ANALYSIS OF RAINFALL DATA FOR GENERATION OF INTENSITY-DURATION-FREQUENCY RELATIONSHIPS FOR SELECTED URBAN CITIES OF BANGLADESH

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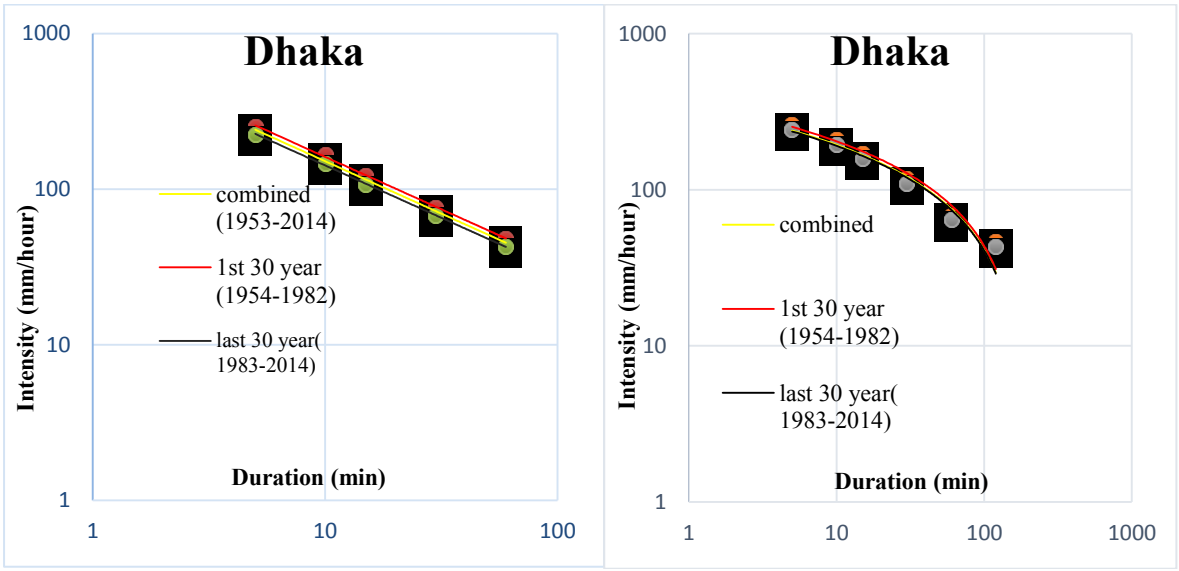
ABSTRACT
This study aims to develop rainfall IDF relationships for five major cities of Bangladesh. The selected cities are Dhaka, Khulna, Chittagong, Barisal and Rajshahi. Two well-known frequency analysis techniques such as Gumbel and Log Pearson Type III (LPTIII) distribution have been used to analyse the rainfall data. Annual maximum rainfall data series for last 60 years (1954-2014) have been collected from Bangladesh Meteorological Department (BMD). Two different procedures have been applied for estimating the short duration rainfall intensities. These are Hershfield method and an empirical formula deduced by Indian Meteorological Department (IMD). Analyses have been done for two annual maximum data series. One series consists of rainfall data of 30 years from year 1954-1982, referred as older series and another as newer series of data range from year 1983-2014. This division of historical data is made to assess the influence of climatic changes on the IDF curves if any. Chi-square test has been used to assess the goodness of fit. It is found that the Gumbel method provides better compliance than that of LPTIII method. Comparison has also been made between two methods of short duration data generation. Rainfall intensity using IMD yields larger value than the Hershfield method. In terms of percentages, IMD gives 10.49% larger for Dhaka, 2.8% for Khulna, 14.16% Chittagong, 5.9% for Barisal, and 8.46% larger for Rajshahi than that of Hershfield method. The coefficients and exponents of expression of IDF relationships for different return periods were calculated by using nonlinear multiple regression method using both the data series. Minor change of IDF curves is observed when compared the results using older and newer data series. It is anticipated that IDF curves presented for urban cities will be useful to estimate the intense runoff for the design of small hydraulic structures.

Keywords: Rainfall data; frequency analysis; short duration rainfall; IDF curves; urban cities

INTRODUCTION
Rainfall Intensity-Duration-Frequency (IDF) curves are graphical exemplifications of the amount of water that falls within a given period of time in catchment areas. One of the first step in many hydrologic design projects, such as in urban drainage design, is the determination of rainfall event or events to be used. Rainfall depth for different return period is important in case of small hydraulic structures such as culverts, small bridges, polder scheme etc. For determining short duration rainfall, Hershfield method seems indispensable in areas where the only useful data are of long duration and in such cases they probably provide the best available estimates of short duration rainfalls with return periods less than 10 years (Siddiqui, 1993). In recent studies, various authors (Dupont and Allen, 2006, Kim et al. 2008) attempted to relate IDF relationship to the synoptic meteorological conditions in the area of hydrometric stations. The short duration rainfall IDF curve was developed for North-Eastern region with return period of 2, 5,10,20,50, and 100 years (Matin, 1984) using Hershfield Method (Hershfield, 1962, Bell, 1964). Daily rainfall data analysed by (Munshi, 2014) to obtain IDF curve for North-Western region of Bangladesh was developed. However, using a long series of historical data (about 60 years) an attempt has been made to assess IDF curves for major cities of Bangladesh.

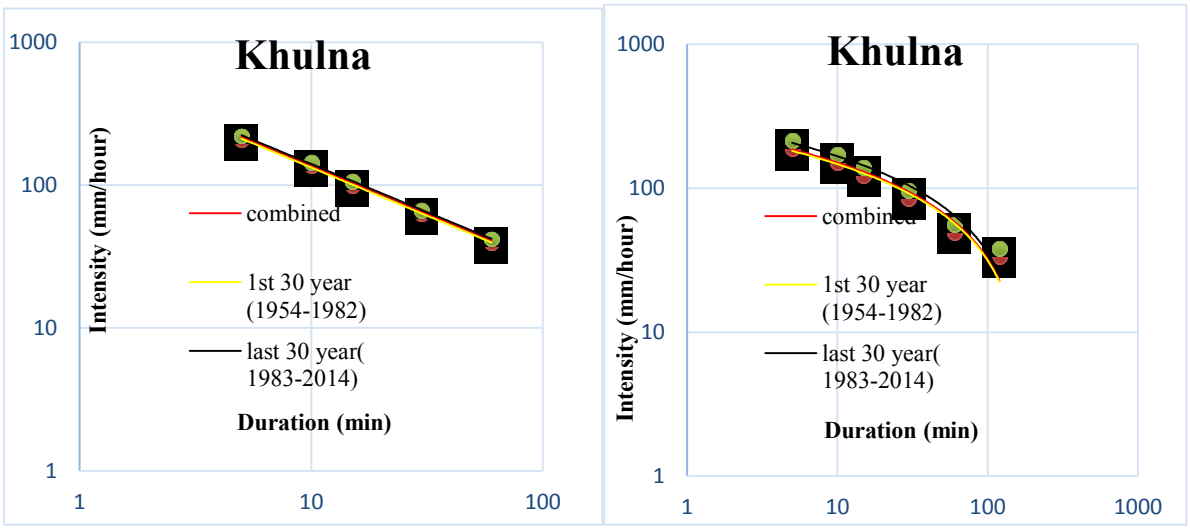
METHODOLOGY

Two well known frequency analysis techniques e.g. Gumbel and Log Pearson Type III (LPTIII) distribution were used. Chi-square goodness of fit test was used and found that the Gumbel Distribution is better fitted for study region (Rasel,M. 2014). The short duration rainfall such as 5min, 10 min , 15min, 30 min 1 hour and 2 hour data have been calculated on the basis of an empirical formula deduced by Indian Meteorological Department (IMD) (method-1) and Hershfield-Wilson diagram which is referred as method-2 (Matin, 1984, Hershfield, 1962, Bell, 1964). The coefficient of exponents of expression of IDF relationship for different return periods (2, 5, 10, 20, 50 and 100 years) were calculated by using nonlinear multiple regression method (Rimi, 2016).



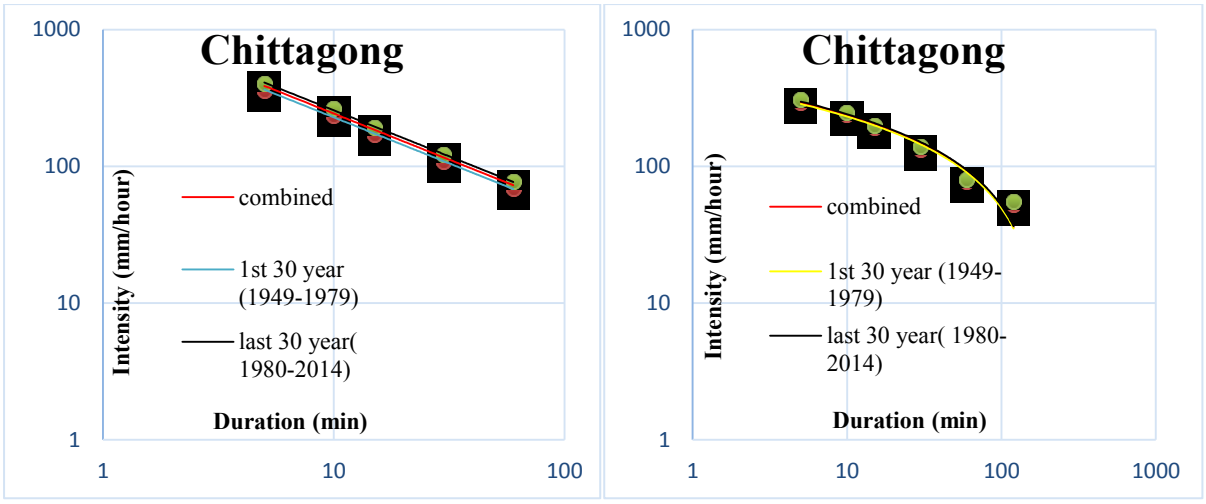
(a) (b)

Fig.1. Comparison of IDF Curve obtained from (a) Indian Method (b) Hershfield Method for Dhaka



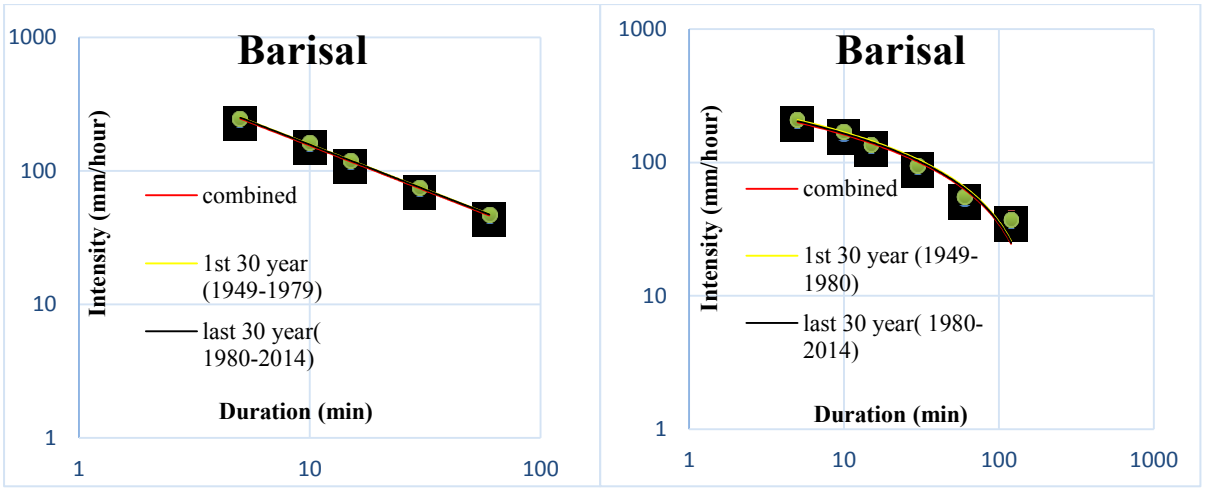
(c) (d)

Fig.2. Comparison of IDF Curve obtained from (c) Indian Method (d) Hershfield Method for Khulna



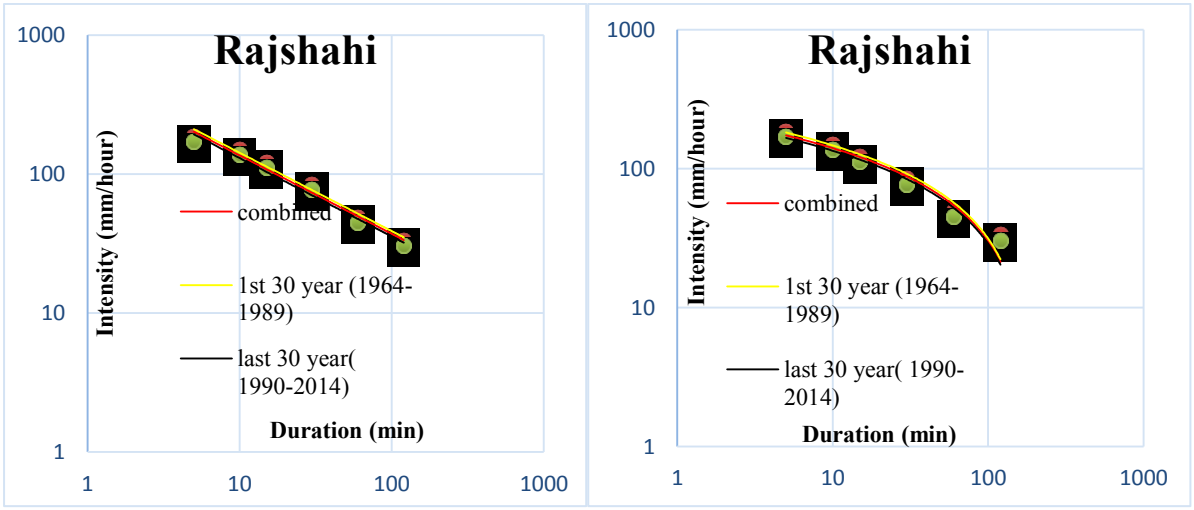
(e) (f)

Fig.3. Comparison of IDF Curve obtained from (e) Indian Method (f) Hershfield Method for Chittagong



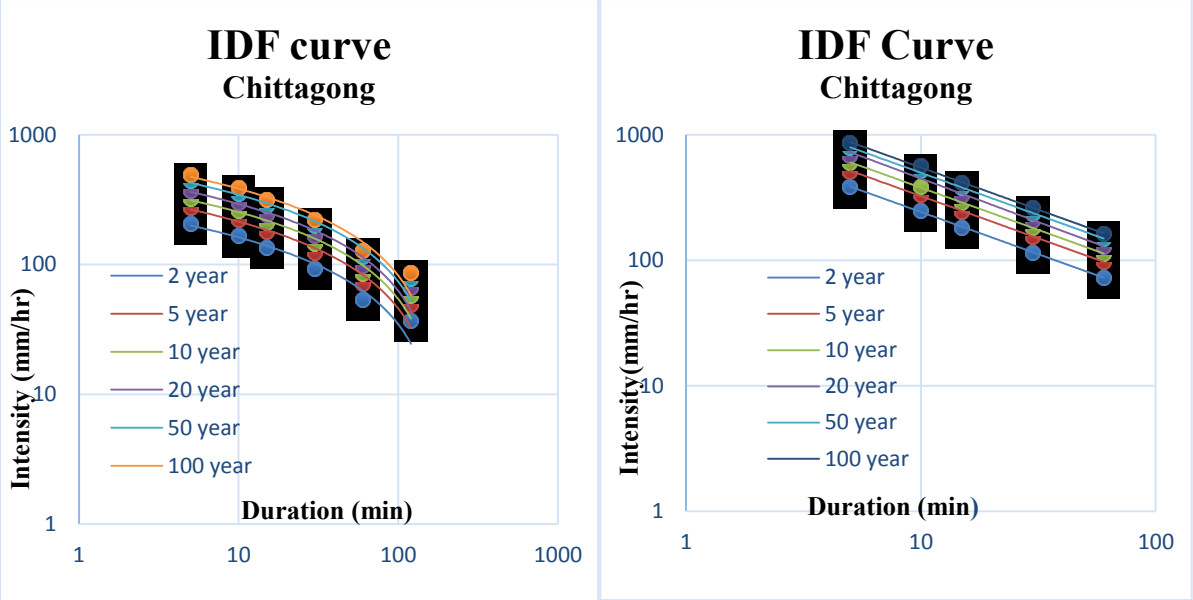
(g) (h)

Fig.4. Comparison of IDF Curve obtained from (g) Indian Method (h) Hershfield Method for Barisal



(i) (j)

Fig.5. Comparison of IDF Curve obtained from (i) Indian Method (j) Hershfield Method for Rajshahi



(i) (ii)

Fig.6. Generated IDF curve by using (i) Indian Method; (ii) Hershfield Method

Table-1: IDF relationships obtained using the Indian method

Urban Stations	IDF Relationship $I = \frac{CT_r^m}{T_d^e}$		% of change between older and newer series	Remarks
	From 1954-1982	From 1983-2014		
Dhaka	$I = \frac{716T_r^{0.215}}{T_d^{0.673}}$	$I = \frac{629.36T_r^{0.239}}{T_d^{0.673}}$	10.62%	Intensity decrease in last 30 year.
Khulna	$I = \frac{602.55T_r^{0.2359}}{T_d^{0.673}}$	$I = \frac{625.9T_r^{0.2614}}{T_d^{0.672}}$	5.57%	Intensity increases in last 30 years
Chittagong	$I = \frac{1012T_r^{0.1913}}{T_d^{0.676}}$	$I = \frac{1122T_r^{0.213}}{T_d^{0.673}}$	11.3%	Intensity increases in last 30 years.
Barisal	$I = \frac{700.32T_r^{0.212}}{T_d^{0.676}}$	$I = \frac{688.3T_r^{0.19}}{T_d^{0.6745}}$	3.16%	Intensity decreases in last 30 years.
Rajshahi	$I = \frac{547.7T_r^{0.2336}}{T_d^{0.673}}$	$I = \frac{544.37T_r^{0.229}}{T_d^{0.673}}$	0.96%	Intensity decreases in last 30 years.

Table-2: IDF relationships obtained using the Hershfield method:

Urban Stations	IDF Relationship $I = \frac{CT_r^m}{T_d^e}$		% of change between older and newer series	Remarks
	From 1954-1982	From 1983-2014		
Dhaka	$I = \frac{660.69T_r^{0.207}}{T_d^{0.595}}$	$I = \frac{619.15T_r^{0.202}}{T_d^{0.595}}$	7.76%	Intensity decrease in last 30 year
Khulna	$I = \frac{501.76T_r^{0..216}}{T_d^{0.563}}$	$I = \frac{512.86T_r^{0.24}}{T_d^{0.562}}$	4.09%	Intensity increases in last 30 years
Chittagong	$I = \frac{749.72T_r^{0.217}}{T_d^{0.564}}$	$I = \frac{776.24T_r^{0.217}}{T_d^{0.563}}$	3.56%	Intensity increases in last 30 years
Barisal	$I = \frac{545.52T_r^{0.217}}{T_d^{0.564}}$	$I = \frac{534.19T_r^{0.219}}{T_d^{0.5645}}$	2.016%	Intensity decreases in last 30 years
Rajshahi	$I = \frac{536.5T_r^{0.2173}}{T_d^{0.563}}$	$I = \frac{476.65T_r^{0.217}}{T_d^{0.564}}$	10.9%	Intensity decreases in last 30 years

Methods Used for Generation of Short Duration Data

***Indian Meteorological Department (IMD*) Method**: The empirical formula provided by IMD is given by,

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

***Hershfield Method*:** One hour data for frequencies 5, 10, 20, 50 and 100 year return periods have been calculated by using the equation presented by Bell (1969) as follows

$$P_T^{60min} = (0.35ln(T) + 0.76)P_2^{60min} \quad (2)$$

24- hour rainfall data for different return periods were then determined by equation,

$$P_T^{24hour} = (0.3602ln(T) + 0.754)P_2^{24hour} \quad (3)$$

RESULTS AND DISCUSSIONS

From the analysis it can be said that the Gumbel method of distribution provides comparatively good fit than LPT-III method. Goodness-of-fit tests were used to choose the best statistical distribution among these techniques.

In this study, the ratio of 2-year, 1-hour to 2-year, 24-hour rainfall was found to vary between 0.394 to 0.546. The mean ratio of 0.463 and a standard deviation of 0.0569 has been considered in Hershfield method for short duration data generation. Murry (1970) reported that this value lies between a range of 0.35 to 0.45 for India, in the continental United States and in South Africa the mean ratio was 0.435 and 0.50 respectively.

The comparison between IDF results obtained using older and newer annual data series and between Indian and Hershfield Method are shown in Fig-1, Fig-2, Fig-3, Fig-4, Fig-5 for five selected urban stations of Bangladesh. Comparison between the two methods are shown in Fig-2 for different return period for Chittagong city containing 60 years data series. The IDF equations of IMD method (method-1) are listed in Table 1 for the five urban stations. The percentage of change between older and newer data series for Dhaka, Khulna, Chittagong, Barisal and Rajshahi which are 10.62% , 5.57%, 11.3%, 3.16%, 0.96%. Table 2 shows the IDF relationship derived by using the Hershfield method (method-2) and the percentage change between the same period of analysis and urban station such as Dhaka, Khulna, Chittagong, Barisal and Rajshahi shows the rate of 7.76%, 4.09%, 3.56%, 2.016%, 10.9%.

Data shows that recent rainfall pattern of Bangladesh is erratic nature. No definite trends are obtained from trend analysis (Rimi, 2016). It is also suggested that short duration recording gauge data should be collected and preserved by BMD in regular basis so that the generated values to develop IDF can be better compared with real data.

CONCLUSIONS

Gumbel method estimates relatively higher rainfall intensity compared to those obtained by LPT III distribution. The results of the chi-square test of goodness of fit show that the Gumbel distribution is acceptable at the average significance level of 2.8%. Two different procedures have been adopted to generate short duration data required for IDF curves of five major cities of Bangladesh. Two annual extreme value series of rainfall data for years 1943-1982 and 1983-2014 have been used for the analyses. No significant change in IDF curves has been found, which reflects a minor influence of changing climate on IDF. Rainfall intensity using IMD yields larger value than those obtained by Hershfield method. IDF curves and relationships presented in this paper will be useful for estimation of storm runoff of urban areas of major cities of Bangladesh.

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