Development of Rainfall Intensity Duration Frequency (R-IDF) Equations and Curves for Seven Divisions in Bangladesh

Munshi Md. Rasel, Sayed Mukit Hossain

Abstract— Due to proliferation in greenhouse gases hydrologic cycle is changing day by day which is causing variations in intensity, duration and frequency of rainfall events. By pinpointing the potential effects of climate change and acclimating to them is one way to reduce urban susceptibility. Since rainfall characteristics are often used for planning and design of various water resources project, reviewing and updating rainfall characteristics (i.e., Intensity–Duration–Frequency (IDF) curves) for future climate situations is necessary. The target of this study was to develop Rainfall IDF empirical equations and curves for seven divisions of Bangladesh to estimate the rainfall intensity for any duration and any return period with least effort. Yearly maximum rainfall data for last 41 years (1974-2014) from Bangladesh Meteorological Department (BMD) was used in this study. Indian Meteorological Department (IMD) empirical reduction formula was used to estimate the short duration rainfall intensity from yearly maximum rainfall data. Gumbel's Extreme-Value Distribution method was used to develop IDF curves and equations. It was found that intensity of rainfalls decreases with increase in rainfall duration. Further, a rainfall of any given duration will have a larger intensity if its return period is large. In other words, for a rainfall of given duration, rainfalls of higher intensity in that duration are rarer than rainfalls of smaller intensity.

Index Terms— Bangladesh Meteorological Department (BMD), Climate Change, Rainfall Intensity, Gumbel's Extreme Value Distribution Method, Rainfall Duration, Rainfall Frequency, Return Period.

1 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) [11]. IDF curves are used to aid the engineers while designing urban drainage works. The establishment of such relationships was done as early as 1932 (see Chow (1988) and Dupont and Allen (2006)) [11 & 12]. Since then, many sets of relationships have been constructed for several parts of the globe. However, such relationships have not been accurately constructed in many developing countries (Koutsoyiannis et al., 1998) [13]. In Bangladesh water logging and flood is a common problem during Monsoon period because of inadequate drainage system. In order to solve this problem new drainage design is needed where rainfall data of different duration is needed. But due to instrumental limitation these data were not available. This study was conducted to develop IDF curves and equations for various duration of rainfall in seven divisions (Dhaka, Chittagong, Barisal, Khulna, Rajshahi, Rangpur, Sylhet) of Bangladesh. In the present study, annual maximum rainfall series is considered for Rainfall Frequency Analysis (RFA). Rainfall in a region can be characterized if the intensity, duration and frequency of the diverse storms occurring at that place are known [1-3]. The frequency-data for rainfalls of various durations, so obtained, can be represented by IDF curves, which give a plot of rainfall intensity versus rainfall duration and recurrence interval.

Matin *et al*. (1984), in their study developed the IDF curve for North-East region Bangladesh and also observed that the rainfall data in this region follow Gumbel's Extreme Value Distribution [4]. Chowdhury *et al*. (2007) developed the short duration rainfall IDF curve for Sylhet with return period of 2, 5,10,20,50, and 100 years [5]. Kim *et al* improved the accuracy of IDF curves by using long and short duration separation technique [6]. They derived IDF curves by using cumulative distribution function (CDF) for the site under consideration using multi-objective genetic algorithm. Khaled *et al* applied L-moments and generalized least squares regression methods for estimation of design rainfall depths and development of IDF relationships [7]. Rashid *et al* applied Pearson Type-III distribution for modelling of short duration rainfall and development of IDF relationships for Sylhet City in Bangladesh [8].

In probability theory, extreme value distributions namely Gumbel, Frechet and Weibull are generally considered for frequency analysis of meteorological variables. On the other hand, Atomic Energy Regulatory Board (AERB) guidelines described that the Order Statistics Approach (OSA) is the most appropriate method for determination of parameters of Gumbel and Frechet distributions [9]. In this present study Gumbel's Extreme Value Distribution method is used to develop IDF curves and equations. In this context, an attempt has been made to estimate the rainfall for different return periods for different durations of 'n' such as 10-min, 20-min, 30-min, 60-min, 120-min, 180-min, 360-min, 720-min, 1440-min adopting Gumbel distributions for development of IDF relationships for seven divisions of Bangladesh. Model performance indicators

- *Munshi Md. Rasel is working as a lecturer in Ahsanullah University of Science and Technology, Bangladesh. E-mail: munshimdrasel@gmail.com*
- *Sayed Mukit Hossain currently pursuing masters degree program inIslamic University of Technology, Bangladesh. He is working as a lecturer in Ahsanullah University of Science and Technology, Bangladesh. E-mail: mukit1271@gmail.com*

(MPIs) such as correlation coefficient (R) is used to analyze the performance of the developed IDF relationships by Gumbel distributions for estimation of rainfall intensity for the stations under study.

2 LOCATION

The study area is Bangladesh. Its position is between latitude 20° 34′ - 26° 38′ N, longitude 88° 01′ -92° 41′ E. For the convenience of analysis the study is based on available data of 35 BMD (Bangladesh Meteorological Department) stations which are compiled into seven divisions of Bangladesh. Past 41 years data (1974-2014) is used in this study.

Fig. 1: Seven Divisions of Bangladesh

3 DATA COLLECTION AND METHODOLOGY

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

3.1 ESTIMATION OF SHORT DURATION RAINFALL

Indian Meteorological Department (IMD) use an empirical reduction formula (EQ. 1) for estimation of various duration like 1-hr, 2-hr, 3-hr, 5-hr, 8-hr rainfall values from annual maximum values. Chowdhury et al (2007), used Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall from daily rainfall data in Sylhet city and found that this formula give the best estimation of short duration rainfall [5]. In this study this empirical formula (EQ. 1) was used to estimate short duration rainfall in all the seven divisions of Bangladesh. Where, P_t is the required rainfall depth in mm at t-hr duration, P_{24} is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in hr.

$$P_t = P_{24}\sqrt[3]{\frac{t}{24}} \quad (1)$$

3UTION

/ was selected to perform the umbel theory of distribution on for IDF analysis owing to na. It is relatively simple and um values or peak rainfalls). e 2, 5, 10, 25, 50 and 100 year ı period and requires several ion P_T (in mm) for each duod T (in year) is given by the

$$P_T = P_{ave} + KS \quad (2)$$

Where K is Gumbel frequency factor given by:

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

Where P_{ave} is the average of the maximum precipitation corresponding to a specific duration.
In utilizing Gumbel's distribution, the arithmetic average in Eq. (2) is used:

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (4)$$

Where Pi is the individual extreme value of rainfall and n is the number of events or years of record. The standard deviation is calculated by EQ. (5) computed using the following relation:

$$S=[\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{ave})^2]^{1/2} \quad (5)$$

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_T (in mm/h) for return period T is obtained from:

$$I_T = \frac{P_t}{T_d} \quad (6)$$

Where T_d is 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. An alternative data format for rainfall frequency studies is that based on the peak-over threshold

concept, which consists of all precipitation amounts above certain thresholds selected for different durations. Due to its simpler structure, the annual-maximum-series method is more popular in practice [10].

4 Result and Discussion

From the raw data, the maximum rainfall (P) and the statistical variables (average and standard deviation) for each duration (10, 20, 30, 60, 120, 180, 360, 720, 1440 min) were calculated. Various duration of rainfalls like 10, 20, 30, 60, 120, 180, 360, 720 and1440 min were estimated from annual maximum 24 hours rainfall data using Indian Meteorological empirical reduction formula. These estimated various duration data were used in Gumbel's Extreme Probability Method to determine rainfall (P_T) values and intensities (I_T) for seven divisions of Bangladesh. At table 1 rainfall frequency (P_T) values and intensities (I_T) for different durations and return periods using Gumbel Method for Dhaka Division was computed. Similarly for all other division rainfall frequency (P_T) values and intensities (I_T) for different durations and return periods using Gumbel Method was computed. From Table 2 it was found that intensity of rainfall decreases with increase in storm duration. Further, a rainfall of any given duration will have a larger intensity if its return period is large. In other words, for a rainfall of given duration, rainfalls of higher intensity in that duration are rarer than rainfalls of smaller intensity. After finding out the rainfall (P_T) values and intensities (I_T) in Fig. 2, 3, 4, 5, 6, 7, 8 Rainfall IDF curves are developed for seven divisions of Bangladesh. Then finally for each division for each return period an equation has been developed, shown in Table 2 to table 8. It was found that the correlation coefficient for each equation is 1 which indicates a strong relationship in IDF equations.

Table 1: Computed frequency rainfall (P_T) values and intensities (I_T) for different durations and return periods using Gumbel Method for Dhaka Division.

10 min (Duration)				**20 min (Duration)**				**30 min (Duration)**			
Pave		24.61mm		Pave		31.00mm		Pave		35.49mm	
S		11.12		S		14.01		S		16.03	
Tr (year)	K	P_T (mm)	I_T (mm/hr)	Tr (year)	K	P_T (mm)	I_T (mm/hr)	Tr (year)	K	P_T (mm)	I_T (mm/hr)
2	-0.164	22.78	136.70	2	-0.164	28.70	86.11	2	-0.164	32.86	65.72
5	0.719	32.60	195.60	5	0.719	41.07	123.22	5	0.719	47.02	94.03
10	1.305	39.11	234.68	10	1.305	49.28	147.85	10	1.305	56.41	112.82
25	2.044	47.33	283.97	25	2.044	59.64	178.91	25	2.044	68.26	136.51
50	2.592	53.42	320.52	50	2.592	67.31	201.94	50	2.592	77.04	154.08
100	3.137	59.48	356.87	100	3.137	74.95	224.85	100	3.137	85.78	171.55
60 min (Duration)				**120 min (Duration)**				**180 min (Duration)**			
Pave		44.71mm		Pave		56.34mm		Pave		64.49mm	
S		20.20		S		25.45		S		29.13	
Tr (year)	K	P_T (mm)	I_T (mm/hr)	Tr (year)	K	P_T (mm)	I_T (mm/hr)	Tr (year)	K	P_T (mm)	I_T (mm/hr)
2	-0.164	41.40	41.40	2	-0.164	52.17	26.08	2	-0.164	59.71	19.90
5	0.719	59.23	59.23	5	0.719	74.64	37.32	5	0.719	85.43	28.48
10	1.305	71.07	71.07	10	1.305	89.55	44.78	10	1.305	102.50	34.17
25	2.044	86.00	86.00	25	2.044	108.36	54.18	25	2.044	124.03	41.34
50	2.592	97.07	97.07	50	2.592	122.31	61.15	50	2.592	139.99	46.66
100	3.137	108.08	108.08	100	3.137	136.18	68.09	100	3.137	155.87	51.96
360 min (Duration)				**720 min (Duration)**				**1440 min (Duration)**			
Pave		81.25mm		Pave		102.37mm		Pave		128.98mm	
S		36.71		S		46.25		S		58.27	
Tr (year)	K	P_T (mm)	I_T (mm/hr)	Tr (year)	K						I_T n/hr)
2	-0.164	75.23	12.54	2	-0.164						.98
5	0.719	107.64	17.94	5	0.719						.12
10	1.305	129.16	21.53	10	1.305						.54
25	2.044	156.29	26.05	25	2.044						.34
50	2.592	176.40	29.40	50	2.592						.67
100	3.137	196.41	32.73	100	3.137						.99

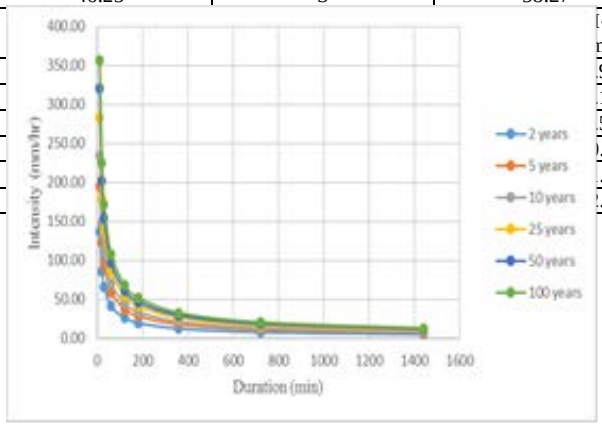

Fig. 2: Rainfall IDF curve for Dhaka Division

Table 2: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Dhaka Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 634.47x^{-0.667}$	1
5	$y = 907.84x^{-0.667}$	1
10	$y = 1089.3x^{-0.667}$	1
25	$y = 1318x^{-0.667}$	1
50	$y = 1487.7x^{-0.667}$	1
100	$y = 1656.4x^{-0.667}$	1

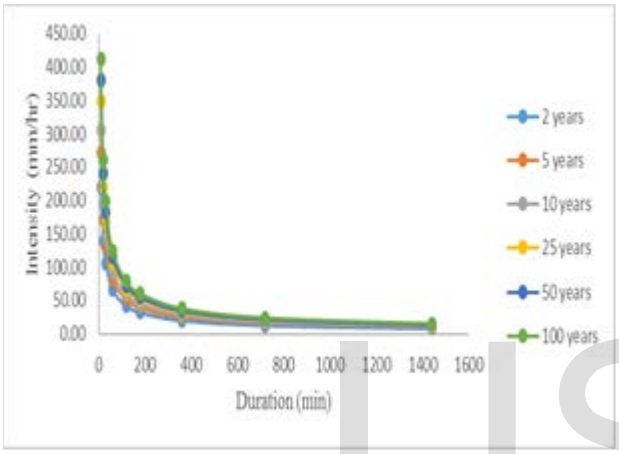

Fig. 3: Rainfall IDF curve for Sylhet Division

Table 3: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Sylhet Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 1023.1x^{-0.667}$	1
5	$y = 1262.4x^{-0.667}$	1
10	$y = 1421.2x^{-0.667}$	1
25	$y = 1621.5x^{-0.667}$	1
50	$y = 1770x^{-0.667}$	1
100	$y = 1917.7x^{-0.667}$	1

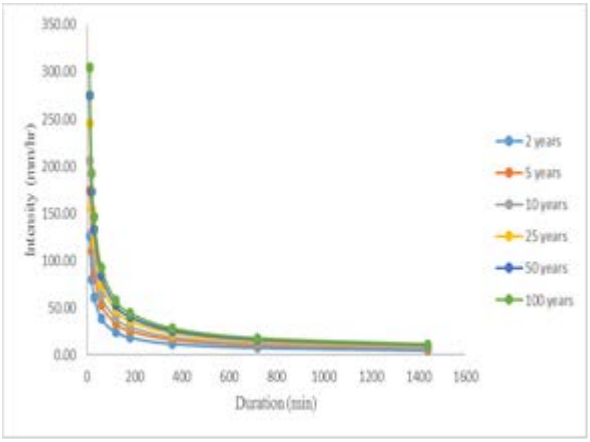

Fig. 4: Rainfall IDF curve for Rajshahi Division

Table 5: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Rajshahi Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 903.7x^{-0.667}$	1
5	$y = 1203.4x^{-0.667}$	1
10	$y = 1402.4x^{-0.667}$	1
25	$y = 1653.2x^{-0.667}$	1
50	$y = 1839.2x^{-0.667}$	1
100	$y = 2024.2x^{-0.667}$	1

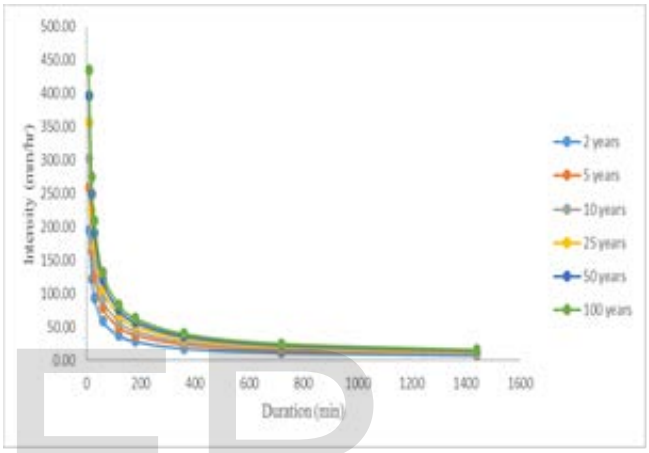

Fig. 5: Rainfall IDF curve for Rangpur Division

Table 4: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Rangpur Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 903.7x^{-0.667}$	1
5	$y = 1203.4x^{-0.667}$	1
10	$y = 1402.4x^{-0.667}$	1
25	$y = 1653.2x^{-0.667}$	1
50	$y = 1839.2x^{-0.667}$	1
100	$y = 2024.2x^{-0.667}$	1

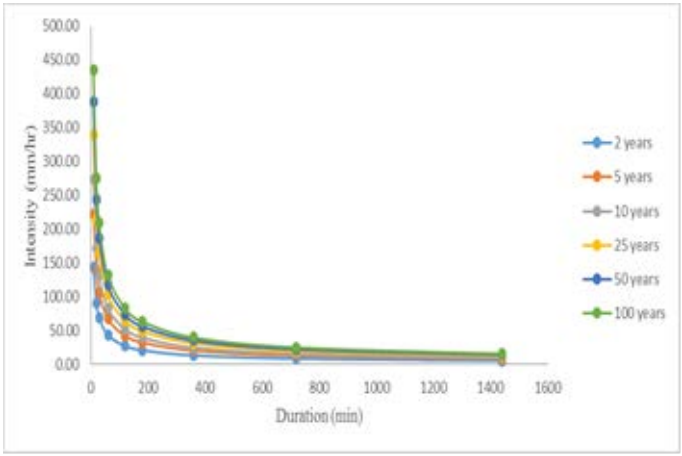

Fig. 6: Rainfall IDF curve for Khulna Division

Table 6: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Khulna Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 665.27x^{-0.667}$	1
5	$y = 1028.8x^{-0.667}$	1
10	$y = 1270x^{-0.667}$	1
25	$y = 1574.3x^{-0.667}$	1
50	$y = 1799.9x^{-0.667}$	1
100	$y = 2024.2x^{-0.667}$	1

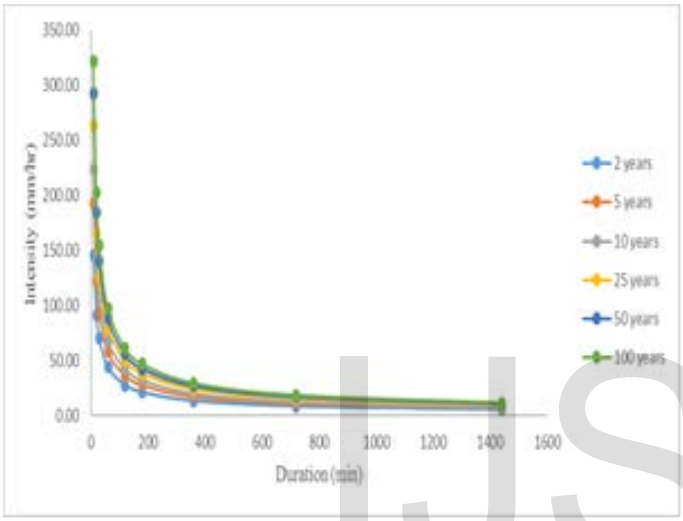

Fig. 7: Rainfall IDF curve for Barisal Division

Table 7: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Barisal Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 674.76x^{-0.667}$	1
5	$y = 893.85x^{-0.667}$	1
10	$y = 1039.2x^{-0.667}$	1
25	$y = 1222.6x^{-0.667}$	1
50	$y = 1358.6x^{-0.667}$	1
100	$y = 1493.8x^{-0.667}$	1

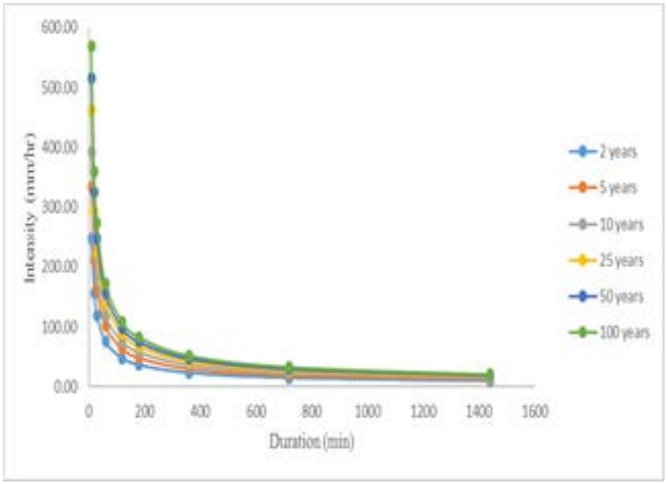

Fig. 8: Rainfall IDF curve for Chittagong Division

Table 8: Rainfall IDF empirical equation for respective return period and their correlation coefficient, R for Chittagong Division

Return Period (yr)	Equation	Correlation Coefficient, R
2	$y = 1151.8x^{-0.667}$	1
5	$y = 1551x^{-0.667}$	1
10	$y = 1816x^{-0.667}$	1
25	$y = 2150.1x^{-0.667}$	1
50	$y = 2397.9x^{-0.667}$	1
100	$y = 2644.3x^{-0.667}$	1

5 CONCLUSIONS

This research presents some insight into the way in which the rainfall is estimated in Bangladesh. Since Bangladesh has different climatic conditions from division to division, a relation for each division has to be obtained to estimate rainfall intensities for different durations and return periods ranging between 2 and 100 years. The parameters of the design rainfall intensity for a given period of recurrence were estimated for each division in this study. The results obtained showed a good match between the rainfall intensity computed by the method used and the values estimated by the calibrated formula with a correlation coefficient of greater than 0.98. This indicated the goodness of fit of the formula to estimate IDF curves in the region of interest for durations varying from 10 to 1440 min and return periods from 2 to 100 years. This study will be helpful in many design problems related to watershed management, such as runoff disposal and erosion control, it is necessary to know the rainfall intensities of different durations and different return periods.

6 ACKNOWLEDGEMENT

Authors are indebted to the Bangladesh Meteorological Department (BMD) for providing the necessary meteorological data.

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