Original Research Article

Derivation of Rainfall Intensity-Duration-Frequency (IDF) Curves of Gainesville, Georgia, United States

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ABSTRACT

This research presents a set of rainfall Intensity-Duration-Frequency (IDF) curves of Gainesville, Georgia, USA for duration of 15 minutes to 24 hours, and return periods of 2, 5, 10, 25, and 100 years. Gumbel and Log Pearson Type III distributions were used to develop the IDF curves from rainfall data. The best rainfall model between Log Pearson III and Gumbel Distribution for the estimation of rainfall in the study area was determined for the different return periods and durations. The result of this study show that the intensity of rainfall increased with the increment in return periods but decreased with the increment in duration. The Gumbel and Log Pearson Type III distributions give maximum intensities of 138.17 mm/hr and 137.75 mm/hr at return period of 100 years with duration of 0.25 hours, respectively.

Keywords: IDF curves, Gumbel distribution, and Log Pearson Type III distribution

1. INTRODUCTION

Design of civil or water resources infrastructure requires information about runoff magnitudes for which the structures will be designed to withstand during their lifetime. IDF curves are widely used to evaluate rainfall events, to derive design storms and assist in designing drainage structures, culverts, bridges, and other hydraulic structures [1,2,3]. These IDF curves play a significant role in operating various hydrologic and water resources engineering projects. In order to estimate these runoff magnitudes, IDF curves are the typical hydrologic tools used by water resources, agricultural, and civil engineers. IDF curves represent a mathematical relationship between the rainfall intensity *i*, the duration *d*, and the return period T [4,5]. The rainfall IDF curve illustrates the relationship between mean precipitation intensity and frequency of occurrence (the inverse of the return period) for different time intervals of a given duration [6].

Developing IDF curves for most countries around the world remains a major challenge because of the limited availability of sufficient long-term rainfall data with adequate spatial distribution [5,7]. Development of IDF curves is based on probabilistic analysis of past records of extreme rainfall [5]. There are several methods that can be used to generate rainfall IDF Curves. Commonly used distributions in IDF and other similar studies include Gumbel, Pearson Type III, and Log normal distributions [8]. [9] found that Gumbel and Log Pearson

Type III distributions fitted well to measured data compared to Log-normal distribution. [4] proposed formulation of IDF relationships, which constitutes an efficient parameterization, facilitating the description of the geographical variability and rationalization of IDF curves.

The objective of this study focuses on the development of IDF curves for the Gainesville, Georgia, USA. Two different frequency distributions namely the Gumbel distribution and the Log-Pearson Type III distributions were fitted to the rainfall data to obtain rainfall intensities for selected return periods (2, 5, 10, 25, 50 and 100 years) and durations (0.25, 0.5, 0.75, 1, 2, 6, 12 and 24 hours).

2. MATERIAL AND METHODS

2.1 DESCRIPTION OF AREA OF STUDY

The city of Gainesville is the county seat of Hall County, Georgia, United States. It is located in central Hall County at 34°18′16″N 83°50′2″W (Fig. 1). The city has a total area of 91.48 km^2, of which 86.43 km^2 are land and 5.05 km^2, or 5.52%, are water [10]. Parts of Gainesville lie along the shore of one of the nation's most popular inland water destinations, Lake Lanier. The average annual temperature in Gainesville is 15.5^{o}C [11]. The mean monthly temperature ranges from 5.1^{o}C in January to 25.4^{o}C in July, with variation in temperature. The average annual precipitation during 1991–2020 was 1411.2 mm.

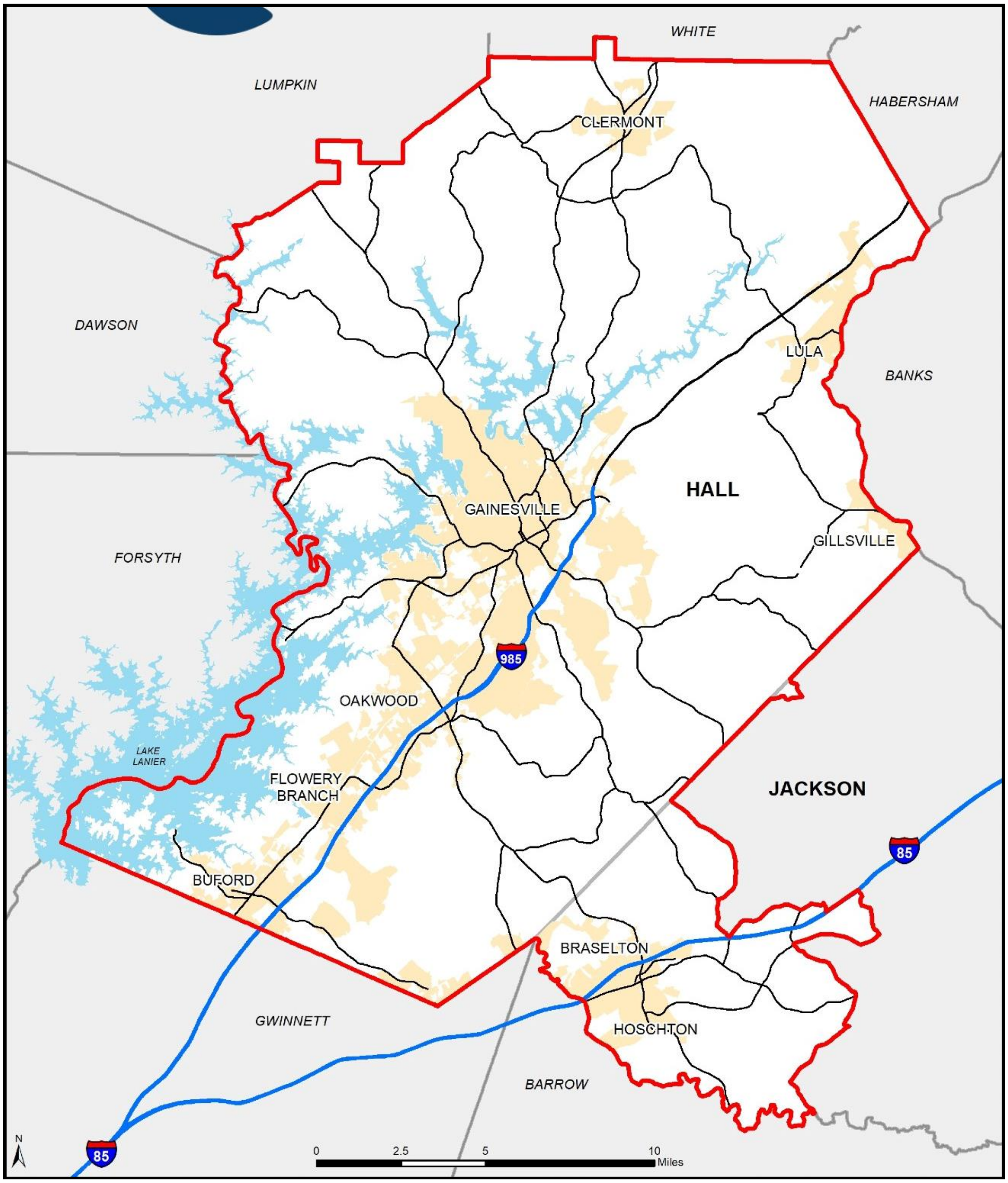

Fig. 1. Map showing location of the study area [12]

2.2 Data collection and analysis

In this study, rainfall data from Dawsonville, Georgia rain gauge station located at Latitude: 34.4206 and Longitude: -84.1039 has been selected for determination of IDF curves of Gainesville, Georgia. The station is located about 37 km from the study area. Historic rainfall data corresponding to the period from 1978 to 2004 (26 years) for Dawsonville was obtained from U.S. National Oceanic and Atmospheric Administration (NOAA) National Weather

Service Hydrometeorological Design Studies Center [13] Precipitation Frequency Data Server was used to develop the IDF curves for the study area. From the data base, the annual extreme values of precipitation for selected durations (15 minutes, 30 minutes, 45 minutes, 1 hour, 2 hours, 6 hours, 12 hours, and 24 hours) were extracted for Dawsonville, GA for each year. Precipitation analyses were performed for eight rainfall durations, and six return periods. Precipitation analyses were performed for eight rainfall durations, and six return periods. The analyses were conducted for return periods of 2, 5, 10, 25, 50, 100 years by utilizing Gumbel and Log-Pearson Type III distributions, which are commonly used frequency analysis methods. The rainfall intensity is the time rate of precipitation, which is expressed in depth per unit of time (mm/hr or in/hr). The rainfall intensity, i_T for the return period T is obtained from equation 1.

$$i_T = \frac{x_T}{T_D} \qquad (1)$$

Where i_T: rainfall intensity, mm/hr

x_T: rainfall depth in mm

T_D: rainfall duration in hours for Gumbel distribution

2.3 Gumbel Distribution

[14] presented the theory of extremes by considering the distribution of the largest or the smallest values for a set of samples of different distributions. It is the most widely used distribution for IDF analysis due to its appropriateness for modelling of maximum data. The design rainfall depth for a given period can be expressed by the following equation [15].

$$x_T = \bar{x} + K_T s \qquad (2)$$

Where x_T: rainfall depth in mm

$\bar{x}$: average of annual precipitation data

s: sample standard deviation of precipitation data

K_T: is the Gumbel frequency factor given by equation 3

T: return period

The Gumbel frequency factor, K_T *is* calculated using equation (3).

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

2.4 Log Pearson Type III (LPT III) Distribution

Log Pearson Type III distribution is one commonly used probability distribution for obtaining the rainfall intensity values. The frequency precipitation for this model can be obtained by the same approach as Gumbel distribution method (equation 2), but the mean and the standard deviation (s) are calculated based on the natural logarithms of the original data values as shown in the equation (4) [8,1,16]. In addition, the frequency factor, K_T in this distribution is a function of both the return period (T in years) and the skewness coefficient. In the LPT III method, frequency factors, K_T values can be obtained from standard tables [17,18]. K_T values have been obtained for the desired return periods by making a set of interpolation between values of standard table.

$$\log x_T = \overline{logx} + K_T S_{\log x} \quad (4)$$

Where:

$logx_T$: logarithm of precipitation depth for any rainfall duration with specified return period *T* (in years)

$\overline{\mathrm{logx}}$: average of logx values

$\mathrm{S_{logx}}$:standard deviation of logx values, and

3. RESULTS AND DISCUSSION

Computed values frequency factors, K_T (for return periods, T = 2, 10, 25, 50, and 100 years) and the rainfall amounts (mm/hr) with respect to specific durations used in Gumbel distribution are given in Table 1. In Gumbel Distribution analysis the frequency factor K_T increases with rise of the return period for any rainfall duration (Table 1).

The frequency factor, K_T in the Log Pearson Type III distribution is a function of both the return period and the skewness coefficient. For example, for Log Pearson Type III distribution frequency factor for a 15-minute duration and 10-year return period with coefficient of skewness of 0.370 was calculated to be 1.310. Table 4 gives the computed summary of K_T values for Log-Pearson distribution for various durations and different return periods computed. Calculated values of K_T for six return periods in Log Pearson Type III distribution are given in Table 2. The intensity values (mm/hr) for eight durations and six return periods using Log Pearson III method are presented in Table 3.

Table 1. Calculated K_T and rainfall values (mm/hr) and with respect to rainfall duration and return period using Gumbel distributions.

Duration (hr.)	Return Periods, T					
	2	5	10	25	50	100
	Frequency Factors, K_T					
	-0.1600	0.7200	1.3000	2.0400	2.5900	3.1400
0.25	82.950	97.730	107.520	119.890	129.070	138.170
0.5	55.410	69.350	78.580	90.240	98.890	107.480
0.75	44.540	54.660	61.360	69.830	76.110	82.340
1	33.620	40.830	45.600	51.640	56.120	60.560
2	21.500	26.000	28.980	32.750	35.540	38.310
6	10.050	11.600	12.620	13.920	14.880	15.830
12	6.150	7.330	8.100	9.090	9.810	10.540
24	3.670	4.610	5.240	6.030	6.610	7.190

Table 2. Log-Pearson frequency factors, K_T for various durations and return periods.

		Frequency Factor, K_T					
Rainfall Duration (hr.)	**Skewness Coff. (*G*)**	**Return Periods, T**					
		2	**5**	**10**	**25**	**50**	**100**
0.25	0.370	-0.060	0.820	1.310	1.870	2.250	2.600
0.5	0.010	0.000	0.840	1.280	1.750	2.060	2.330
0.75	-0.030	0.000	0.840	1.280	1.740	2.040	2.310
1	-0.100	0.020	0.850	1.270	1.720	2.000	2.250
2	0.240	-0.040	0.830	1.300	1.830	2.180	2.500
6	0.140	-0.020	0.830	1.300	1.800	2.130	2.430
12	0.580	-0.100	0.800	1.330	1.930	2.350	2.740
24	0.300	-0.050	0.820	1.310	1.850	2.210	2.540

Table 3: Calculated rainfall values with respect to duration and return period using Log Pearson Type III distribution.

Rainfall Duration (hr.)	**Return Period, T**					
	2	**5**	**10**	**25**	**50**	**100**
0.25	83.230	98.340	108.050	120.080	128.950	137.750
0.5	55.960	70.420	79.420	90.300	98.120	105.710
0.75	45.140	55.550	61.870	69.370	74.680	79.770
1	34.180	41.590	45.990	51.120	54.670	58.040
2	21.620	26.210	29.130	32.730	35.370	37.980
6	10.160	11.720	12.660	13.770	14.550	15.300
12	6.130	7.320	8.120	9.140	9.920	10.720
24	3.660	4.620	5.270	6.090	6.710	7.340

The IDF curves obtained by fitting the Gumbel and the Log Pearson Type III distributions to rainfall data are respectively presented in Figs. 2 and 3. The Gumbel distribution gives a maximum intensity of 138.17 mm/hr at return period of 100 years with duration of 0.25 hours and minimum intensity of 3.67 mm/hr at return period of 2 years with duration of 24 hours. The Log Pearson Type III distribution gives a maximum intensity of 137.75 mm/hr at return period of 100 years with duration of 0.25 hours and minimum intensity of 3.66 mm/hr at return period of 2 years with duration of 24 hours.

The rainfall intensity values obtained using the Gumbel and the Log Pearson Type III distributions are close for almost all return periods and rainfall durations. As shown in Figs. 2 and 3 the intensity of rainfall increased with the increment in return periods but decreased with the increment in duration in any specified return period.

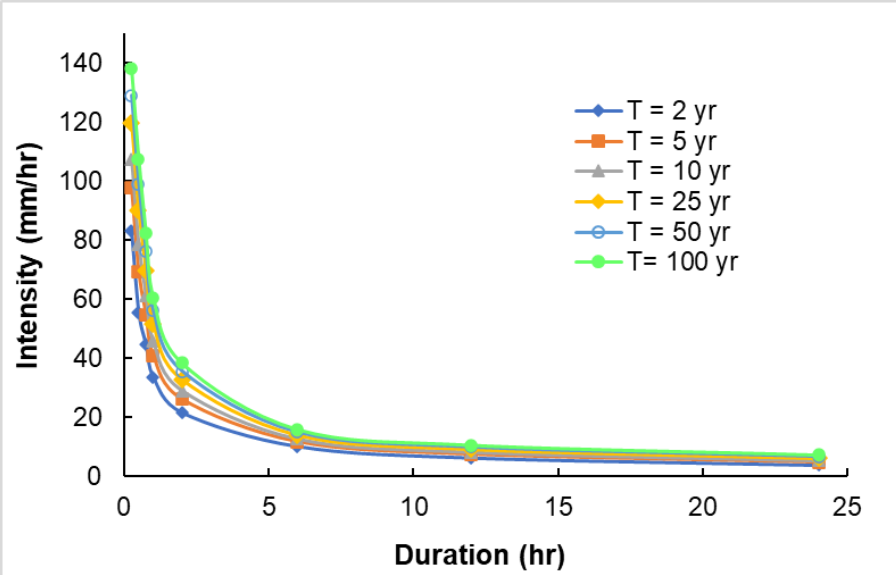

Fig. 2. IDF curves of Gainesville, GA for the duration of 0.25 to 24 hrs and six events by Gumbel distribution.

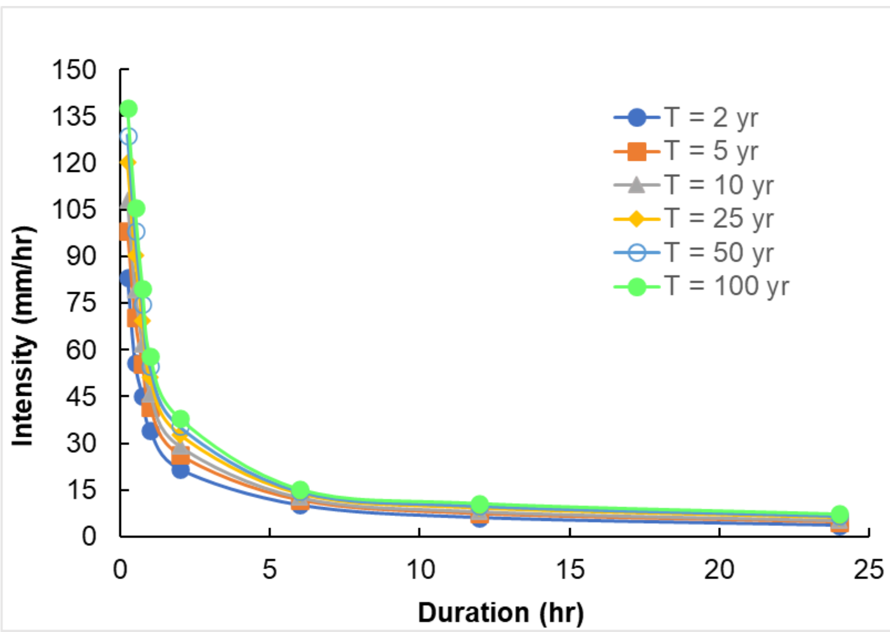

Fig. 3. IDF curves of Gainesville, GA for the duration of 0.25 - 24 hrs and six events by Log Pearson Type III distribution.

3.1 Goodness-Of-Fit Test

The chi-square (χ^2) goodness-of-fit test is used to determine whether the observed frequencies are significantly different from expected frequencies or not in one or more categories. Chi-square statistic between observed and expected frequencies is given by equation (5) below,

$$\chi^2 = \sum \frac{(O-E)^2}{E} \tag{5}$$

Where,

O: observed frequency.

E: expected frequency.

The smaller the difference between the observed and the expected frequencies (O – E) in the equation (5), the smaller the chi-square (χ^2) will be, indicating a good fit; otherwise, it is a poor fit. Thus, a chi-squared test for goodness of fit is always right tail of the chi-square distribution. The χ^2 critical value can be obtained in a table of probabilities for the chi-square distribution with degrees of freedom (*df*) = *k-1*, where *k* represents the number of categories. The goodness-of-fit tests were used to choose the best statistical distribution between the Gumbel and Log Pearson type III techniques. Table 4 shows the results of the chi-square goodness of fit test on annual series of rainfall.

Table 4. Results of chi-square goodness-of-fit test on annual maximum rainfall.

Distribution	Duration in minutes							
	15	30	45	60	120	360	720	1440
Gumbel	0.281	0.700	0.716	0.572	0.906	0.700	1.566	2.844
Log Pearson Type III	0.272	0.649	0.645	0.490	0.870	0.637	1.592	2.870

It was found that the chi-square values obtained for the Gumbel and Log Pearson type III methods, the data fit the distributions at the level of significance of α = 0.05, which yields χ^2 critical < 3.84.

4. CONCLUSION

In this study IDF curves for the city of Gainesville, Georgia USA for rainfall durations of (15 minutes, 30 minutes, 45 minutes, 1 hour, 2 hours, 6 hours, 12 hours, and 24 hours) have been obtained. The analyses were conducted for return periods of 2, 5, 10, 25, 50, and 100 years by utilizing Gumbel and Log-Pearson Type III distributions, which are commonly used frequency analysis methods. The results showed that rainfall intensity reduced as the duration of the storm increased, and if the return period of the rainfall was large, rainfall of any specific duration showed a higher intensity. The Gumbel and Log Pearson Type III distribution models developed in this study are in agreement with literature theory which shows higher intensity occurring at lower duration and lower intensity at higher duration [19].

The chi-square values for both Gumbel and Log Pearson type III distributions are significantly below the χ^2 critical region and are very close at all the return periods and have the same trend, it is difficult to say that one distribution is better than the other. Further research is recommended with long-term rainfall data to verify the results obtained for the study area. The result of this study can be used by water resource planners, managers, designers, and decision makers for the city of Gainesville, Georgia.

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