Indian Journal of Geo Marine Sciences
Vol. 49 (07), July 2020, pp. 1269-1279

Estimation of flood mitigation parameter for Tiruchirappalli city using Mathematical Relational Model

N Surendar[$] & R Nisha*[,†]

[a]Department of Civil Engineering, National Institute of Technology Tiruchirappalli, Tiruchirappalli – 620 015, India
[E-mail: [†]nisha@nitt.edu; [$]surendarnatarajan86@gmail.com]

Received 19 July 2019; revised 30 August 2019

Intensity Duration Frequency (IDF) curve is a mathematical tool used for generating rainfall depth characteristics for various return periods. It is a critical parameter for analyzing extreme events such as floods in urban areas. IDF curves are needed in the planning and design of useful urban drainage structures. The objective of this investigative study is to develop IDF curves for the observed rainfall conditions in the city of Tiruchirappalli, located in the southern state of Tamil Nadu, India. The trends of the intensity, duration and return periods of rainfall are statistically analyzed by Gumbel, Log Pearson Type III, and Log-normal distribution methods for five rain gauge stations situated in the city, from 1976 to 2016 and tested for goodness-of-fit. The Chi-square and Kolmogorov – Smirnov techniques are the goodness-of-fit tests used to determine the best fit. The constant mitigation parameters for the five stations are calculated by the distribution methods, and it is found that the Gumbel distribution method is an appropriate one to predict flood inundation reliably. The rainfall intensities are obtained from this method, and isopluvial maps are generated for different durations and return periods. The results obtained will serve as valuable information for the planning and management of drainage structures in Tiruchirappalli and help avoid future flood disasters.

[**Keywords**: Constant parameters, Gumbel, IDF curve, Rainfall, Return Period, Tiruchirappalli city]

Introduction

The IDF curve is a mathematical relationship between rainfall, intensity, and duration. It generally forms a graphical link between rainfall, intensity, duration, and frequency to quantify the amount of rainfall that occurs in urban areas. In Kupwara district of Kashmir valley, Abdul *et al*.[1] developed IDF curves by using three different frequency distributions, namely Gumbel, Pearson Type III, and Log-Pearson Type III distributions. The rainfall intensity for Riyadh city was evaluated by an empirical formula with some limitations[2]. So the analysis was carried out by Log Pearson Type III and Gumbel distribution methods. The depth-duration-frequency curve for Saudi Arabia was studied[3]. In the study, Saudi Arabia was divided into six rainfall zones. The study showed that rainfall trends of individual and regional stations would change in the future. The IDF curve for Baghdad city is constructed after gathering maximum daily rainfall data for a decade (2004-2014)[(ref. 4)]. The (IMD) Indian Meteorological Department formula was used to convert daily data into hourly data of different rainfall intensities of 0.25, 0.5, 1, 2, 3, 6, 12, and 24 hrs for different return periods of 2, 5, 10, 25, 50, and 100 years. The frequency analysis was carried out to find intensity duration frequency relations. The Kolmogorov-Smirnov (KS) test was used to test the goodness of fit. The results obtained showed there was no significant difference between the two distribution techniques applied and the results were found to be within the significance level. A generalized IDF formula is derived from the recorded data of various rainfall depths, i.e., R_1^{10} (1 h, 10-year precipitation depth), R_{24}^{10} (24 h, 10-year precipitation depth), and R_1^{100} (1 h, 100-year precipitation depth)[5-7]. IDF curves were conceptualized during the last century[8]. IDF curves are developed based on the specific requirement of a particular region. Similar IDF curves are used to determine the hydrological risk and assess the probability of extreme events in the United States of America. In urban cities, floods primarily occur due to variation in the intensity of rainfall and improper design of urban storm drainage systems. IDF curves are essential for proper planning and construction of urban drainage systems[9]. In subsequent studies, few authors tried to relate IDF to the synoptic climatological situations[10]. The IDF curves for Saudi Arabia were developed for Najran and Hafr Albatin areas using the Gumbel and LPT III frequency analysis methods[11]. The study showed that the Gumbel distribution method has a quite high significance than LP III distribution. Good results were obtained in this study of the rainfall volume from the two distributions, compared to earlier research studies in the country. The controlling factors of the IDF equations and coefficient of correlation for different return periods were established. The daily precipitation data of 30 stations were analyzed for the semi-arid region of Northern China from 1956 to 2000[12]. For the development of IDF curves, it is first necessary to convert the daily data into hourly data for further analysis[13]. The generated curves were used for designing a new drainage system in the city. Since the curve was designed for maximum rainfall intensity, the designed structures were guaranteed to be safe[14]. IDF curves are extensively used for estimating rainfall intensity for various durations and return periods[15,16,18]. A study was conducted in the northwestern region of Bangladesh to estimate rainfall depths for different return periods by the distribution methods[19-21]. The Gumbel and LPT III distributions were used for generating IDF curves. It was found that Gumbel method gave higher values than LPT III distribution method and the goodness of fit was identified by the Chi-square test; the IDF curves were generated for different return periods for finding the best fit probability distribution methods for the northwestern region. IDF curves were also generated for other major urban cities like Bengaluru[22] and Guwahati[23] in India.

The regional constants were created by using Sherman Morrison method and Log Pearson method, to obtain good results[24-25]. Al-Madinah city, situated in the western part of Saudi Arabia developed rapidly resulting in a high change in land use and land cover and developed an empirical formula from IDF curves for the city[26]. The formula was derived from Gumbel and LP III frequency methods. The developed empirical formula was used for forecasting the return period for a given storm duration. The relationship between the rainfall intensity, duration, and frequency for Indian conditions is developed from data collected from 80 rain-gauge stations across India. The IDF curves were derived using an empirical equation, and they were modified[27]. IDF curve for the Barak River basin in Manipur, India is developed[28]. In this study, the 24-hours of annual maximum rainfall and hourly maximum rainfall data collected was used for analysis by using Gumbel, Log Pearson Type III, and Lognormal probability distribution functions. The goodness-of-fit tests suggested that the LP Type III distribution was suitable for the area. The IDF curves and isopluvial maps for rainfall intensities of 0.5 to 24 hours duration were generated.

The relationship developed by Kothyari and Garde method[28] gives good results for Indian conditions. The constant parameters developed from this method are used for comparing the parameters developed for other regions in India. Rainfall patterns for different hydrologic conditions were considered to generate the equation for IDF curves for extrapolating to100 years[29,30]. The mean annual rainfall (R) of 24 hrs and 2 years rainfall, R_2^{24}, was considered for developing the IDF curve. The IDF curve for Mumbai city was developed from the rainfall data collected from Colaba and Santa Cruz stations for the duration of 108 (1901 to 2008) and 58 (1951 to 2008) years[31]. The IDF relationship was developed by studying the maximum rainfall intensity that occurred on 26th July 2005.

The objectives of the current exploratory study are to produce IDF curves and constant mitigation parameters for 5 stations in Tiruchirappalli city by using IDF equation. The rainfall from (1976-2016) of maximum rainfall event is used for the analysis of historical rainfall data. The study also aims to prove the best probability distribution method by calculating rainfall intensity for various durations. From the available literature, it is inferred that the IDF curves have been developed for major cities in India, but limited studies are available for medium-sized cities. The IDF curve produced will be used for planning and construction of storm sewers in the Tiruchirappalli city, and to ensure that they can handle excessive rainfall thereby alleviating potential flood disasters.

Materials and Methods

Study area

Tiruchirappalli is a medium-sized city located in Tiruchirappalli district of Tamil Nadu. The city forms part of the Cauvery River basin which is the only perennial river in the city. The northern branch of the Cauvery, known as 'Coleroon' mainly acts as a flood carrier, while the southern branch is known as Cauvery. It has several streams; the main streams are Ayyar and Uppar in the North and Koraiyar in the South shown in Figure 1. Being a low-lying area of flat plains, the level of floodwater should be considered while designing a drainage system. The average yearly rainfall over the city varies around 730 mm to 900 mm. The minimum is around 731.9 mm in the western part which gradually increases in the north, east and south, reaching a maximum of around 908.5 mm. The most common forms of rainfall in the study area are thunderstorms, drizzle, moderate, and light rain. The city enjoys a humid climate. It is generally hot and dry from April to June and pleasant weather from November to January. The alluvial plains are limited to the northern part of the city. The shallow and deep pediments evenly spread throughout the city CWC[6]. The city experiences floods, especially during the North-East monsoon and floods have occurred in the years 1924, 1952, 1954, 1965, 1977, 1979, 1979, 1983, 1999, 2000 and 2005.

Methodology

The methodology adopted for the present study is shown in Figure 2 and explained as follows: the annual and daily rainfall data is collected for the study area. The collected data is analyzed statistically by distribution methods, and the best-fit distribution method is identified for the study area. In the present study, probability distribution methods like Gumbel,

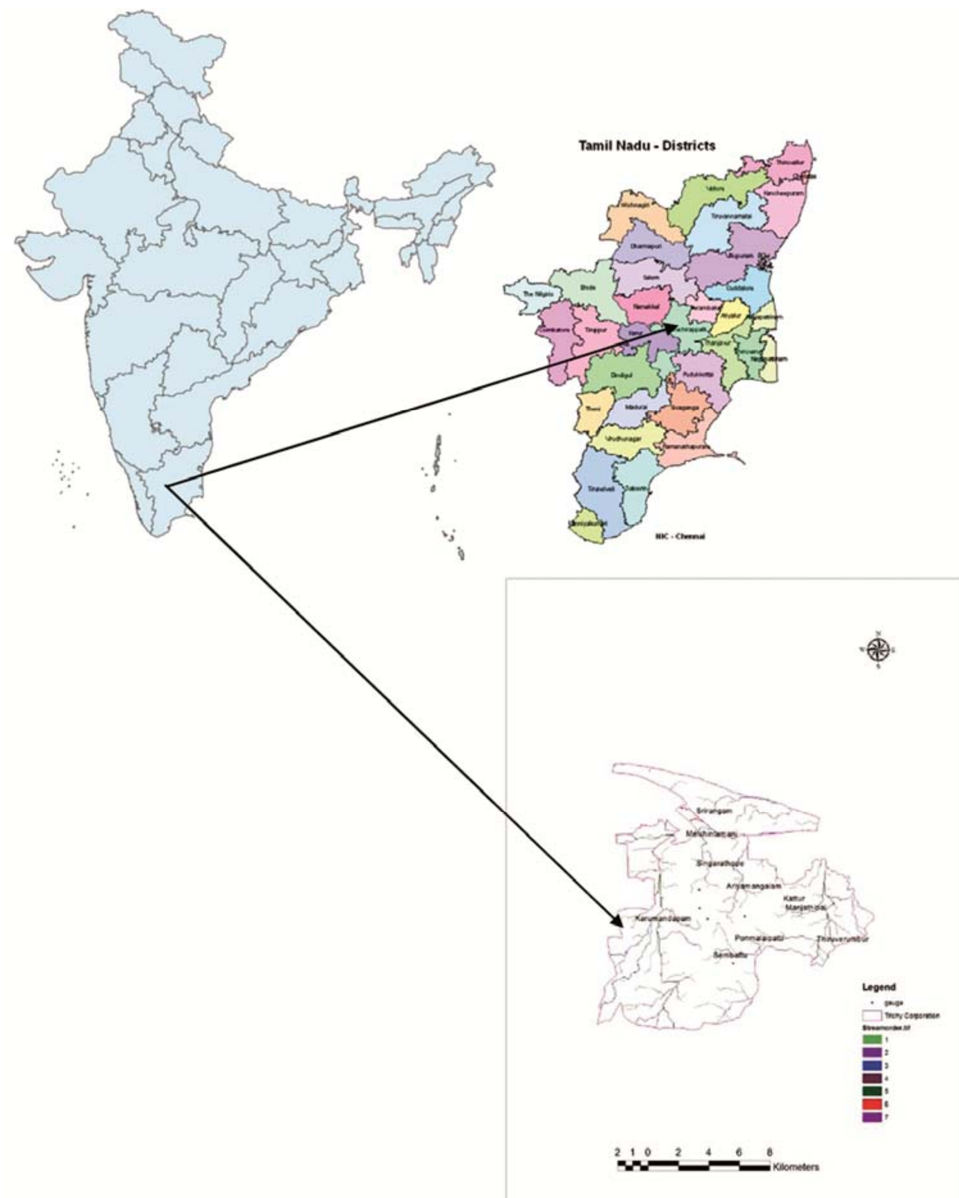

Fig. 1 — River boundary map of the study area

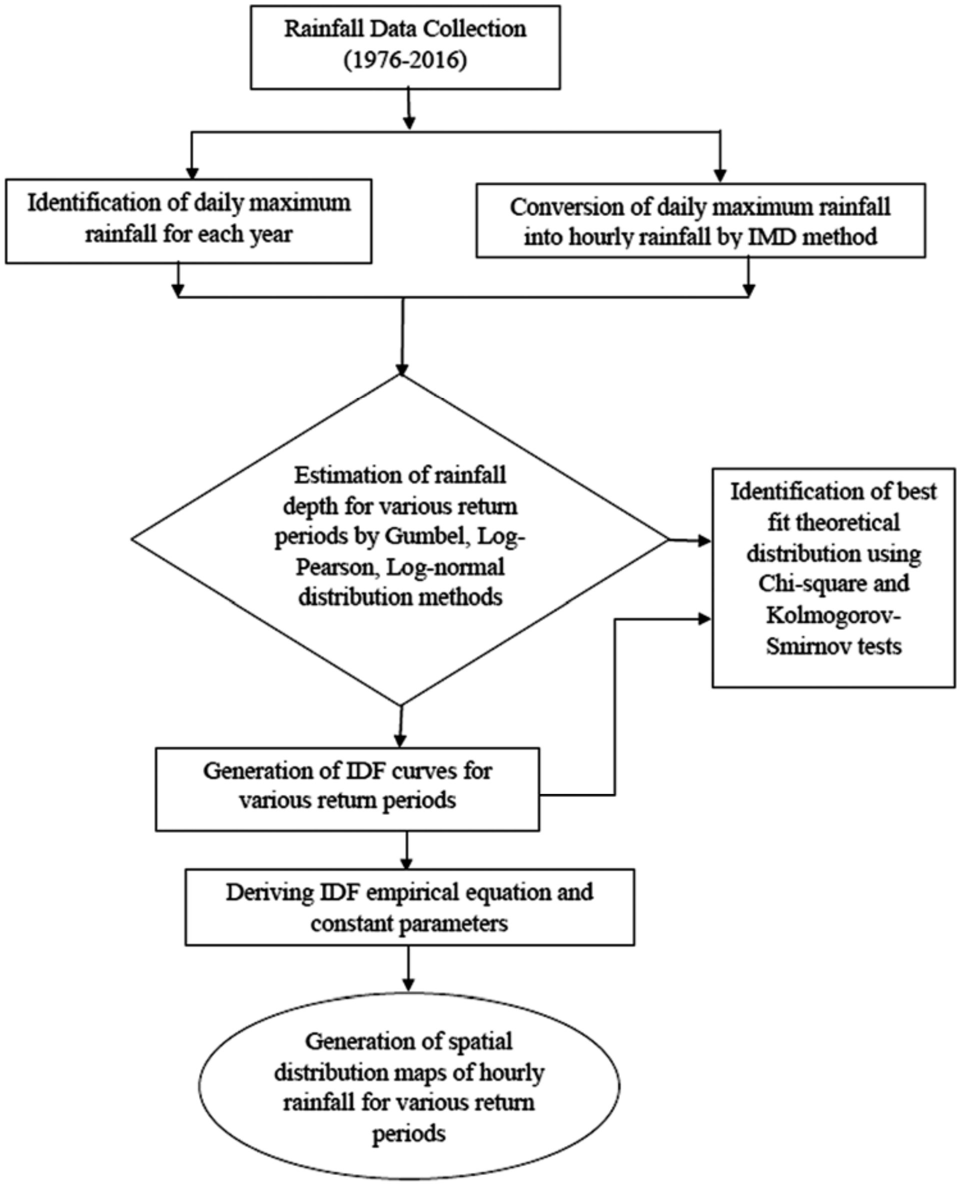

Fig. 2 — A flowchart depicting the methodology of the study

Log Pearson Type-III and Log-normal distributions methods are used. The rainfall data is arranged into intervals with defined ranges. The mean, standard deviation, and coefficient of variance are determined from the data. The Chi-square and Kolmogorov techniques are used to identify suitable probabilities and the best fit. The method that gives the least Chi-square and Kolmogorov values are used for further analysis. The statistical analysis techniques used give rainfall depth for different return periods and durations. The spatial interpolated maps are produced covering various return periods.

Data collection and analysis

Rainfall data acquisition and preliminary analysis

The rainfall data for Tiruchirappalli city is collected for the years 1976 to 2016. The data collection includes yearly and daily rainfall data. The yearly rainfall data is obtained from the website http://www.indiawaterportal.org, and the daily data is collected from the State Surface and Groundwater Data Centre, Chennai. The mean and standard deviations are calculated using annual and daily rainfall data. The daily data is converted into hourly data by IMD (Indian Metrological Department) techniques due to the requirements for single event flood analysis. The average analysis of rainfall is done to determine the rainfall trend in the city, as shown in Figure S1. It is noted that the trend of rainfall decreases gradually in the average analysis. So the rainfall pattern is analyzed for different seasons from (Jan-May) non-monsoon, (June-Sep) southwest monsoon and in north-east monsoon (Oct-Dec) as shown in Figure 3. From the figure it is observed that the pattern of rainfall increases during north-east monsoon from (1995-2016). In non-monsoon season (Jan-May) rainfall pattern increases due to the high intensity of rainfall in a single day and month observed during (2004-2008). The varying rainfall from (1985-2016) shows decreased pattern in southwest monsoon season.

IDF curves are generated for the different return periods for 5 locations chosen in the city between the latitudes and longitudes of 10°48’2’’ N to 78°41’10’’ E for Trichy town and 10°47’44’’ N to 78°41’11’’ E for Junction. The latitude and longitude of CLC compound and Airport are 10°45’6’’ N to 78°42’2’’ E; Ponmalai lies between 10°47’26’’ N to 78°42'47’’ E. The rainfall station in the city, are shown in Figure 4.

Rainfall frequency analysis

The rainfall frequency analysis is done to determine the magnitude and intensity of the precipitation. The frequency analysis is carried out to fix the probability distribution methods. The frequency analysis is done using the methods shown in Table 1, where m and N represent the rank and the number of data’s used for the analysis. The frequency is estimated using rainfall data for 40 years. The rainfall data are ranked in descending order to calculate return periods for various frequency analysis methods to determine the appropriate probability distribution methods. The magnitudes of rainfall are calculated by different frequency analysis measures shown in Figure S2.

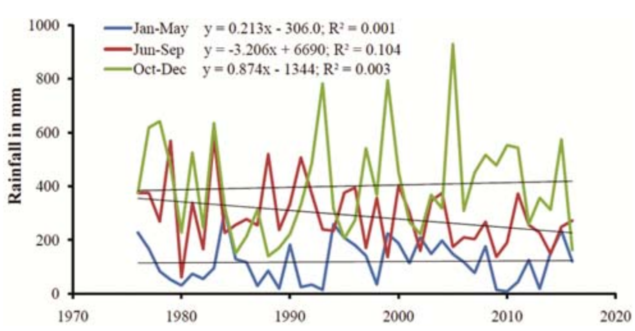

Fig. 3 — Rainfall pattern non-monsoon (Jan-May), southwest monsoon (June-Sep), and northeast monsoon (Oct-Dec)

The Weibull and California methods have the minimum annual rainfall values; the suitable distribution methods are Normal and Log-normal distributions. The Hazens method gives little higher values compared to Weibull and California methods, and it fits with Pearson Type III distribution. It is also observed that the Beard and Chegodayev methods give the highest values where it fits with Log Pearson Type-III and Gumbel distribution. In the case of hourly rainfall data conversion, Gumbel and Log Pearson Type-III are the best distribution methods when compared to other methods.

The methodology adopted in the study

Development of IDF curves

For the proper design of urban drainage storm sewers and hydraulic structures, the estimation of

Table 1 — Frequency analysis and distribution methods

S. No	Frequency analysis methods	Probability distribution methods
1	California = m/N	Normal distribution
2	Weibul = m/(N+1)	Log-normal distribution
3	Hazen = (m-0.5)/N	Pearson Type-III distribution
4	Beard = (m-0.31)/(N+0.38)	Log-Pearson Type-III distribution
5	Chegodayev = (m-0.3)/(N+0.4)	Gumbel value distribution

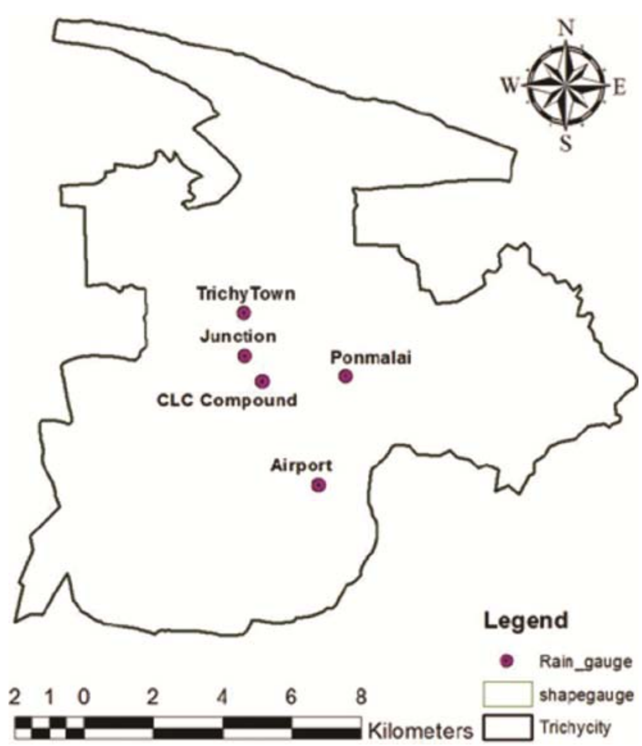

Fig. 4 — Rain gauge stations in the study area

rainfall intensity is necessary. The IDF equation includes the estimates of rainfall intensities of various durations and returns periods. The frequently used theoretical distribution methods like Gumbel distribution and Log Pearson Type-III, Log-normal distribution are used to develop the relationship between rainfall intensity, duration, and return periods from rainfall data.

Conversion of daily data into hourly data

For this purpose, the empirical formula obtained from the Indian Meteorological Department (IMD), shown below in Eq. (1). The daily annual maximum rainfall data is converted into hourly rainfall data for different durations like 1, 4,8,12 and 24 hours[21]. From the various studies, it is noted that this equation is more useful for estimation of short duration of rainfall from daily rainfall data and it is a more suitable method for converting daily data into hourly data.

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

Where, P_t is rainfall depth in mm of t-hr duration, P_{24} is daily rainfall in mm and t is the period of rainfall for which rainfall depth is required in hours.

Gumbel distribution

The Gumbel distribution method is used for calculating rainfall depth for 2, 5, 10, 50 and 100-year return periods. The precipitation P_t (in mm) for each time with a specified return period T is given by following formula[8],

$$X_T = X_{ave} + K_T S \qquad \dots (2)$$

$$k_T = -\frac{\sqrt{6}}{\pi}\{[0.5772 + \ln\left[\ln\frac{T}{T-1}\right]\} \qquad \dots (3)$$

Where, X_{ave} is the average of the maximum rainfall corresponding to a particular duration and S is the standard deviation of rainfall data, as shown in Eq. (2). The Gumbel frequency factor (K_T) shown in Eq. (3), a function of the return period. It gives the actual return period for different duration rainfall values when multiplied with standard deviation.

Log Pearson Type-III

In 1967, the USA Water Resources Council suggested that Log Pearson Type-III distribution should be adopted as standard flood frequency distribution by all U.S. federal government agencies[22]. It is used to compute the rainfall intensity at different durations and return periods to generate IDF curves for the stations. It involves logarithms of the measured values and logarithmically transforms data to identify the mean, standard deviation. The frequency of rainfall is acquired using Log Pearson Type-III method. The simplified Eq. (4) for this distribution is given as follows[19],

$$P = \log(P_i) \qquad \dots (4)$$

$$P_T = P_{ave} + K_T S^* \qquad \dots (5)$$

Where, P_T is rainfall peak of a particular frequency, P_{ave}, stands for average maximum precipitation and S is the standard deviation of rainfall. K_T is the Pearson frequency factor, which depends on the return period (T) and the skewness coefficient (C_s)[8,22]. By calculating the skewness coefficient, recurrence interval, frequency factor K_T, the Log Pearson Type-III distribution can be determined. The antilog of Eq. (5) provides the rainfall depth for the given return period.

Log-normal distribution

The Log-normal distribution method is the most critical distributions used in the field of hydrology. It is a bell-shaped symmetrical distribution having a coefficient of skewness equal to zero. It identifies the causative factors for many hydrologic variables that act multiplicatively than additively. The logarithmic of these variables is the product of these causative factors that follow a normal distribution. If normal distribution follows logarithmic value, then it is known as Log-normal distribution, as shown in Eq. (6).

$$f = \frac{1}{x\sigma L\sqrt{2\pi}}\, exp\left[-\frac{1}{2}\left(\frac{lnx-\mu_L}{\sigma_L}\right)^2\right] \qquad \dots (6)$$

Where, μ_L is mean of logarithms of x, and σ_L = standard deviation of ln(x), exp is the exponential function with base e = 2.718. $\frac{1}{x\sigma L\sqrt{2\pi}}$ is a constant factor that makes the area under the curve of f(x) from -∞ to ∞ = to 1.

The frequency factor for a normal distribution is given by Eq. (7).

$$k_T = x_T \frac{\mu}{\sigma}. \qquad \dots (7)$$

This is the same as the standard normal variate z, i.e., frequency factor k_T = z and rainfall depth for the given return period.

Goodness of fit test

Chi-square test

The standard normal square of a variate is known as Chi-square variate with a degree of freedom. It is an approximate test for large values of n[ref. 13]. The validity of the Chi-square test depends on 'goodness of fit' between theory and the experiment, as shown in Eq. (8). It depends only on the set of observed and expected frequencies and degree of freedom[17].

$$\gamma^2=\sum_{i=1}^{k}\frac{(O_{i-}E_i)^2}{E} \quad \ldots (8)$$

γ^2 do not consider any population parameters, where O_i and E_i represent the observed and expected frequencies, respectively. The class interval numbers are denoted by k. If the observed frequencies have smaller values than expected frequencies, the more the small values it denotes goodness of fit. It leads to the acceptance of the null hypothesis whereas a weak fit leads to the rejection of the hypothesis. The critical region falls to the right and left tails of the Chi-square distribution and is tested for a level of significance (α) at 5 and 10 %[11,13].

Kolmogorov- Smirnov (K-S) test

Kolmogorov -Smirnov is an alternative to the Chi-square test. The data for this test is arranged in descending order of magnitude. The cumulative probability *P (xi)* for all the data is calculated by Weibull's method. The theoretical cumulative probability *F (xi)* for each of the observations is obtained from the assumed distribution. The absolute differences between $P(x_i)$ and $F(x_i)$ are calculated by Eq. (9).

$$\Delta= \left|P_{x_i} - F_{xi}\right| \quad \ldots (9)$$

The critical value of Kolmogorov-Smirnov statistics Δ_o is obtained using KS static table available in standard references. If $\Delta < \Delta_o$, it is accepted that the hypothesis is at a level of significance and it is assumed the distribution is a good fit. The advantages of the K-S test over the Chi-square test are that it does not lump the data, and it is easier to compute Δ than χ^2. This test can be adopted when the sample size is small[17].

Derivation of IDF curve and equation

The above mentioned statistical data can be made more concise with the help of an Intensity –Duration-Frequency diagram. In using this curve, it is possible to determine the typical intensity of rainfall for a specific duration and return period. The curve can be used to design the various types of flood mitigating structures such as drainage pipelines, storm sewers, and reservoirs. The small structures are designed for a small return period, and the large structures are designed for a 100 year return period. For deriving the curves, IDF formulae and an empirical equation are used. These equations represent the relationship between maximum rainfall intensity and duration.

A simple method is adopted to develop IDF curves for the regions of interest in the current study are used to calculate rainfall intensity for return periods. The equation is converted into a linear equation by logarithmic conversion to calculate all the mitigating parameters[2,8,16].

The methods which involve estimating the mitigation parameters from Eq. (10) are acquired from the IDF curves.

$$I = \frac{CTr^m}{Td_e} \quad \ldots (10)$$

Where k = CT_r^m and e represent the slope of the straight line. The natural logarithm of K value is computed from Gumbel, Log Pearson Type-III and Log-normal distribution methods along with the natural logarithmic for rainfall period T_d. The values of the log I are plotted on the y-axis and the values of log T_d on the x-axis for all the return periods using the above methods.

Generation of ISO Pluvial maps for the various return periods

The rainfall depth for different rainfall durations, for 5 rain-gauge stations in Tiruchirappalli city, is interpolated using the Geo-statistical analyst tool in ArcGIS. It shows the spatial distribution of rainfall depth of the rain-gauge locations in the study area. The Iso-pluvial maps are produced using the Inverse Distance Weighted (IDW) technique in GIS[24]. To interpolate a value for any unmeasured location, this technique is used for executing whether the measured point has a local impact when the distance decreases[28].

Results and Discussion

The present study is aimed at developing IDF curves for determining the extent of rainfall in Tiruchirappalli city and deriving constant mitigation parameters for 5 stations in the city. The IDF curves are generated by using Eq. (10). It is observed that for various return periods Trichy Town and Airport have maximum rainfall intensity of 10 to 11 mm/hr, respectively. The rainfall intensity is analyzed by Gumbel, Log Pearson Type-III, and the Log-normal distribution. The distribution methods are checked for the goodness of fit. The Chi-square and Kolmogorov-Smirnov goodness of fit tests are used to find the best distribution.

The Gumbel method estimate the rainfall depth for various return periods by applying rainfall intensity and duration, as shown in Table 2, and other LPT III, and Log-Normal distribution are shown in supplementary Tables S1 and S2. The rainfall intensity increases with an increase in the return period for all stations in the Gumbel method. Similarly, in LPT III also, as the return period increases the intensity increases for all the 5 stations. In the Log-normal distribution, there are some fluctuations in the intensity during an increase in the return period. The values obtained from Log-normal distribution are different from those of the other two methods. The constant mitigation parameters for the city are derived from the rainfall intensity and duration and applied in the IDF equation.

Table 2 — Rainfall intensity and duration for different return periods using Gumbel method

Return period	1 hr	4 hrs	8 hrs	12 hrs	16 hrs	20 hrs	24 hrs
Town							
2	0.8	1.6	2.3	2.8	3.2	3.6	4
5	1.2	2.4	3.4	4.2	4.8	5.4	5.9
10	1.5	3	4.2	5.1	5.9	6.6	7.2
50	2.1	4.1	5.9	7.2	8.3	9.3	10.1
100	2.3	4.6	6.6	8	9.3	10.4	11.4
Junction							
2	0.78	1.57	2.22	2.72	3.14	3.51	3.84
5	1.08	2.16	3.05	3.74	4.32	4.83	5.29
10	1.27	2.55	3.61	4.42	5.1	5.7	6.24
50	1.7	3.41	4.82	5.9	6.81	7.62	8.35
100	1.89	3.77	5.33	6.53	7.54	8.43	9.24
Airport							
2	0.79	1.57	2.22	2.72	3.14	3.52	3.85
5	1.14	2.28	3.23	3.96	4.57	5.11	5.59
10	1.38	2.76	3.9	4.77	5.51	6.16	6.75
50	1.9	3.79	5.36	6.57	7.59	8.48	9.29
100	2.12	4.23	5.99	7.33	8.46	9.46	10.37
Ponmalai							
2	0.8	1.6	2.3	2.8	3.2	3.6	3.9
5	1.2	2.4	3.3	4.1	4.7	5.3	5.8
10	1.4	2.9	4.1	5	5.7	6.4	7
50	2	4	5.6	6.9	7.9	8.9	9.7
100	2.2	4.4	6.3	7.7	8.9	9.9	10.9
CLC							
2	0.71	1.42	2	2.45	2.83	3.16	3.47
5	1.12	2.25	3.18	3.9	4.5	5.03	5.51
10	1.4	2.8	3.96	4.85	5.6	6.27	6.86
50	2.01	4.02	5.68	6.96	8.03	8.98	9.84
100	2.27	4.53	6.41	7.85	9.06	10.13	11.1

The Chi-square test for annual rainfall series is shown in Table S3. In stations like CLC and the Airport, the hypothesis that normal distribution fits the data can be accepted at 10 % level of significance which produces $\chi_{0.1,10}$cal < 15.99, $\chi_{0.1,7}$cal < 12.02. At the other stations like Trichy Town, Junction and Ponmalai, $\chi_{0.01,4}$ cal < 13.28, $\chi_{0.1,7}$ < 15.99 and the data can be accepted at 1 % level of significance. Almost all the data fits at 1 % level of significance and fits the distribution.

The Kolmogorov test is also carried out for the annual rainfall series, as shown in Table 3. CLC and Trichy town has a maximum value of Δ 0.15 and Δ_0 value 0.22, where $\Delta < \Delta_o$ the data fits at 5 % level of significance. Junction, Airport, and Ponmalai have maximum values of Δ = 0.13, 0.16, 0.2 and Δ_0 values around 0.17, 0.19 and 0.18, where $\Delta < \Delta_o$ almost all the data fits at 5 % level of significance. From the above two tests, it is noted that the Kolmogorov test fits all the data at 5 % level of significance and in Chi-square test some variations are seen in the level of significance like 10 and 1 %. These tests help conclude that the Gumbel distribution has better goodness of fit when compared to the other two methods.

The rainfall intensity values are taken from these three distribution methods, and the constant parameters are derived, as shown in Table 4. The obtained constant parameters are compared to the constants derived for IDF equation of Southern India "C" value 7.1[refs. 27-28]. The constant parameters obtained are within the limit.

The parameters derived from the IDF formula are adjusted by the method of least squares to get the correlation coefficient. The coefficient is 0.96 for all stations by both Gumbel and LPT III distribution methods, but in case of Log-normal distribution CLC has a coefficient of 0.95, and the other stations have low correlation coefficients that range from 0.57 to 0.74.

It is noted that the Gumbel distribution method produces higher values of rainfall intensity when compared to the other two methods. So the IDF curves generated by Gumbel distribution method for the city are shown in Figure 5. There is a slight difference in intensity values produced by Gumbel and Log Pearson Type-III distribution methods. There is much difference in intensity values obtained using

Table 3 — Kolmogorov-Smirnov test

CLC		Town		Junction		Airport		Ponmalai	
F(zi)	∣Pxi-Fxi∣	F(zi)	∣Pxi-Fxi∣	F(zi)	∣Pxi-Fxi∣	F(zi)	∣Pxi-Fxi∣	F(zi)	∣Pxi-Fxi∣
1.00	-0.03			1.00	-0.03			0.99	-0.01
0.99	-0.05	0.93	0.01	0.96	-0.02	0.97	-0.02	0.80	0.15
0.91	0.00	0.82	0.09	0.94	-0.03	0.94	-0.01	0.77	0.16
0.88	-0.01	0.80	0.08	0.90	-0.02	0.89	0.02	0.68	0.22
0.84	0.00	0.79	0.06	0.86	-0.01	0.87	0.01	0.68	0.20
0.80	0.00	0.66	0.16	0.77	0.05	0.81	0.04	0.63	0.23
0.73	0.05	0.65	0.13	0.74	0.05	0.69	0.15	0.61	0.23
0.71	0.03	0.62	0.13	0.67	0.09	0.65	0.16	0.60	0.22
0.66	0.05	0.62	0.10	0.67	0.06	0.62	0.16	0.58	0.22
0.65	0.03	0.62	0.07	0.66	0.04	0.61	0.15	0.57	0.20
0.64	0.01	0.59	0.07	0.65	0.02	0.60	0.14	0.56	0.19
0.58	0.03	0.55	0.07	0.64	-0.01	0.59	0.13	0.56	0.16
0.56	0.02	0.48	0.11	0.61	0.00	0.58	0.12	0.56	0.14
0.39	0.15	0.46	0.10	0.57	0.00	0.55	0.11	0.56	0.12
0.39	0.13	0.45	0.08	0.54	0.01	0.51	0.13	0.55	0.11
0.36	0.12	0.45	0.05	0.54	-0.02	0.50	0.12	0.54	0.09
0.36	0.10	0.36	0.11	0.44	0.05	0.49	0.11	0.51	0.11
0.35	0.07	0.35	0.09	0.41	0.05	0.47	0.10	0.51	0.08
0.34	0.05	0.31	0.09	0.30	0.13	0.46	0.08	0.48	0.07
0.34	0.01	0.31	0.06	0.26	**0.13**	0.42	0.10	0.46	0.06
0.28	0.04	0.31	0.03	0.26	0.11	0.40	0.10	0.45	0.05

Table 4 — Generated parameters for 5 stations in Tiruchirappalli city

Region	Gumbel method				Log Pearson Type III				Log-Normal distribution			
	Parameter											
	c	m	e	R^2	c	m	e	R^2	c	m	e	R^2
Trichy town	2.5	5.05	0.91	0.96	3.67	1.09	0.51	0.96	2.53	0.035	0.9	0.57
Junction	2.4	5.22	0.89	0.96	1.93	0.006	0.006	0.96	2.49	0.04	0.89	0.74
Airport	2.4	5.08	0.9	0.96	1.93	1.02	0.011	0.96	2.5	0.039	0.9	0.7
Ponmalai	2.2	4.63	0.88	0.96	1.93	1.02	0.011	0.96	2.52	0.037	0.8	0.63
CLC compound	2.2	4.63	0.88	0.96	1. 1	0.01	0.017	0.96	0.061	1.464	0.01	0.95

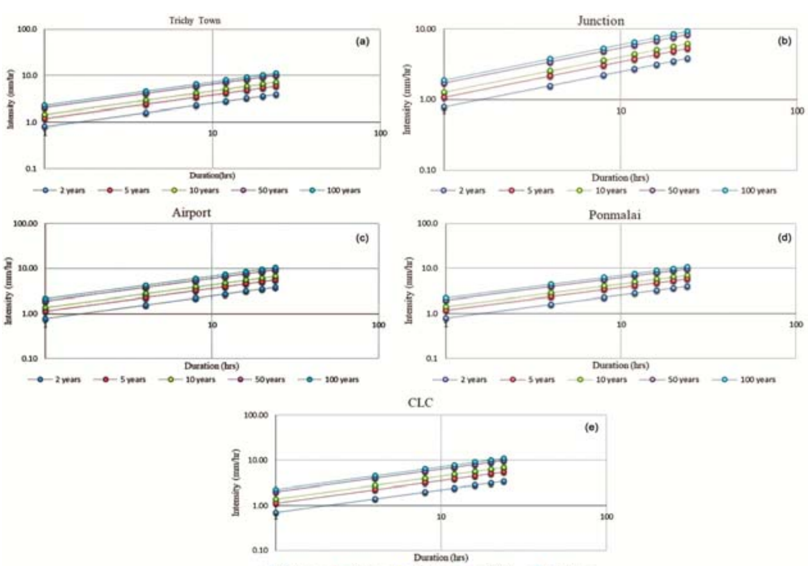

Fig. 5 — IDF curves generated by frequency distribution method for various rain gauge station in the city: (a) Trichy town, (b) Junction, (c) Airport, (d) Ponmalai, and (e) CLC compound

Log-normal distribution when compared with the other two methods. Since Gumbel method produces high rainfall intensity values with increase in return period, these values are adopted for generating iso-pluvial maps for various durations, as shown in Figure S3. The map shows that the maximum spatial distribution of rainfall of around 10 to 11 mm/hr is observed in Trichy town and Airport and the minimum distribution is in CLC compound for an increase in return period for the hours of 1, 4, 8, 12, 16, 20 and 24.

Conclusion

The present analytical study deals with the calculation of rainfall intensity for different durations and return periods for Tiruchirappalli city. The yearly, seasonal average rainfall pattern of the city is studied by linear trend analysis and shows an increase and decrease in trend. In the yearly analysis, the increase in trend is observed in the last 20 years. Similarly, increase is also observed in monsoon and non-monsoon season. The factors influencing in trend depends upon urbanization, local alteration in the hydrological cycle, and duration of rainfall intensity. The trend decreases during southwest monsoon is due to irregular rainfall pattern in the city. The three probability distribution methods are used to calculate the intensities. Amongst these methods, the Gumbel distribution method gives higher values compared to the other two methods. This method is used for generating Intensity Duration Frequency curves for 5 stations in the city. The IDF formula is used for developing curves and the constant parameters for the chosen 5 stations. The results show that the obtained parameters have a high correlation coefficient of 0.96 for Gumbel method and it is taken as a suitable distribution technique for all the stations in the city. The IDF curves and parameters generated for the study can be used to effectively manage flood risks by proper designing of flood-carrying capacity, particularly for newly designed drainage networks, to avoid existing flood risk and prevent the possibility of future flood damage.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_49(07)1269-1279_SupplData.pdf

Acknowledgments

The authors extend their thanks to State Surface and Groundwater Data Centre, Chennai for providing rainfall data.

Conflict of Interest

The author declares there is no conflict of interest.

Author Contributions

The first author NS contributed in this study by data collection, analysis, results and preparation of manuscript. The results and manuscript were reviewed and corrected by second author RN.

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