American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Modelling of Short Duration Rainfall IDF Equation for Sagaing Region, Myanmar

Sai Htun Htun Thein*

Department of Civil Engineering, Technological University Lashio, Lashio,

The Republic of the Union of Myanmar

Email: htun.78.thein@gmail.com

Abstract

Changes in the hydrologic cycle due to increase in greenhouse gases cause variations in intensity, duration, and frequency of precipitation events. This study regards the development of the IDF curves for Sagaing rainfall station in Myanmar. Sagaing is a rapidly growing city in terms of population and intense urban growth, due to which ponds and lakes are continuously encroached by human activities. Daily maximum rainfall data for the year 1989 to 2018 (30 years) was collected from Department of Meteorology and Hydrology (DMH) and the empirical reduction formula was used to estimate the short duration rainfall using different probability distributions. Gumbel's Extreme Value Distribution and Log Pearson Type III Distribution are used to forecast rainfall for various return periods. Hourly rainfall were converted for shorter duration. Then, rainfall intensity for these shorter durations were determined using empirical formula and, IDF curves for studied stations were developed. Moreover, empirical equations related with rainfall intensity and duration were also developed using least square method. The IDF curve was then plotted for short duration rainfall of 15, 30, 60, 120, 180 , 240, 300, 360, 420, 480, 540, 600, 660 and 720 minutes for a return period of 5, 10, 25, 50 and 100 years. The result of IDF curves and empirical equations can be used for planning and designing hydraulic structures and water resources related projects. The correlation value R for various return period has -1. It is seen in the study that equation $i = x * t_d^{-y}$ with parameter, x varying between 500 and 900 whereas the parameter y remains a constant of 0.67 is the best IDF empirical formula.

Keywords: IDF Curve; Empirical Reduction Formula; Gumbel's Extreme Value; Log Pearson Type III.

----

* Corresponding author.

1. Introduction

Degradation of water quality, property damage and potential loss of life due to flooding is caused by extreme rainfall events. Historic rainfall event statistics (in terms of intensity, duration, and return period) are used to design flood protection structures and many other civil engineering structures involving hydrologic flows. Any change in climate produces modifications in extreme weather events, such as heavy rainfall, heat and cold waves, in addition to prolonged drought occurrences [3]. Myanmar suffers from climate change impacts on water cycle by sudden change of weather pattern such as flood and long drought and thus sustainability of water environment in some areas facing difficulties. Due to the climate change impacts, rainfall pattern and rainfall intensity are significantly changed occasionally in some parts of the country depending on the topographical condition in Myanmar. As a consequence, lesser inflows into the reservoirs, resulting in irrigation water shortage problems particularly in dry season. Rainfall intensities of various frequencies and durations are the important parameters for the hydrologic design of storm sewers, culverts and many other hydraulic structures. Short-term, high-intensity rainfall that occurs in inland areas with poor drainage often produces urban flash floods [7]. Densely populated areas have a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots increases runoff by reducing the amount of rain absorbed by the ground. During periods of heavy rainfall, storm drains may become overwhelmed and flood roads and buildings. Low spots, such as underpasses, underground parking garages, and basements are especially vulnerable to flash floods. Subway stations and rail lines are also vulnerable to flash floods [1]. The determination of the probable frequency of extreme rainfall events of different intensities and durations is the basic step in designing a flood control structure, in order to provide an economic size of the structure. Data providing information about return periods of extreme rainfall events of various intensities and durations are vital. Rainfall intensity-duration-frequency (IDF) is one of the most important tools in hydrology and hydraulic design used by engineers in planning, designing and operating rainwater infrastructures [5,6]. IDF relationships are suitable for estimating design storms (DS) to obtain peak discharge and hydrograph shape in any hydraulic design. Since rainfall characteristics are often used to design hydraulic structures and urban drainage system, reviewing and updating rainfall characteristics such as intensity, duration and frequency are essentially required. Therefore, this study also focuses on developing IDF curves and proposing empirical equations related with rainfall intensity and duration of various frequencies for selected station in Myanmar [2,8].

2. Background of the Study Area

Sagaing is the capital of Sagaing Region and located the Ayeyarwady River, 20 km to the south-west of Mandalay on the opposite bank of the river, Sagaing, with numerous Buddhist monasteries is an important religious and monastic centre It lies between North Latitude 22°18' and 21°56' and East Longitude 95°2' and 95°24'. Temperatures are very high throughout the year, although the winter months (December–February) are significantly milder (around 21°C in January). The early monsoon months from April to July are especially hot, with average high temperatures reaching 38.4 °C (101.1 °F) in April. Sagaing received 139 millimetres (5.5 in) of rainfall on 19 Oct 2011. This was a new record for rainfall within 24 hours in October in Sagaing for the last 47 years. The previous record was 135 millimetres (5.3 in) on 24 Oct 1967. The following Figure 1 shows the location map of the study area.

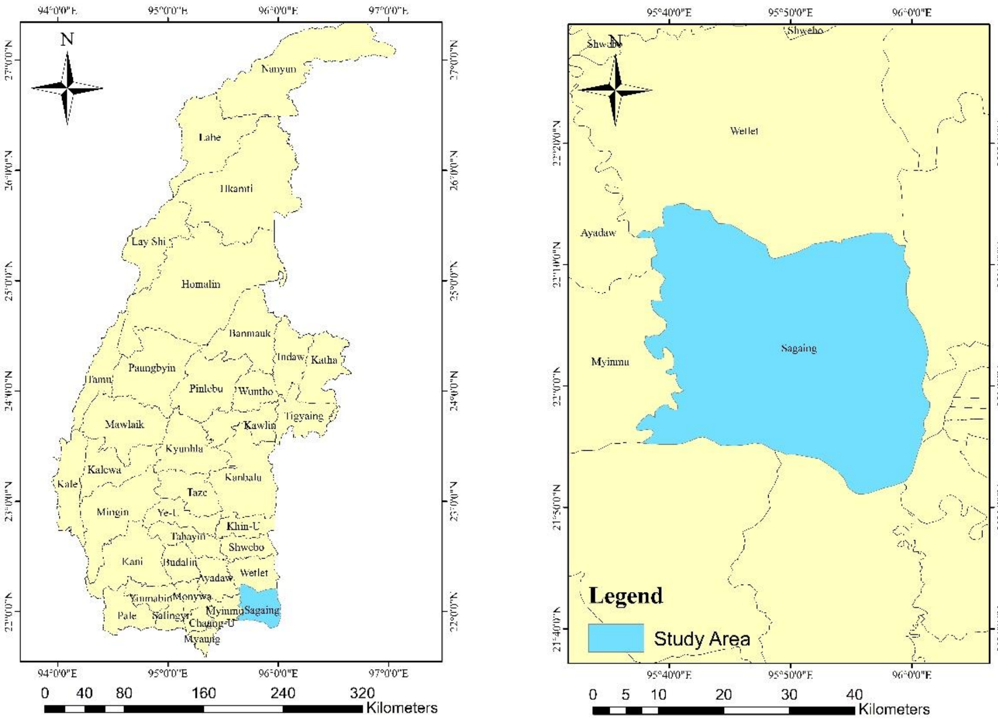

Figure 1: Location Map of Sagaing

3. Methodology

The daily 24 hour rainfall data for the years 1989 to 2018 was collected from DMH. It was analysed and the annual maximum 24 hour rainfall data was extracted as shown in Figure 2. This data was used for the estimation of Short Duration Rainfall Intensity Duration Frequency.

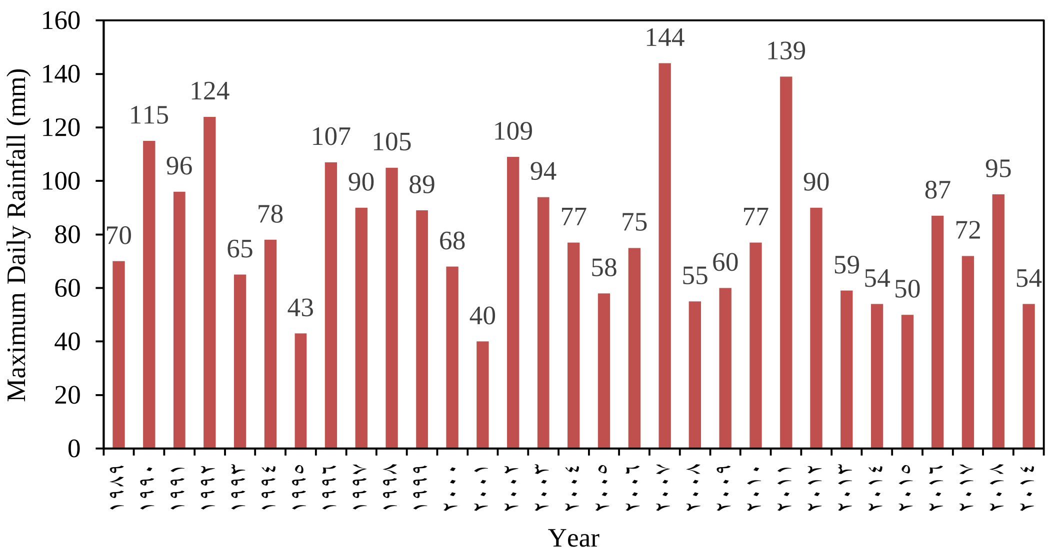

Figure 2: Daily Maximum Rainfall (1989-2018)

3.1. Empirical Reduction Formula

The annual maximum daily rainfall were converted into shorter duration (1/4, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12-hrs) values using Equation 1.

$$P_t = P_{24}\,(t / 24)^{1/3} \qquad (1)$$

where, P_t = the required precipitation depth in mm for the duration of t-hour

P_{24} = annual maximum daily rainfall (mm) and

T = the time duration (in hours) for the required precipitation depth.

3.2. Rainfall Intensity

Rainfall intensity is the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period. It is expressed in depth units per units time, usually as mm per hour (mm/hr).

$$I_t = P_t / T_D \qquad (2)$$

where, I_T = rainfall intensity

P_T = hourly rainfall depth

T_D = duration in hours.

The frequency of the rainfall is usually defined by reference to the annual maximum series, which consists of the largest values observed in each year [10].

3.3. IDF Empirical Equations

IDF empirical equations are the equations that estimate the maximum rainfall intensity for different duration and return period. IDF is a mathematical relationship between the rainfall intensity i, the duration t_d and the return period T.

$$i = \frac{a}{b + t_d} \qquad (3)$$

$$i = x^*(t_d)^{-y} \qquad (4)$$

where, i = the rainfall intensity in mm/hr,

t_d = the rainfall duration in min

a, b, x, and y are the fitting parameter. These empirical equation indicates that for a given return period the rainfall intensity decreases with increases in rainfall duration. The intensity duration function formulas are the empirical equations representing a relationship among maximum rainfall intensity and other parameters of interest such as rainfall duration and frequency [9].

3.4. Probability Distribution

Frequency analysis of hydrologic data use probability distributions related to the magnitude of extreme events to their frequency of occurrence. It is generally assumed that a hydrological variable has a certain distribution type. Some of the most important probability distributions are used in hydrology. Gumbel and Log Pearson Type III distributions were identified to be the most suitable for IDF construction [6].

A. Gumbel's Extreme Value Distribution

Gumbel distribution is used to analyze such variables as monthly and annual maximum values of daily rainfall and river discharge volumes, and also to describe droughts. The Gumbel distribution is used for extreme (maxima and minima values) respectively of hydrological variables. The importance of the Gumbel distribution in practice is due to its extreme value behavior. It has been applied either as the parent distribution or as an asymptotic approximation, to describe extreme wind speeds, rainfall, minimum temperature, floods, rainfall during droughts and geological problems etc [6,11].

The rainfall (P_T) corresponding to a given return period (T) using the Gumbel's Distribution is given by:

$$P_T = \sigma + KS \tag{5}$$

where, σ = average annual daily maximum rainfall.

S = standard deviation of annual daily maximum rainfall.

T = return period and

K = frequency factor given by:

$$K = -\frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right) \tag{6}$$

B. Log-Pearson Type III Distribution

The log-Pearson type 3 (LP3) distribution has been one of the most frequently used distributions for hydrologic frequency analyses since the recommendation of the Water Resources Council (1967, 1982) of the United States as to its use as the base method. The Water Resources Council also recommended that this distribution be fitted to sample data by using mean, standard deviation and coefficient of skewness of the logarithms of flow data [i.e., the method of moments (MOM)]. A large volume of literature on the LP3 distribution has since been published with regard to its accuracy and methods of fitting or parameter estimation. In past year, Phien and Jivajirajah (1984) applied LP3 distribution to annual maximum rainfall, annual streamflow and annual rainfall. The Log-Pearson Type III distribution is calculated using the general equation [5,10]:

$$P_T^* = P^*_{ave} + K_T S^* \quad (7)$$

$$P_{ave}^* = \frac{1}{n}\sum_{i=1}^{n} P^* \quad (8)$$

$$P^* = \log(P_i^*) \quad (9)$$

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

Where P_T^*= logarithmic extreme value of rainfall

Pave*= average of maximum precipitation corresponding to a specific duration

S*= standard deviation of P* data

K_T = Pearson 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 equation.

$$C_S = \frac{n\sum_{i=1}^{n}\left(P^* - P_{ave}^*\right)^3}{(n-1)(n-2)(S^*)^3} \quad (11)$$

3.5. Least Square Method

A line of best fit is a straight line that is the best approximation of the given set of data. It is used to study the nature of the relation between two variables. A line of best fit can be roughly determined using an eyeball method by drawing a straight line on a scatter plot so that the number of points above the line and below the line is about equal (and the line passes through as many points as possible). A more accurate way of finding the line of best fit is the least square method. Least square method is applied to find the parameter x and y for development of empirical equations correlating with intensity and duration [7]. Regression Analysis was applied to find the parameter a, b, x and y for the rainfall IDF empirical formula. Correlation coefficient (R) was estimated to find the best fit IDF empirical equation. For a specific return period the equation that gives R value nearer to 1 have the best fit [7].

$$y = a + bx \quad (12)$$

$$b = r\, SD_x/SD_y \quad (13)$$

$$a = \overline{Y} - b\overline{X} \quad (14)$$

where, r = correlation coefficient

y = least square regression line

b = the slope of the regression line

a = the intercept point of the regression line and the y-axis

$\overline{X}$ = mean of x value

$\overline{Y}$ = mean of y value

SD_x = standard deviation of x

SD_y = standard deviation of y

4. Results and Discussions

Frequency analysis for maximum daily rainfall are conducted using Equation 2.9. By using Equation 2.10, K value for different return periods are determined by Gumbel's and Log Pearson Type III Distribution. Also, the rainfall (P_t) corresponding of a given return period (T) is determined using Gumbel's Extreme Value Distribution. Table 1 and 2 give the rainfall for various return periods and K values for the Sagaing station. Rainfall for different return periods are used to change hourly rainfall to develop Intensity-Duration-Frequency (IDF) curve. Using empirical reduction formula Equation 2.1, shorter duration (1/4, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 hrs) rainfall series are generated from rainfall for different return periods and shown in Table 3 and 4. The IDF curves for different return by Gumbel and Log Pearson Type II distribution are shown in Figures 3 to 6 with semi log and log log scale.

Table 1: Rainfall for Various Return Periods at Sagaing Station by Gumbel's Method

Sagaing Station	Rainfall for Various Return Periods (mm)				
	5 years	10 years	25 years	50 years	100 years
K value	0.719	1.304	2.044	2.592	3.136
P	102.077	117.735	137.541	152.208	166.768

Table 2: Rainfall for Various Return Periods at Sagaing Station by Log Pearson Type III Methods

Sagaing Station	Rainfall for Various Return Periods (mm)				
	5 years	10 years	25 years	50 years	100 years
K value	0.848	1.264	1.698	1.973	2.215
P	103.97	119.17	137.41	150.37	162.82

Table 3: Hourly Rainfall for Sagaing (Extreme Value Extracted by Gumbel)

Duration(hr)	Hourly Rainfall data for Various Return Periods (mm/hr)				
	5 years	10 years	25 years	50 years	100 years
0.25	22.293	25.713	30.038	33.241	36.421
0.5	28.088	32.396	37.846	41.882	45.888
1	35.388	40.816	47.683	52.768	57.815
2	44.586	51.425	60.077	66.483	72.843
3	51.039	58.868	68.771	76.104	83.384
4	56.175	64.792	75.692	83.763	91.776
5	60.513	69.795	81.536	90.231	98.863
6	64.304	74.168	86.645	95.885	105.057
7	67.695	78.079	91.214	100.941	110.597
8	70.776	81.633	95.366	105.535	115.630
9	73.610	84.902	99.184	109.761	120.261
10	76.241	87.936	102.729	113.684	124.559
11	78.702	90.775	106.046	117.354	128.580
12	81.019	93.446	109.166	120.808	132.364

Table 4: Hourly Rainfall for Sagaing (Extreme Value Extracted by Log Pearson Type III)

Duration(hr)	Hourly Rainfall data for Various Return Periods (mm/hr)				
	5 years	10 years	25 years	50 years	100 years
0.25	22.706	26.027	30.011	32.839	35.559
0.5	28.608	32.792	37.811	41.375	44.802
1	36.044	41.316	47.639	52.129	56.446
2	45.412	52.054	60.021	65.678	71.118
3	51.984	59.588	68.707	75.183	81.410
4	57.216	65.585	75.622	82.749	89.603
5	61.634	70.649	81.461	89.139	96.522
6	65.496	75.076	86.565	94.725	102.570
7	68.949	79.034	91.130	99.719	107.978
8	72.087	82.631	95.278	104.258	112.893
9	74.974	85.940	99.093	108.433	117.413
10	77.654	89.012	102.635	112.308	121.610
11	80.160	91.885	105.948	115.934	125.536
12	82.519	94.589	109.066	119.345	129.230

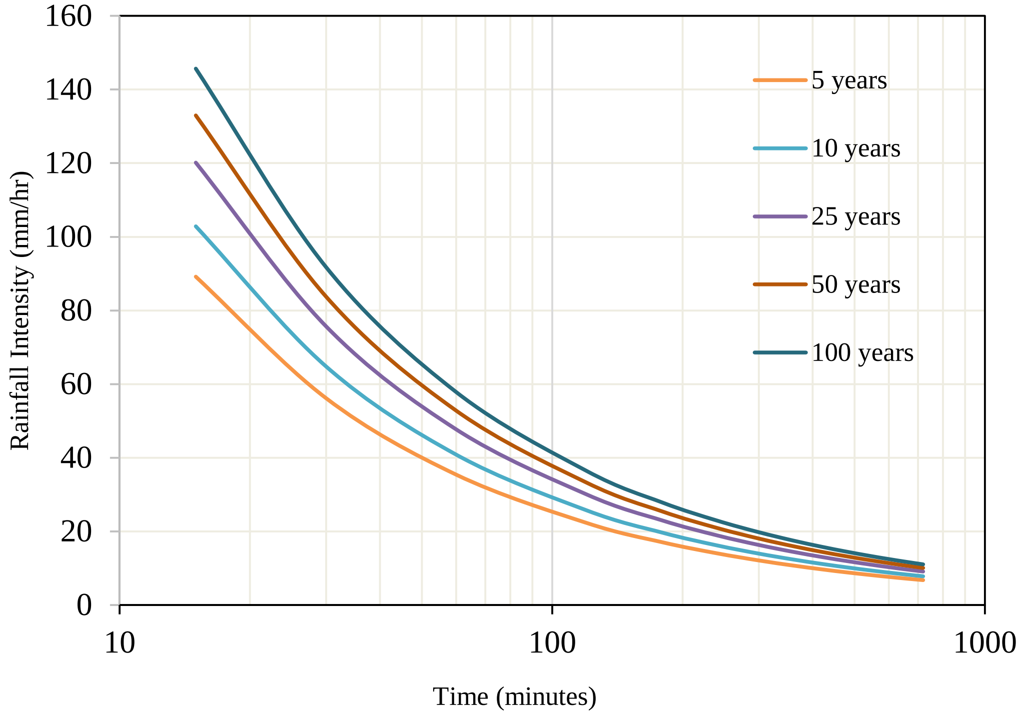

Figure 3: Intensity Duration Frequency Curve (semi-log) for Sagaing Station by Gumbel's Distribution

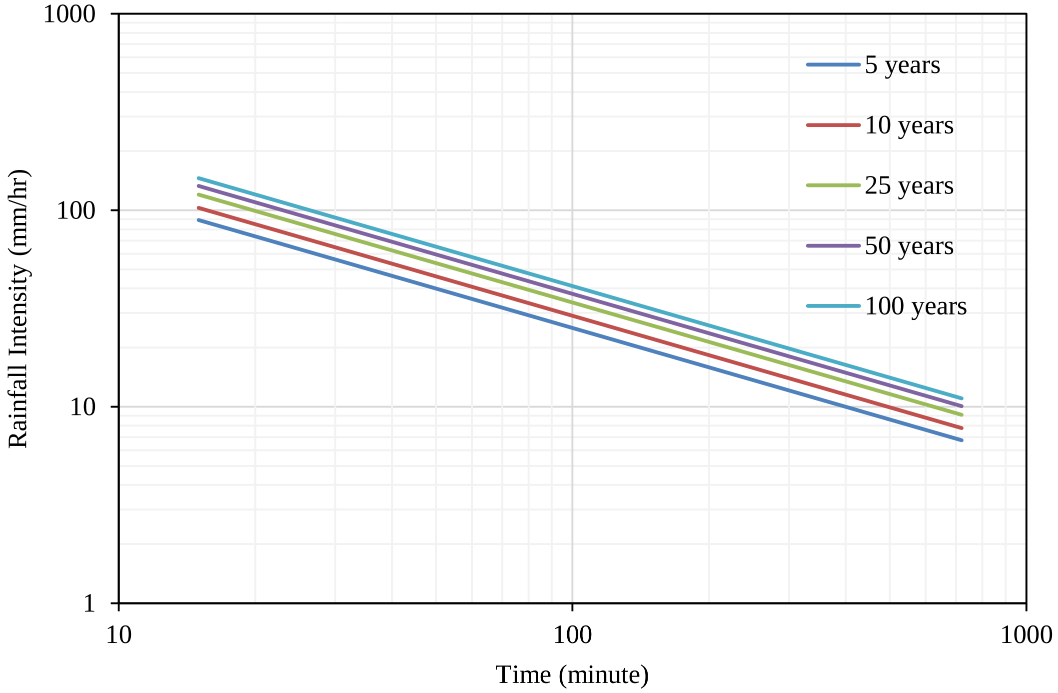

Figure 4: Intensity Duration Frequency Curve (log-log) for Sagaing Station by Gumbel's Distribution

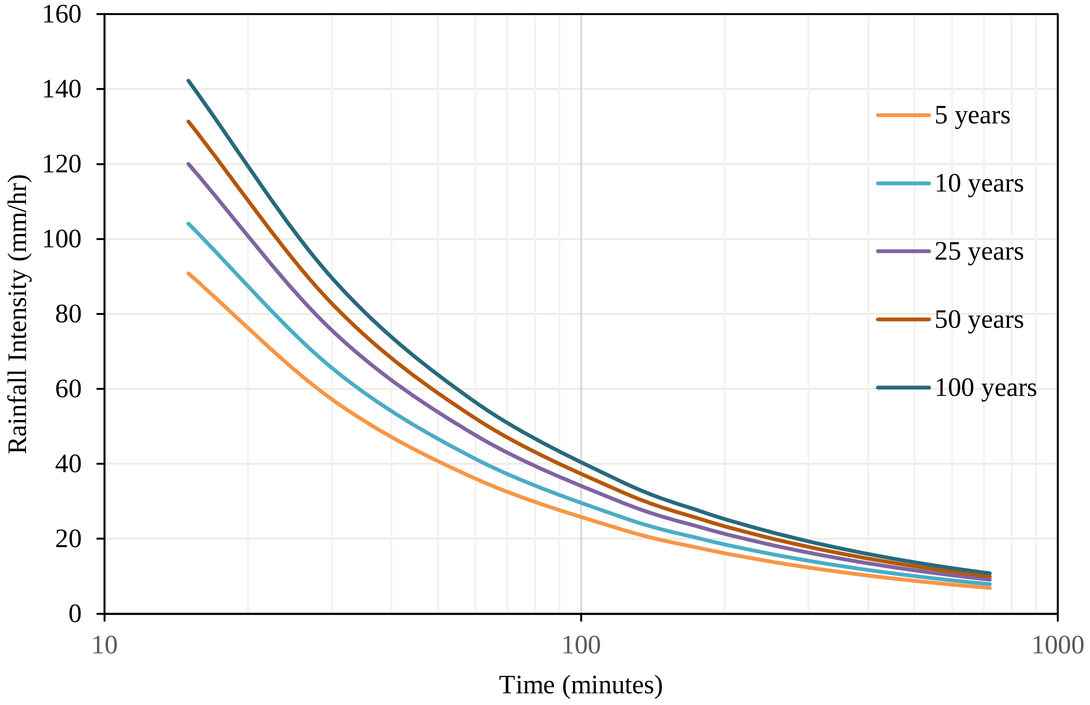

Figure 5: Intensity Duration Frequency Curve (semi-log) for Sagaing Station by Log Pearson Type III Distribution

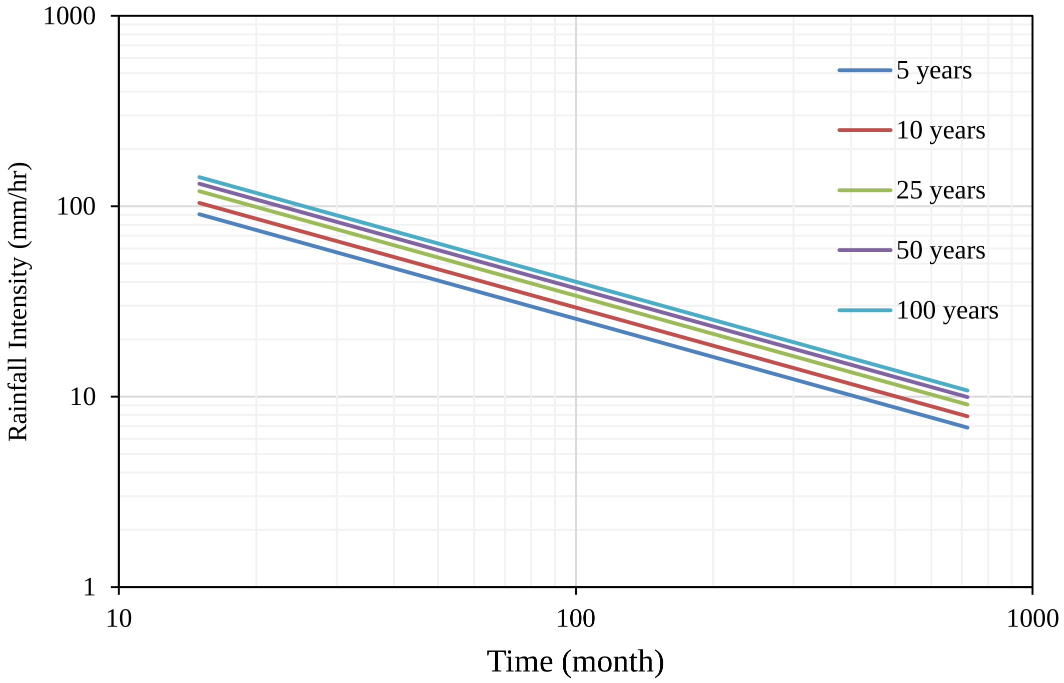

Figure 6: Intensity Duration Frequency Curve (log-log) for Sagaing Station by Log Pearson Type III Distribution

To develop the empirical equation regarding with intensity and duration, Equation 2 and least square method are used. Then, this equation is transformed in the form of taking logarithm to find x and y. Intensity and duration from Table 3 and 4 are used as dependent and independent variables for least square method. Then, Table 5 and 6 summarized empirical equations for different return periods and R values for Sagaing station (Gumbel's and Log Pearson Type III).

Table 5: Empirical Equations and Correlation Coefficient (R) by Gumbel's Method

Return period (yr)	x	y	Intensity, $i = x * (t_d)^{-y}$	Correlation Coefficient, R
5	547.27	0.67	$i = 547.27* (t_d)^{-0.67}$	-1
10	631.23	0.67	$i = 631.23* (t_d)^{-0.67}$	-1
25	727.42	0.67	$i = 727.42* (t_d)^{-0.67}$	-1
50	816.08	0.67	$i = 816.08* (t_d)^{-0.67}$	-1
100	894.15	0.67	$i = 894.15 * (t_d)^{-0.67}$	-1

Table 6: Empirical Equations and Correlation Coefficient (R) by Log Pearson Type III

Return period (yr)	x	y	Intensity, $i = x * (t_d)^{-y}$	Correlation Coefficient, R
5	557.42	0.67	$i = 557.42* (t_d)^{-0.67}$	-1
10	638.95	0.67	$i = 638.95* (t_d)^{-0.67}$	-1
25	736.74	0.67	$i = 736.74* (t_d)^{-0.67}$	-1
50	806.18	0.67	$i = 806.18* (t_d)^{-0.67}$	-1
100	872.95	0.67	$i = 872.95* (t_d)^{-0.67}$	-1

As a discussed, the calculated extreme rainfall value, P for Gumbel's and Log Pearson Type II are not differ and it is evidence that the value range from 102.077 to 162.82 for 5 years and 100 years return period. It is evident that the developed empirical equations correlating rainfall intensity and rainfall duration for different return periods have good correlation since R value are one for every station. The value of x is different, but y is the same for every return period because time duration (t_d) is the same for various return periods in every station. The value of x in the IDF equation, it is seen that the value range between 500 and 900 for both distribution methods. But the value of y remain the constant for different return period. The constant value x is not very different in both method and it has not very differ in 5, 10, 25 and 50 year but a little differ in 100 year return peroids. The use of IDF curves is cumbersome and hence a generalized empirical relationship was developed for two forms of equations through method of least squares. These IDF equations will help to estimate the rainfall intensity for any specific return period in Sagaing city in a short time and more easily. This study will help for planning and designing of any water resources project in Sagaing city specially the urban drainage management.

5. Conclusion

In this study, empirical reduction formula is used to convert hourly rainfall and intensities were determined. These estimated short duration rainfall data were used in Gumbel and Log-Pearson Type III probability distribution methods to determine the rainfall and their corresponding return periods. It was found in the study that R values for all probability function, was -1. It is noted that the extreme value by Gumbel and Log-Pearson value have good correlation. Then, IDF curves were constructed by using rainfall intensity and duration. While the curve-shaped graph are obtained when the data is plotted on semi-log paper, straight lines are obtained on log-log paper. Besides, rainfall intensity and duration were used to develop empirical equations related with rainfall intensity and duration. Therefore, the empirical equations for all stations under study were proposed by correlating rainfall intensity and duration using least square method. Finally, it is concluded that this study proposes the IDF curves and empirical equations which can be used as essential parameters in hydraulic design of urban drainage structures such as storm sewers, culverts and aqueducts and, planning for water resources projects.

References

[1] Rambabu Palaka, G. Parjwala P.: Development Of intensity Duration Frequenc Curves For Narsapur Mandal, Telangana State, India, (2016).

[2] Sipple, S. et al.: Bias Correction Methodology For Climate Impact Simulations, Ensemble bias correction, (2016).

[3] Logah, K Et Al,: Developing Short Duration Rainfall Intensity Frequency Curve ForAccra In Ghana, International Journal Of Latest Research In Engineering And Computing, 53 (2013) 67-73 (2013).

[4] Indian Institute of Scienc, Centre for Ecological Sciences, Energy and Wetlands research group, Study Area, Bangalore, Topography, Water Resources, and Meteorology, (Nov, 2012)

[5] MRashid Et A.: Modelling Of Short Duration Rainfall Intensity Duration Frequency Equation Sylhet

City In Bangladesh. Arpn Journal Of Science And Bangladesh, Arpn Journal Of Science And Technology, 74 (2012) 35-41 (2012)

[6] Jaya Rami Reddy “A text book of Hydrology”, University Science Press, New Delhi, Design Flood, 14: 453 – 489 (2011).

[7] Eman Ahmed Hassan El-Sayed. “Generation of Rainfall Intensity Duration Frequency Curves For Ungauged Sites”, Nile Basin Water Science & Engineering Journal,”4 (1), 112-124 9 (2011).

[8] MRashid Et A.: Modelling Of Short Duration Rainfall Intensity Duration Frequency Equation Sylhet City In Bangladesh. Arpn Journal Of Science And Bangladesh, Arpn Journal Of Science And Technology, 74 (2012) 35-41 (2012)

[9] Ranatunga, D. G. L., (2001) “Towards More Efficient Hydraulic and Hydrological Design of Cross Drainage Structures using New Developed Intensity Duration Frequency Equations”, Transactions 2001, Volume I – Part B, The Institution of Engineers, Sri Lanka 2001, pp.01-12.

[10] Dahman, E. R. and Hall, M. J. (1990) Screening of Hydrological Data: Tests for Stationarity and Relative Consistency, IILRI, The Nethrlands.

[11] Dwyer, I. J. & Reed, D. W. “Allowance for Discretization in Hydrological and Environmental Risk Estimation (ADHERE)”, Report No.13, Institute of Hydrology, Wallingford, 1995, UK.