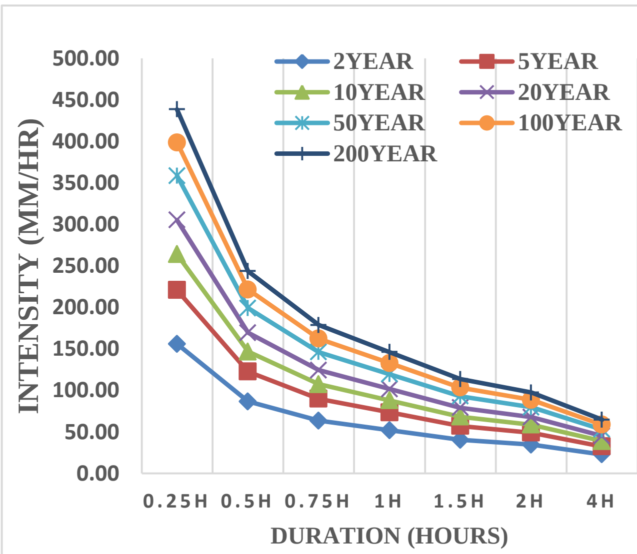

Fig. 10. IDF curve for Ikeja.

V. Conclusion and Recommendation

This work shows the development of rainfall Intensity-Duration- Frequency curve from the daily rainfall data. In particular, to obtain durations shorter than 24 hours, USDA generalised accumulated rainfall curve for storm type A was applied for the downscaling of the daily rainfall data. The IDF curves were obtained later using the probability of Gumbel.

The rainfall IDF curves developed in this study are immensely useful in estimation of rainfall intensity for the design of flood control structures and water resources development. Finally, we recommend the IDF curves for the prediction of rainfall intensities in the selected towns.

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