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Development of Rainfall Intensity-Duration-Frequency Relationship And Isohyetal Map For Bangladesh

#1Mohammed Alauddin, *2Rokshana Pervin, #3Farhana Mustari

#1Professor, Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur 1707, Bangladesh
**2Assistant Professor, Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur 1707, Bangladesh*
#3Deputy Director, Department of Environment, Ministry of Environment, Forest and climate change, Dhaka, Bangladesh

Abstract
Waterlogging and floods are common problems in Bangladesh during the monsoon because of inadequate drainage with the increasing frequency of extreme rainfall. Rainfall data is important for the hydrologic design of any water resources projects to minimize water-related disasters. This study analyses the available rainfall data to develop an Intensity-Duration-Frequency (IDF) relationship for eight divisions of Bangladesh. The IDF relations show that Chittagong and Sylhet are the areas of high rainfall compared to other areas, and the lowest rainfall intensity is found in the Rajshahi region. Other areas like Dhaka, Barisal, Mymensingh, Khulna, and Rangpur have relatively less rainfall. Also, isohyetal maps are made for several durations of storms and for different return periods to extract rainfall data at any location of the country to help designing water resources projects.

Keyword: *IDF relationship, Isohyetal map, Rainfall*

I. INTRODUCTION

Bangladesh is a low-lying delta, where irregularities and uncertainties in rainfall events are being observed in recent years. The country is facing tremendous problems related to water, particularly water logging and floods during the rainy season. For solving these problems, the appropriate hydrologic design is necessary based on the available rainfall data. However, in many cases, these data are not accessible because of instrumental restrictions. Therefore, the hydrologic tool, rainfall Intensity-Duration-Frequency (IDF) model, is very effective in planning, designing, and operating water resources projects. The frequency of rainfall data for different durations can be signified by IDF curves, which give a plot of rainfall intensity against rainfall duration for different recurrence intervals. Furthermore, the IDF curves are used as an aid when designing drainage structures for any engineering project. The curves allow the engineers to design safe and economical flood and drainage congestion measures.

The first attempts to generate regional IDF curves for Slovakia [1]. A comprehensive IDF curve based on 68 stations covering the area of Slovakia was generated using the data mostly from the period of 1931–1960 [2]. Separation of long and short-duration rainfall is important for the accuracy of IDF curves. Kim et al. were used a multi-objective genetic algorithm and cumulative distribution function (CDF) for deriving the IDF curves [3]. In recent studies, many authors tried to relate the IDF relationship to the synoptic meteorological circumstances in the zone of hydrometric stations [4].

A number of studies were conducted for generating IDF curves for Bangladesh using several methods. Gumbel's Extreme Value Distribution method was used to generate IDF curves [5] and many others. Furthermore, The IDF curves for short-duration rainfall were generated over the Sylhet division with return periods of 2, 5, 10, 20, 50, and 100 years [6]. Rasel and Islam were analyzed daily rainfall data to obtain IDF curves for the North-Western region of Bangladesh [7]. The IDF curves were developed for the central region of Bangladesh by using two common frequency analysis techniques such as Gumbel and Log Pearson Type III (LPTIII) distribution [8]. Although substantial studies were conducted to generate IDF curves over Bangladesh, most studies were carried out for particular areas and short return periods. Hence, further studies are required to generate IDF curves for the whole country considering longer return periods and various rainfall durations so that people from any part of the country can utilize the curves and maps in making a hydrologic design for water resources projects. In addition, to understand the rainfall IDF relationship and the effect of rainfall spatially, isohyetal maps generation is essential [10]. The estimation of the total depth and intensity of rainfall over the particular area can be easily presented by isohyetal maps.

Therefore, the present study is mainly aimed at developing an intensity-duration-frequency relationship with curves for major divisions/cities of Bangladesh separately and showing the spatial distribution of rainfall by isohyetal maps all over the country.

II. METHODOLOGY

In this study, rainfall records of 43 years (1975 to 2017) were used, which were collected from the Meteorological Department of Bangladesh, where the data of daily rainfall depth were available. First, the depth of rainfall for different durations was calculated from these. To represent the IDF relationship for a division, the Thiessen Polygon method was used to determine the average intensity for the area. Gumbel's Extreme Value Distribution method was used for the frequency analysis to develop the relationship between rainfall intensity and storm duration for different return periods.

A. Short Duration Rainfall

Indian Meteorological Department (IMD) uses an empirical equation. Eqn. (1) for estimating rainfall intensity. Chowdhury et al. were 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 gave the best estimation of short-duration rainfall [6]. Therefore, in the current study, the same formula was used to estimate the short duration rainfall for various durations such as 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 6 hr, and 12 hr from the annual maximum daily rainfall found from daily rainfall records at various weather stations.

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

Where Pt is the required rainfall depth in mm at t-hr duration, P24 is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in an hour.

B. Averaging of Maximum Rainfall

Multiple weather stations are placed in some regions. The Thiessen Polygon method was used to estimate average rainfall over that area. In this method, the recorded rainfall at each rain gauge station is given a weightage according to its position with respect to the boundary of the area. The average intensity of rainfall over the area is expressed in the equation as follows:

$$\boldsymbol{P_{avg} = \frac{P_1 A_1 + P_2 A_2 + \ldots + P_n A_n}{A_1 + A_2 + \cdots + A_n}} \quad \ldots\ldots(2)$$

Where $\boldsymbol{P_1}$, $\boldsymbol{P_2}$, …, $\boldsymbol{P_n}$ are the intensities of recorded rainfall at the respective stations *1, 2, .., n* and $\boldsymbol{A_1}$, $\boldsymbol{A_2}$, …, $\boldsymbol{A_n}$ are the areas of the Thiessen Polygons, respectively.

C. Gumbel Theory of Distribution

The most widely used statistical method, Gumbel distribution, which is an extreme value distribution, is used to model maximums and minimums. This method has been used to predict the extreme rainfall events that can occur after a certain age. The Gumbel method calculates the intensities of rainfall for different durations with recurrence intervals of 2, 5, 10, 25, 50, and 100 years. A precipitation PT (in mm) for each duration with a specified return period T (in a year) is given by the following equation:

$$\boldsymbol{P_T = P_{avg} + KS} \quad \ldots\ldots(3)$$

where *K* is the Gumbel frequency factor. The factor is a function of the return period, and sample size, when multiplied by the standard deviation, gives the departure of rainfall of desired return period from the average. *K* is given by:

$$\boldsymbol{K = -\frac{\sqrt{6}}{\pi}[0.5772 + ln[ln[T/(T-1)]]]} \quad \ldots\ldots(4)$$

P_{avg} is the average of the maximum precipitation corresponding to a specific duration. For using Gumbel's distribution, the arithmetic average in equation (iii) is used as follows:

$$\boldsymbol{P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P_i} \quad \ldots\ldots(5)$$

where P_i is the extreme individual value of rainfall and *n* is the number of events or years of record. The standard deviation *S* is calculated by using the following equation:

$$\boldsymbol{S = \left[\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{avg})^2\right]^{\frac{1}{2}}} \quad \ldots\ldots(6)$$

Then the rainfall intensity, I_T (in mm/hr) for return period *T* is obtained from:

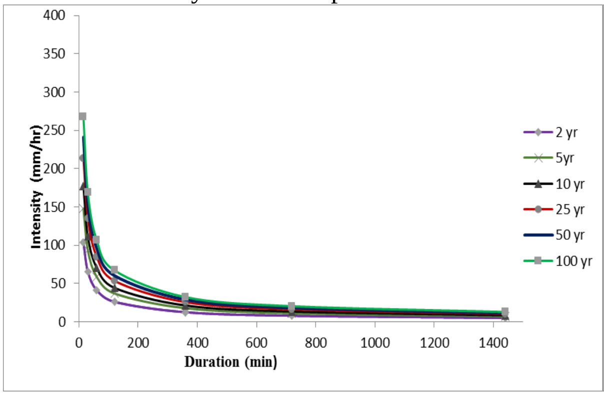
$$\boldsymbol{I_T = \frac{P_T}{T_d}} \quad \ldots\ldots(7)$$

where T_d is the duration in hours.

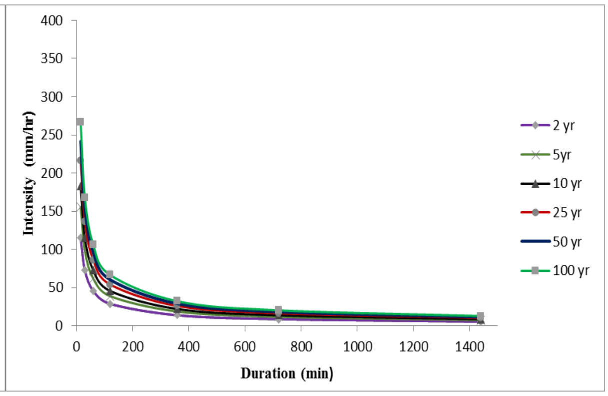
III. RESULTS AND DISCUSSION

The purpose of this study was to develop IDF curves for eight divisions of Bangladesh and derive an equation for each division to utilize the rainfall data for designing water resources projects in the country. Rainfall estimates in mm and their intensities in mm/hr for various return periods and different durations were evaluated using the method mentioned in the preceding section.

From the raw data, the maximum rainfall and the statistical variables (average and standard deviation) for each duration (15, 30, 60, 120, 360, 720, 1440 min) were calculated. These estimated rainfall data of various durations were used in Gumbel's Extreme Value Distribution method to determine rainfall (PT) values and intensities (IT) for several frequencies for eight cities of Bangladesh. From Fig. 1, it was found that higher intensity of rainfall occurs for low to the high duration of rainfall in Chittagong city: 170.27 mm/hr for 2 years return period, 228.39 mm/hr for 5 years return period, 266.96 mm/hr for 10 years return period, 315.61 mm/hr for 25 years return period, 351.68 mm/hr for 50 years return period and 387.56mm/hr for 100 years return period and for rainfall duration of 15 minutes. Again, in Chittagong city, 8.12 mm/hr for 2 years return period, 10.89 mm/hr for 5 years return period, 12.73 mm/hr for 10 years return period, 15.05 mm/hr for 25 years return period, 16.77 mm/hr for 50 years return period and 18.48 mm/hr for 100 years return period for rainfall duration 1440 minutes or 1 day. Sylhet is found as the area of the second-highest rainfall intensity among eight cities. However, Rajshahi city is found as the minimum rainfall area in Bangladesh.



(a)



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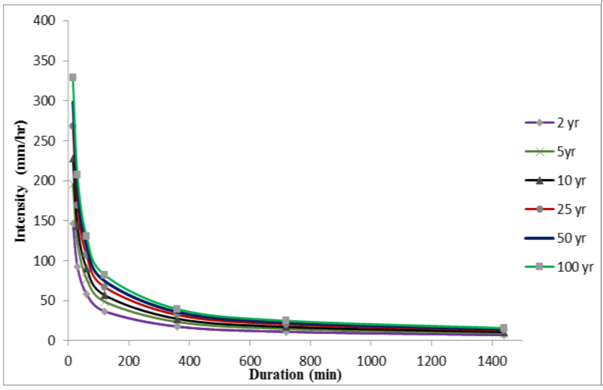

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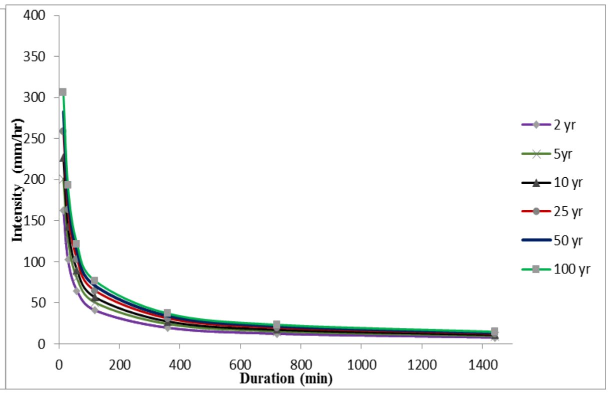

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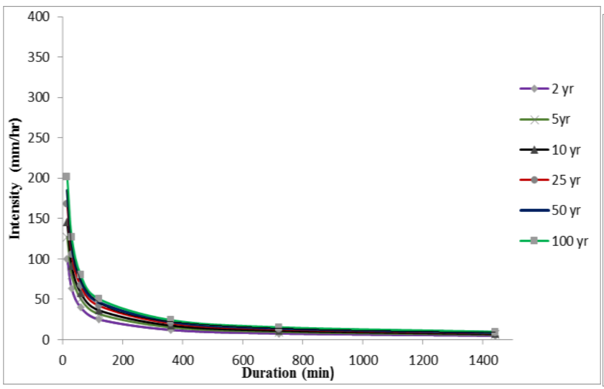

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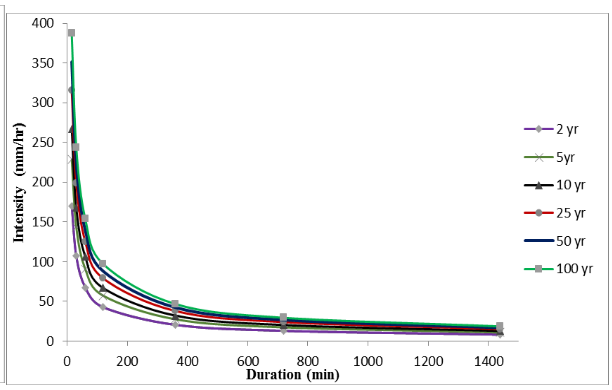
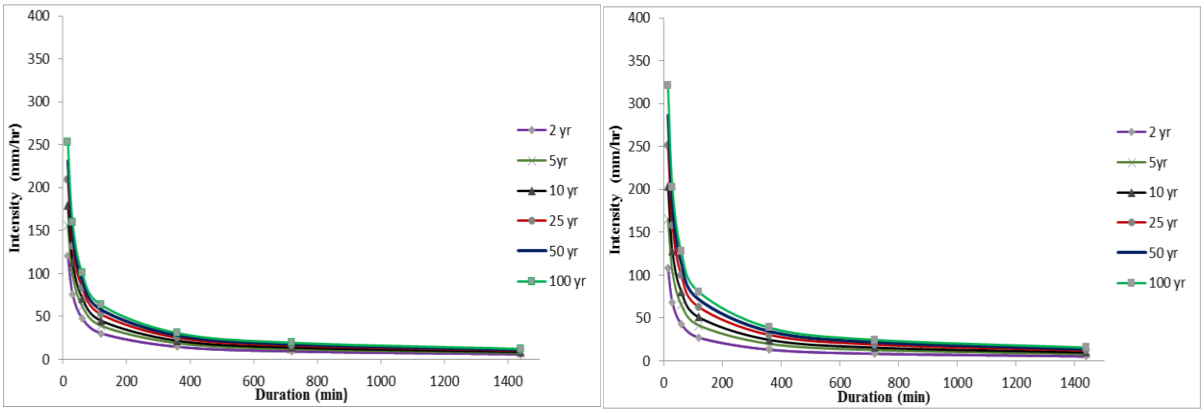


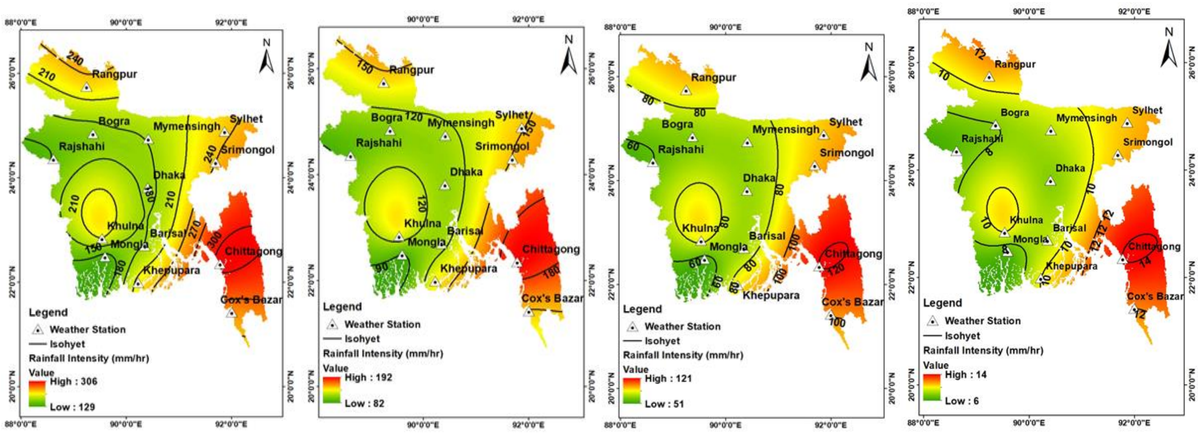
(f)



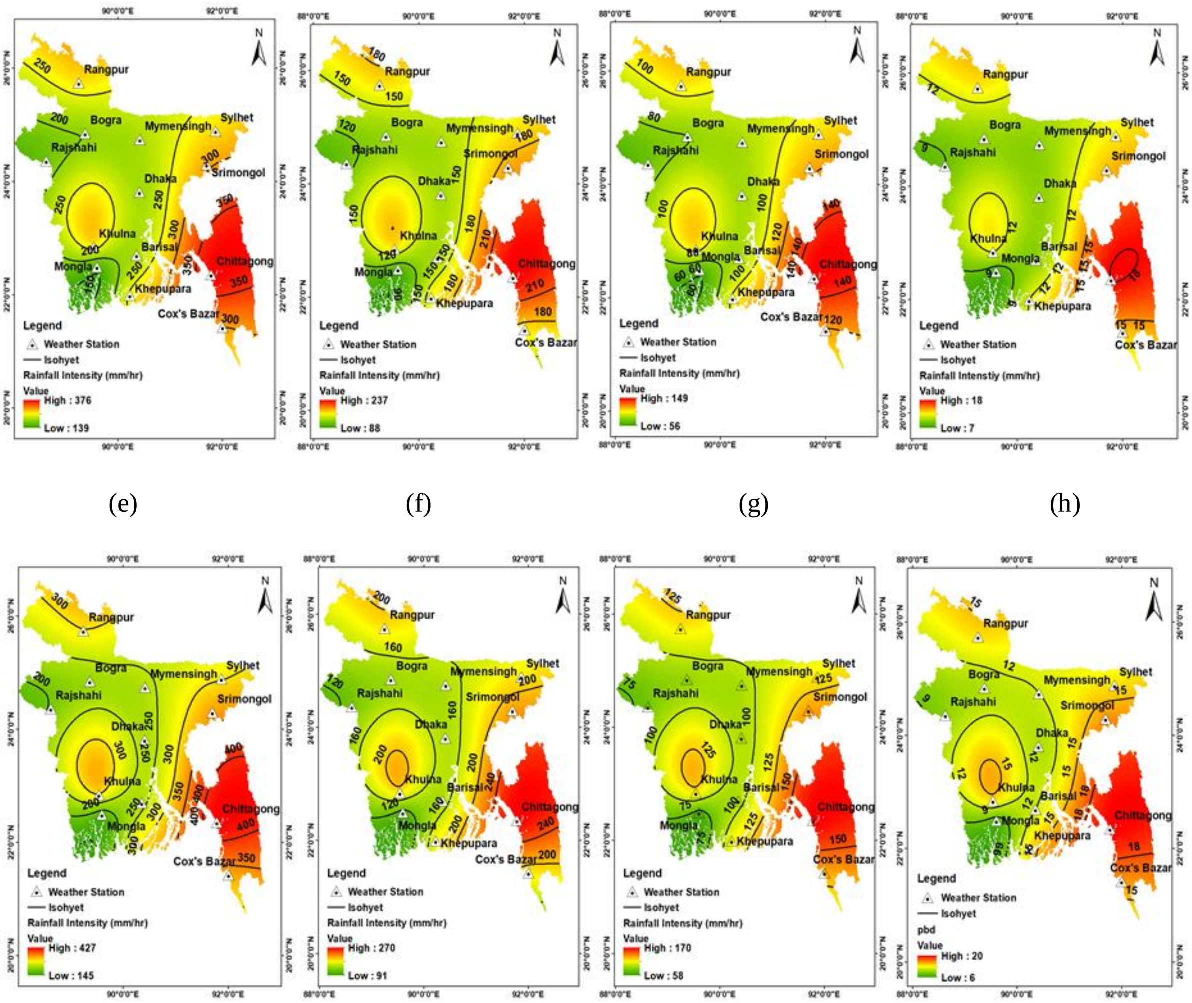
(g) (h)

Fig.1 IDF curves for various divisions of Bangladesh (a) Dhaka division; (b Mymensingh division; (c) Rangpur division; (d) Sylhet division; (e) Rajshahi division; (f) Chittagong division; (g) Barisal division; (h) Khulna division;

From the analyses of rainfall data and calculated values of intensities for various return periods and rainfall durations for thirteen stations, isohyetal maps have been developed for the country. Here, the isohyetal maps for return periods of 10, 25, and 50 years and for rainfall durations of 15 min, 30 min, 1 hr, and 24 hr have been presented as these are the most common short duration rainfall in the study area. From Fig. 2, this can be observed that for 15 min duration, the intensity of rainfall varies from 129 to 306 mm/hr, 139 to 376 mm/hr, and 145 to 427mm/hr for the return period 10, 25, and 50 years, respectively. And for 30 mins duration, the intensity of rainfall varies from 82 to 192 mm/hr, 88 to 237 mm/hr, and 91 to 270mm/hr for return periods 10, 25, and 50 years. Again for 60 min duration, the intensity of rainfall varies from 51 to 121 mm/hr, 56 to 149 mm/hr, and 58 to 170mm/hr for return periods 10, 25, and 50 years. 1-day duration intensity of rainfall varies from 6 to 14 mm/hr, 7 to 18 mm/hr, and 6 to 20mm/hr for return periods 10, 25, and 50 years.



(a) **(b)** **(c)** **(d)**



(e) (f) (g) (h)

(i) (j) (k) (l)

Fig. 2 Isohyetal maps of Bangladesh for the frequency of 10 yrs and duration (a) 15 min, (b) 30 min, (c) 60 min, and (d) 24 hrs; for the frequency of 25 yrs and duration (e) 15 min, (f) 30 min, (g) 60 min and (h) 24 hrs; and for the frequency of 50 yrs and duration (i) 15 min, (j) 30 min, (k) 60 min and (l) 24 hrs.

IV. CONCLUSION

The present study presents some insight into the way of finding rainfall intensities and estimates for various frequencies and durations of rainfall in eight divisions of Bangladesh. Since the areas are different in geologic and climatic conditions from division to division, a relation for each division has been obtained to estimate average peak rainfall intensities in the area. The Gumbel distribution method was employed to develop the IDF relationships in the study area. Isohyetal maps of Bangladesh for various recurrence intervals and different durations of rainfall were developed. From the study, it has been established that Chittagong and Sylhet are the most precipitation-prone zone. So that, these areas have risks of flooding and drainage congestion due to local rainfall if drainage is not provided properly.

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