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DEVELOPMENT OF RAINFALL INTENSITY–DURATION-FREQUENCY (IDF) CURVE FOR KASTINA, NIGERIA

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ABSTRACT

Every year damage cause by flood waters becomes major concern in different communities across Katsina state and entire nation, mostly these flood waters appear unusual causing sever damages to life and properties. This unusual damage by flood water is cause due to proliferation in green house gases, which is rapidly changing hydrologic cycle which varietal events. Since rainfall characteristics are very important in planning and design of different water resources project, reviewing and updating these characteristics are very important in planning and design of different water resources project such review and updating become necessary. [i.e., intensity-duration-frequency (IDF). The reason of this study was to develop rainfall IDF empirical equations for Katsina city and environs, 47 years (1997-2017), data got from the Nigeria meteorological agency (NIMET) Abuja, was used to estimate the short duration rainfall intensity using yearly maximum rainfall data. Gumbel extreme – value and log Pearson III distribution methods was used to develop IDF and equations. It was found that log Pearson III distribution fits the data best, and also intensity of rainfall decreases with increase in rainfall duration, further, a rainfall of any given duration will have a larger intensity and its return period is large.

Keywords: *Rainfall Intensity, Return Periods, Rainfall Duration, Rainfall Frequency.*

INTRODUCTION

Rainfall intensity – duration – frequency IDF curves are graphical representations of the amount of water that falls within a given period of time in catchment areas (DuPont and Allen 2000). IDF curves are used to aid the engineers while designing urban drainage works. The establishment of such relationship was done as early as 1932 (chow,1988) and DuPont and Allen (2006). Since then, many sets of relationship have not been accurately constructed in many developing countries (koutsoyiannis et al, 1998). (koutsoyiannis et.al, 1998; koutsoyiannis 2003) Cited that the IDF relationship is a mathematical relationship between the rainfall intensity I, the duration d, and the return period T (or, equivalent the annual frequency of exceedance f typically referred to as frequency only). Indeed, the IDF – curves allow for the estimation of the return period of an observed rainfall event or conversely of the rainfall amount corresponding to a given return period for different times. The design of any hydraulic structure require precise understanding of extreme flow that will approach such structure, in urban storm water management the dimension of various hydraulic structures to control flood water is based on the return period of such flood. The information of such rainfall flood is often expressed as intensity – duration – frequency curves obtained from a statistical study of rainfall events.

Moreover, manifestations global warming across the planet are recognized today (IPCC, 2001). The fact that this waning will affect the intensity and frequency of rainfall is well accepted by the scientific community (De Toffo etal; 2009). To better protect life and properties it is necessary to subsequently updating.
Rainfall intensity – duration – frequency relationship by scientist and engineers for safe and cost effective design and management of hydraulic structures this is the prime aim of the present study.

LITERATURE REVIEW

Elsebale, (2011) Use two common frequency analysis techniques to develop IDF relationship from rainfall data for two regions in Saudi Arabia.These techniques are Gumbel and log pearson Type III distribution (LPT). The results obtained using Gumbel distribution are slightly higher than LPT III Distribution.

Ify Nwagazie, Masi and G sam, (2019), study rainfall intensity duration frequency frequency (IDF) for port-Harcourt, a comparative analysis was carried out between PDF and N pdf,The normal distribution model ranked the best.

Aysar Tuama AL –Awadi, (2016) Carried out assessment of intensity duration frequency (IDF) models for Baghdad City Iraq. The results showed that for Gumbel.log normal and log

Pearson type III distribution no big difference from the three techniques applied and all of them located at the acceptable significance level with small priority to log Pearson Type III distribution.

MATERIALS AND METHODS

Study Area

Katsina state, is located in the north – western region of Nigeria, within the coordinate $12^{0}50'N$ 7^{0} $30'E$ and 12^{0} $25'N$, $7^{0}50'E$, it covers a total land area of its landscape is largely dominated by the Sahel savannah vegetation.

Data Source

The data used in this research study was obtained from the Nigerian meteorological agency (NIMET) Abuja. It made up of daily average rain fall (mm) recorded in Katsina from 1997 to 2017. Maximum annual daily rainfalls were analysed for the study.

Developments of IDF Curves

For accurate hydrological analysis of hydraulic design, the IDF relationships comprise the estimate of rainfall intensities of different durations and recurrence intervals. Two commonly used theoretical distributions were used to develop the relationship between rainfall intensity, storm duration, and return periods from rainfall data for the region under study the Gumbel and log person III distribution were used. The development of an IDF carves requires implementation of the following steps:

Selection and processing of the maximum rainfall events.

Development of PDF distributions to select the best fit to the data series.

The distribution that has the best fit provides the mean to calculate the intensity for a given duration of different return period.

Gumbel Probability Distribution

This distribution is one of the most widely used in arid regions to estimate the maximum rainfall depth for different return period.

The probability density function (P D F) of this distribution takes the form of

$$P = I - e^{-e^{-y}} \quad (1).$$

Were the symbol P designating the probability of a given value being equal to or exceeding I and Y is the reduced varieties usually estimated from a statistical table

Frequency precipitation PT (in mm) for each duration with a specified return period T (in year) is given by the following equation.

$$PT = Pave + KS \quad (2).$$

Were k is Gumbel frequency factor given by

K= $\sqrt{\frac{6}{\pi}}$ [0.5772+In[In[$\frac{T}{T-I}$]]] (3).

Where pave is the average of the maximum precipitation corresponding to a specific duration.

The average in equation (2).

Is pave = $\frac{1}{n}\sum_{i=1}^{n} Pi$ (4).

Where P2 is the individual extreme value of rainfall and n is the number of events or years of record. The standard deviation is computed using the following relation:

S= $[\frac{1}{n-1}\sum_{i-1}^{N}(Pi - Pave)^2]^{½}$(5).

Where S is the standard deviation of P data. The frequency factor (K), which is a function of the return period and sample size, when multiplied by the standard deviation gives the departure of a desired return period rainfall from the average.

Then the rainfall intensity, I (in mm/h) for return period T is obtain from:

It= $\frac{Pt}{Td}$ (6)

Where Td is duration in hours.

From the raw data, the maximum precipitation (p) and the statistical variables (average and standard deviation) for each duration. (5,10,15,30,60,120,180,360,720,1440min). Were computed.

Table 1 below show the computer frequency precipitation (PT) values and intensities (IT) for different duration and return periods.

Table 1 computed frequency precipitation values and intensities for different durations and return periods using Gumbel distribution for Katsina region.

Tr(year)	5min,pave =8.83			10min pave = 12.61		
	K	PT	I	K	PT	I
2	0.13	8.785	105.42	- 0.013	17.26	103.56
5	0.061	9.040	108.92	0.061	12.9	77.23
10	0.41	9.213	11.1	0.11	13.13	78.64
25	0.174	9.430	113.61	0.174	13.43	80.42
50	0.220	9.589	115.53	0.220	13.05	81.71
100	0.266	9.748	117.45	0.266	13.87	83.01
Tr (year)	15min pave = 14.94			30min pave = 21.53		
	K	PT	I	K	PT	I
2	-0.013	14.85	59.44	-0.013	21.43	42.86
5	0.061	15.30	61.2	0.061	22.01	44.02
10	0.111	15.60	62.4	0.011	22.41	44.82
25	0.174	15.97	63.88	0.174	22.91	45.82
50	0.220	16.24	64.96	0.220	23.27	46.54
100	0.266	16.51	66.04	0.266	23.64	47.28

Tr(year)	60min pave = 30.5				120min pave =43.55	
	K	PT	I	K	PT	I
2	-0.013	30.34	30.34	-0.013	48.26	21.63
5	0.061	31.23	31.23	0.061	43.96	21.98
E	0.41	31.83	31.83	0.41	44.29	22.145
25	0.174	32.58	32.58	0.174	44.71	22.36
50	0.220	33.123	33.13	0.220	45.02	22.51
100	0.266	33.68	33.68	0.266	45.33	22.67

Tr(year)	180min pave=53.02			360min pave = 72.57		
	K	PT	I	K	PT	I
2	-0.013	43.26	21.63	-0.013	72.19	12. 03
5	0. 061	43.96	21.98	0. 061	74.36	12.39
10	0.41	44.29	22.145	0.41	75.82	12.64
25	0.174	44.71	22.36	0.174	77.66	12.94
50	0.210	45. 02	22.51	0.270	79. 011	13.17

100	0.266	45.33	22.67	0.266	80.36	13.39

Tr(year)	720min pave=106.5			1440min pave = 54.68		
	K	PT	I	K	PT	I
2	-0.013	105.99	8.83	-0.013	149.8	6.24
5	0. 061	108.88	9.07	0.061	153.84	6.41
10	0.111	110.84	9.24	0.174	160.01	6.67
25	0.174	113.30	9.44	0.174	160.01	6.67
50	0.220	115.1	9.59	0.220	162.53	6.77
100	0.266	116.89	9.74	0.266	165.04	6.88

Log Pearson Type III

The LPT III probability distribution is used to calculate the rainfall intensity at different durations and return periods. The mean and standard deviation are determined using the same manner as with Gumbel distribution, the frequency precipitation is obtained using LPT III method. The following equations were used as follows:

P* = Log(P} (7).

$P^*_T = P^*ave + kts^*$ (8).

$P^*_{ar} = \frac{1}{n} \sum_{i=1}^{n} P^*$ (9).

$S^* = \left[\frac{1}{n-1} \sum_{i-1}^{N} (P* - P*ave)^2 \right]^{½}$ (10).

Where P*, P*ave and S* are as defined previously, but based on the logarithmically transformed pi values. K1 is the person frequency factor which depends on return period (T) and skewness coefficient (cs).

the skewness coefficient cs is required to compute the frequency factor for this distribution. The skewness coefficient is computed by equal C L below

$Cs = \frac{n\sum_{i-1}^{n}(Pt* - P*ave)^3}{(n\ \ 1)(n\ \ 2)(s*)^3}$ (11).

if the coefficient of skewness Cs=o then the frequency factor K will be equal to Z. Where

$Z = W - \frac{2.515517 + 0802853W + 0.010328W^2}{1 + 1.432788W + 0.18926W^2 + 0.001808W^3}$ (12).

$W = \left[in\left(\frac{1}{P^2}\right) \right] ½$ (13).

$P = \frac{1}{T}$ (14).

Where $(0 < P \le 0.5)$

If coefficient of skewness CS is not equal to zero, then Frequency factor

$$kT = Z + \left((Z^2 - 1)\, k + \frac{1}{3}(Z^3 - 6z)k^2\, (Z^2 - 1)k^3 \right)$$

$$+Zk^4 + \frac{1}{3}ks$$

(15).

Where $k = \frac{cs}{6}$ (16).

Table 2 below show computer frequency precipitation P*T value and intensities (IT) for katsina zone using LPT III distribution.

Computed frequency precipitation values and intensities for different durations and return periods using LPT III method for Katsina zone

Table 2.

Computed precipitation (PT) and intensity log person III method.												
Tr(year)	Duration (min)											
	5				10				15			
	KT	P*T	PT	IT	KT	P*T	PT	IT	KT	P*T	PT	IT
2	-0.24		0.61	7.32	0.018		1.06	6.3	0.023		1.15	4.6
5	-9.3X10^{6}		0.92	11.04	0.37		1.11	6.7	0.85		1.31	5.2
10	1.3		1.3	15.6	0.37		1.24	7.4	1.31		1.40	5.6
25	-0.055		0.90	10.8	1.31		1.30	7.8	1.72		1.50	6
50	2.07		0.73	8.82.1	1.73		1.4	8.1	2.09		1.55	6.2
100	2.3		1.52	18.2	2.37		1.39	8.3	2.35		1.60	6.4
	5				10				15			
	KT	P*T	PT	IT	KT	P*T	PT	IT	KT	P*T	PT	IT
2	0.034		1.30	2.6	0.034		1.4	1.4	0.034		1.7	0.85
5	0.85		1.31	2.62	0.85		1.53	1.5	0.85		1.9	0.96
10	1.3		1.50	2.9	1.3		1.6	1.6	1.3		2.03	1.01
25	1.7		1.52	3.04	1.7		1.7	1.7	1.7		2.13	1.06
50	2.06		1.56	4.14	2.06		1.71	1.71	2.06		2.2	1.11
100	2.3		1.60	3.2	2.3		1.75	1.8	2.3		2.3	1.14
	5				10				15			
	KT	P*T	PT	IT	KT	P*T	PT	IT	KT	P*T	PT	IT
2	0.034		1.72	0.6	0.034		1.9	0.32	0.034		1.91	0.2
5	0.85		2.91	0.7	0.85		3.7	0.62	0.82		2.06	0.17
10	1.3		2.30	0.8	1.3		4.7	0.8	1.3		2.15	0.18
25	1.7		2.5	0.83	1.7		5.6	0.93	1.7		2.22	0.19
50	2.06		2.6	0.9	2.06		6.4	1.06	2.06		2.3	0.19
100	2.3		2.8	0.92	2.3		6.9	1.15	2.3		2.34	0.195
	1440											
	KT	P*T	PT	IT								

2	0.034		1.6	0.07
5	0.85		3.3	0.28
10	1.3		4.3	0.36
25	1.7		5.2	0.43
50	2.6		5.9	0.50
100	2.3		6.5	0.54

Derivation of IDF Equation

The IDF formulae are the empirical equation representing a relationship between maximum rainfall intensity as a dependant variable and other parameters of interest, for example the rainfall duration and frequency as independent variables. There are several commonly used functions relating those variables previously mentioned found in the literature of hydrology application (see chow (1988); burke and burke (2008) and Nhat et al. (2006). To derive an equation for calculating the rainfall intensity (I) for the regions of interest, there are some required steps for establishing an equation to suit the calculation of rainfall period which depends mainly on the results obtained from the IDF curves. The following were use to estimate the equation parameters. By applying the logarithmic conversion, where i.e is possible to convert the equation into a linear equation.

The following steps are followed: Convert the original equation in the form of power-law relation (See Chow (1988); kou tsoyiannis etal. (1998); and Alhassoun (2011) as follows

$$I = k = \frac{CT_r^m}{Td^e} \qquad (17).$$

By applying the logarithmic function to get

10gI= I0gk-e logTd (18).

Where k= CT_r^m (19).

and e represents the slope of the straight line

Calculate the natural logarithm for (k) value found from Gumbel method or from LPT III method as well as the natural logarithmic for rainfall period Td. Plot the values of (10gI) on the y-axis and the value of (log Td) on the x axis for all the recurrence intervals for the methods.

From the graphs (or mathematically) we find the value of (e) for all recurrence intervals where, then we find the average e values, e average by using the following equation:

$$Eave = \frac{\sum e}{n} \qquad (20).$$

Where n represents recurrence intervals (years) value noted as Tr.

From the graph, we find (logk) values for each recurrence interval where (logk) represents the Y- intercept values as per gumbel method or LPT III method. Then we convert Eq (19) into a linear equation by applying the natural logarithm to become
logk= logc+mlog Tr (21).

Plot the values of (log k) on the y-axis and the values of (log Tr) on the x axis to find out the values of parameters c and m as per Gumbel method or LPT III where (m) represents the slope of the straight line and (c) represents the (anti log) for the y intercept.

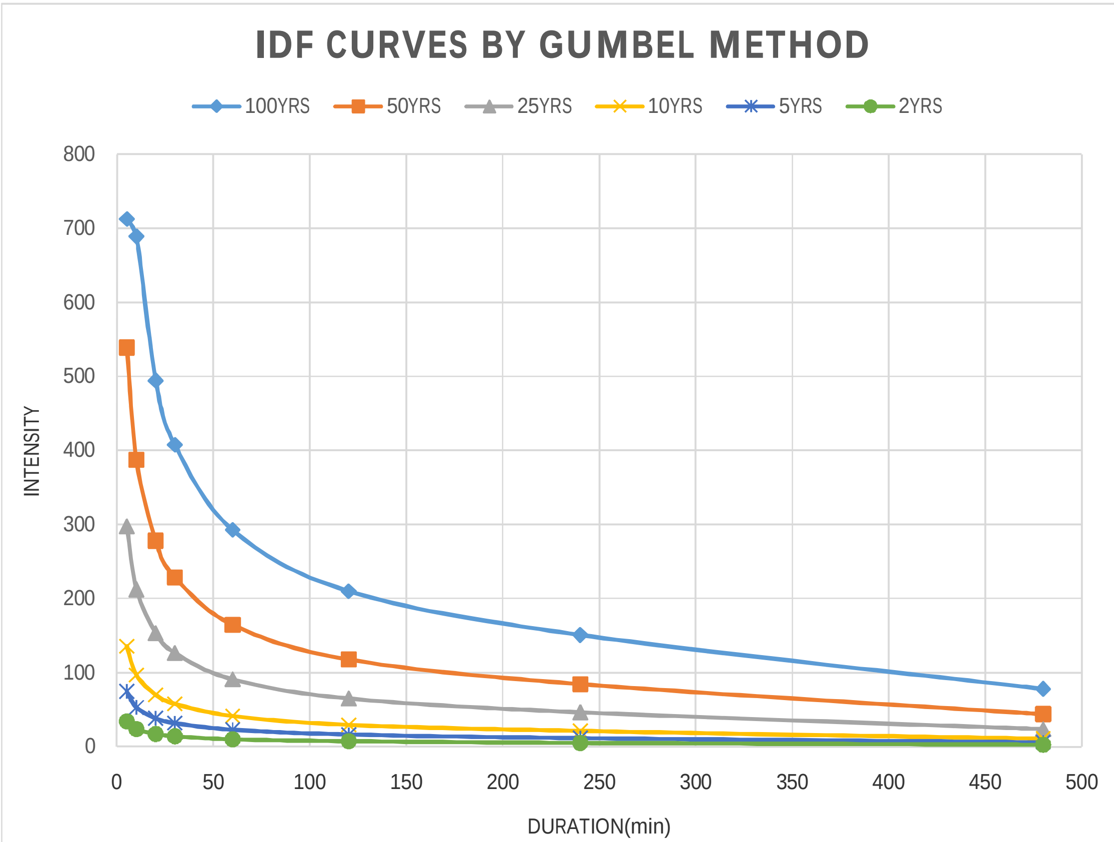
Goodness of Fit Test.
The aim of the test is to decide how good is a fit between the observed frequency of occurrence in a sample and the expected frequencies obtained from the hypothesised distributions. A goodness –of-fit test between observed and expected frequencies is based on the chi-square quantity, which is expressed as

$$X^2 = \sum_{T-1}^{k} \frac{(Oi-Ei)}{Ei} \quad (22).$$

Where X^2 is a random variable whose sampling distribution is approximated very closely by the chi-square distribution the symbols Oi and Ei represents the observed and expected frequencies, respectively, for the I – th class interval in the histogram. The symbol k represents the number of class intervals. If the observed frequencies are close to the corresponding expected frequencies the x^2 value will be small, indicating a good fit; otherwise, ie is a poor fit. A good fit leads to the acceptance of null hypothesis, where as a poor fit leads to its rejection. The critical region will, therefore, fall in the right tail of the chi-square distribution for a level significance equal to , the critical value is found from readily available chi-square tables and X^2> constitutes the critical region (see al-shaikh (1985) and oyebande (1982)).

RESULTS AND ANALYSIS

The purpose of this study was to develop IDF curves and derive an empirical formula to estimate the rainfall intensity at Katsina city and environs. The IDF curves for civil engineering project, the curves allow the engineer to design safe and economical flood control measures according to the IDF curves, rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. Figs 1and 2 -below show results of IDF curves obtained, which shows log pearson III distribution ranked best, as obtained by Ify Nwaogazie and masi G sam for port-harcourt.



Intensity = $\frac{40.74\,Tr^{0.8571}}{Td^{0.4778}}$.

Fig 1, IDF curve by Gumbel method at kastina Region.

$$I = \frac{6.31Tr^{1.15}}{Td^{1.06}}$$

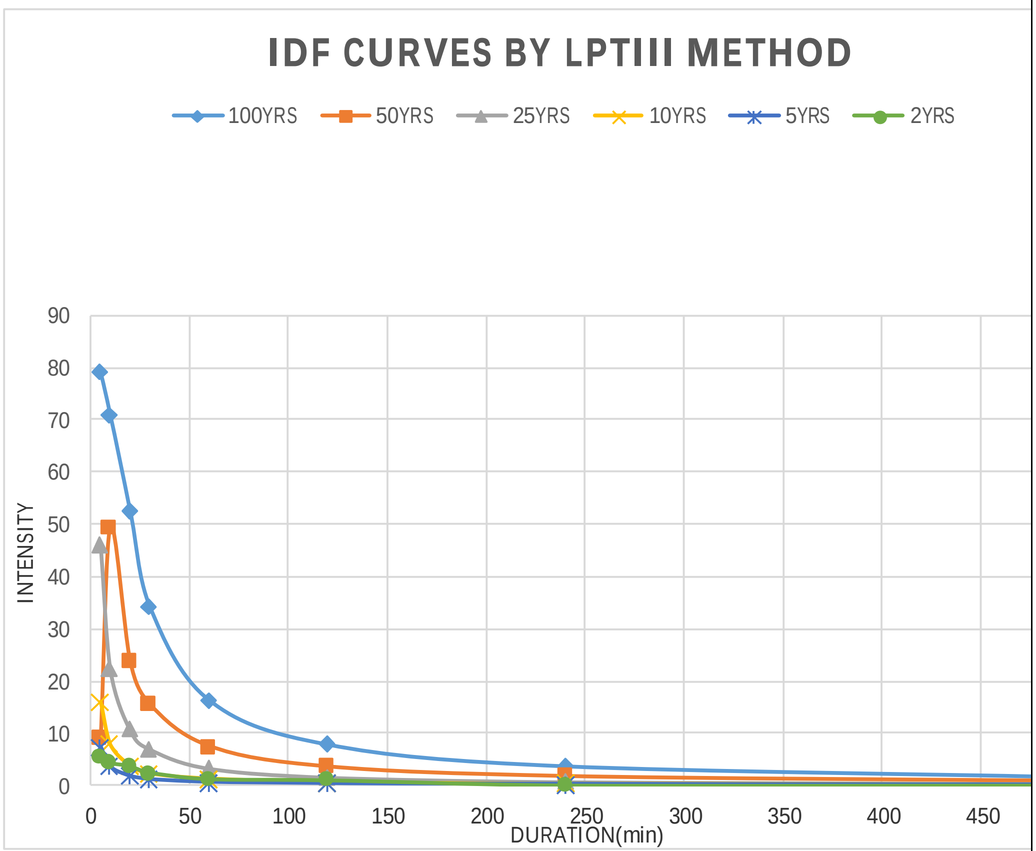


Fig 2, IDF curve by LPT III method at kastina Region.

Table 4.1 The parameters values used in deriving formulas.

Region	Parameter	Gumbel	Log Pearson
Katsina	C	40.74	6.31
	M	0.857	1.15
	e	0.4773	1.06

N.B; the parameters estimation of the IDF equations based on the rainfall (mm).

Table 4.2 below show results of chi-square goodness of fit test.

Distribution	Chi-square results		
	X^2 data	X^2 0.1	X^2 0.5
LPT III.	0.13	6.5	7.81
Gumbel.	76.4	9.24	11.07

CONCLUSIONS

The results obtained showed the correlation coefficient is very high for LPT III which is 0.75 at 100 years this indicates the goodness of fit of the formulae to estimate IDF curves in Kastina region. Results of the chi-square goodness of fit test on annual series of rainfall are shown in table 4, seen the hypothesis that log pearson type III distribution fits the data can be accepted at 5% and 10% significance level, while for Gumbel distribution the hypothesis did not fits the data at 5% and 10% significance level.

RECOMMENDATION

LPT III distribution in this research study give rainfall intensity in good correlation with observed data, present formulae that fits the distribution while the Gumbel distribution did not fit the data the chi-square test was used to test the goodness of fit. LPTII formula will serve best IDF for kastina while Further studies are recommended to verify the use of Gumbel distribution and update the IDF curves.

REFERENCE

Aysar tuama Al-awadi, 2006. Assessment of intensity duration frequency (IDF) models for Baghdad city Iraq. Journal of applied sciences research.

Awofadeju A.S Akanni, A.O. Ojeleke T.A., and Oguntayo A.A 2018. Development of rainfall intensity-duration-frequency curves for south western Nigeria. International journal of engineering and Technology,vol 10.

Celiorli Caroloso, 2009. Generation of intensity duration frequency curves for lages/sc Brazilian international journal of science.

Hadadin, N.A, 2005 rainfall intensity duration-frequency relationship in the mujib basin in Jordan. Journal of applied science.

Hatem A. Ewea, Amrom and Nassirs. Al-amrI, 2018. Modeling of IDF curves for storm water design in makkah, Almukarramah region, the kingdom of Saudi Arabia.

Ibrahim H. Elsebaise 2011.

Development rainfall intensity-duration-frequency relationship for two regions in Saudi Arabia. International journal of science.

Kushang shah, Dr. Suvarna Shar 2017.

Rainfall analysis for the development of IDF relationships A case study of nadodara city international journal of advance engineering and research development.

Lekan oyebande, 2009. Deriving rainfall intensity-duration-frequency relationships and estimates for regions with inadequate data. Hydrological Science Journal.

L nwaogazie, masi, Sam 2019.

Probability and non-probability rainfall for port-har court metropolis Nigeria.

Nassir S, Al-Amri, Ali M, and Subyani, 2017. Generation of Rainfall intensity duration frequency (IDF) Curves for in gauged sites in Arid region. International Journal of Science.

Soro, G.E, T.A Goula B, FW. Kouass; and B Srohourou. 2010. Update of intensity – Duration – frequency curves for precipitation of short Duration in tropical Area of West Africa (Cote Divoire) Journal of Applied Sciences.