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Development of intensity duration frequency curve, equation and nomograph for Udaipur

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■ **ABSTRACT :** For most water engineering projects, estimation of peak intensity of rainfall for different return periods using IDF curves are necessary. These curves are pre-requisite for planning, design, management of various hydraulic structures, urban storm water drainage and water conservation structures. IDF curves can be developed through the application of appropriate statistical distributions based on the historic records of rainfall data. In this paper a mathematical relationship has been developed between maximum intensity of rainfall and Return Period (5, 10, 25, 50, 100, 200, 300, 400, 500 and 1000 years) for various rainfall duration (1, 2, 3, 6, 12 and 24 hour) using best fit distribution. 28 years (1986-2014) of rainfall mass curves have collected and analyzed to get rainfall intensities for various durations from raingauge station installed in Meteorological Observatory, College of Technology and Engineering campus, Udaipur. Around 03 different probability distributions model (Gamble's extreme value type I, Logpearson type III, Normal distribution) were used to evaluate maximum rainfall intensity for various durations. Kolmogorov-Smirnov and Chi-squared tests were used for the goodness of fit of the probability distributions. Results showed that Gumbel distribution found to be have least critical values for both the tests for all durations hence consider as the best fit distribution for given sample population. The derived precipitation intensities were utilized for generation of intensity duration frequency curve and equation. A nomograph has also developed with 03 parallel parameter scale using method suggested by Luzzadar (1964) to represent this relationship in a graphical form.

■ **KEY WORDS :** Chi-square, Kolmogorov-smirnov, Nomograph, IDF equation

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Out of rainfall characteristics, rainfall intensity is by far the most important one. The rainfall intensity is inversely proportional to its duration of occurrence and directly proportional to the return period. Intense storm generally last for very short durations. In a specified return period (frequency) and for a given duration of occurrence, storm of higher intensity is less likely to be occur then a storm of lower intensity. Thus the analysis of rainfall intensities, duration and frequency at any location provides very valuable information for the use of designed engineer or hydrologists, who are engaged in designing water control structures, for controlling flood from small watersheds. With the aid of this tool, the occurrence of rainfall intensities of various durations can be predicted for flood control structures. Hydrological design are done on the basis of safely conveying runoff expected from rainstorm of specified frequency, intensity and duration.

The establishment of such relationships was done as early as 1932 (Chow, 1988) and DuPont and Allen, 2006). Since then, many sets of relationships have been constructed for several parts of the globe. Babu (2001) developed the rainfall intensity-duration-return period equation and nomographs for 24 locations along with the general equation for nomographs for MP state using Gumbel's extreme distribution for various return periods. Ibrahim (2012) has derived IDF relationship at Najran and Hafralbatin regions in the Kingdom of Saudi Arabia. Gumbel and the Log Pearson Type III distribution (LPT III) were used to evaluate designed values. Dirk (2013) collected 101 years daily rainfall data from Royal Meteorological Institute at Brussels, Belgium for the development of such curve From these data 10-minute precipitation depths, the maximum value in each year for various time periods were determined. The annual maximum series were subsequently analyzed with the help of the Gumbel distribution. Tfwala *et al.* (2017) estimated the precipitation intensities and their uncertainties (lower and upper limits) for durations of 0.125, 0.25, 0.5, 1, 2, 4, and 6 h and return periods of 2, 10, 25, 50 and 100 years in the Ghaap plateau, Northern Cape Province, South Africa using the Generalized Extreme Value (GEV) distribution to develop IDF curves.

METHODOLOGY

Description of study area:

Udaipur district is situated between 23^0 40' and 25^0 30' north latitude and 73^0 0' and 74^0 35' east longitude. It is located in the south eastern part of Rajasthan and lies in Aravali ranges. (Google map, cited on 25 May. 2019).

Collection of data:

Daily rainfall mass curves from 1986-2014 (28 Years) have collected from raingauge station installed in meteorological observatory station in CTAE campus, Udaipur. From these bulk data, the dominant and maximum intensity of rainfall for durations of 01, 02, 03, 06, 12 and 24 hr. have determined (one for each years).

Tests for goodness of fit:

Measures of goodness of fit typically summarize the discrepancy between observed values and the values expected under the model in question.

In stochastic hydrology two tests are most widely used to test whether or not a particular distribution adequately fits a set of observation.

Chi-square test:

The chi-squared test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more categories (Raghunath, 2006).

$$\chi_c^2 = \sum_{i=1}^{N} \frac{(N_i - E_i)^2}{E_i}$$

where N is the total number of observations, N_i is the observed relative frequencies, and E_i is the theoretical or probable relative frequencies. The hypothesis that the data follows a specific distribution is accepted if,

$$\chi^2_{data} \le \chi^2_{\alpha-1,\,k-p-1}$$

where α is the significance level and K-P-1 is the degree of freedom. Test is carried out at 10% significance level.

Kolmogorov-smirnov test:

In statistics, the Kolmogorov–Smirnov test is a non-parametric test of the equality of continuous (or discontinuous), one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution. The absolute difference between theoretical cumulative probability F(x) and calculated cumulative probability P(x) is calculated.

$$\Delta = \text{Maximum}\,|P(x) - F(x)|$$

The critical value of kolmogorov-smirnov test statistics Δ_α is obtained from the Kolmogorov-smirnov table for 10% significance level. If $\Delta < \Delta\alpha$, accept the hypothesis. For sample size more than 50, use following formula for critical values of Kolmogorv-smirnov test statistics.

$$\Delta_\alpha = \frac{122}{\sqrt{N}} (\alpha = 10\%)$$

Probability distribution models:

Gumbel's extreme value distribution model:

Gumbel found that the probability of occurrence of an event, equal or larger than a value is given by the equation,

$$P(X \ge x_0) = 1 - e^{-e^{-y}}$$

where P is the probability of occurrence, X is the event of the hydrologic series, x_0, is the desired value of the event, Y is the reduced variable = α (x-a)

$$\alpha = \bar{x} - 0.45005\sigma_z$$

σ_x= the standard variation

$$y = \frac{1.2825(x - \bar{x})}{\sigma_x} + 0.577$$

$$y_p = -\ln[-\ln(1-p)]$$

Since T=1/p, the value of the reduced variate or the value of given return period T in terms of natural logarithms is given as

$$y_t = -\left[\ln\ln\frac{T}{T-1}\right]$$

Log-pearson type III distribution:

It was Karl's Pearson (1930) who developed this method. It is recommended to convert the data series to logarithms.

z = log x

Applying general equation, z_T data series can be expressed a

$$z_T = \bar{z} + K_f\sigma_z$$

K_f is determined by using the standard table for a specific value of c_z and recurrence interval T.

Formula for $\bar{z}$, σ_z and c_z given as;

$$\bar{z} = \frac{\sum z_i}{N}$$

$$\sigma_z = \sqrt{\frac{\sum(z - \bar{z})^2}{N - 1}}$$

$$c_z = \frac{N\sum(z - \bar{z})^2}{(N-1)(N-2)\sigma_z^3}$$

$$x = 10^z$$

Normal distribution:

It is also a most widely used method in extreme value distribution

$$X_T = \mu + K_T\sigma$$

$$K_T = \frac{X_T - \mu}{\sigma} = Z$$

$$K_T = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}$$

0<P<0.5 However the value of must be ranges from 0 to 0.5

Estimation of the constants for IDF relationship:

The maximum intensity varies inversely with duration and directly with return period. Generally an equation of the form (Ghnshyamdas, 2014).

$$I = \frac{kT^x}{t^n}$$

Taking logarithms on both sides transforms equation into a linear form.

$$I = \frac{C}{(t)^n}$$

$$C = kT^x$$

$$\text{Log } I = \text{Log } C - n \text{ Log } t$$

Plot the values of (log I) on the y – axis and the value of (Log t) on the X- axis for all the recurrence. From the graphs (or mathematically) we find the value of (n) for all recurrence intervals where n represents the average slope of the straight line. Then find out the average n value by using the following equation.

$$n_{avg} = \frac{\sum n}{N}$$

where N represents the total number of recurrence intervals. On transforming

$$\text{Log } C = \text{Log } k + x \text{ Log } T$$

Plot the values of (log C) on the y- axis and the values of the (log T) on the x-axis to find out the values of parameters represents the slope of the straight line (x) and intercept (antilog =k). Finally by substituting the parameters equation is developed.

Development of nomograph:

A nomograph is an alignment chart consisting of a set of suitably graduated parallel scales. The procedure suggested by Luzzadar (1964) was adopted for development of nomograph. The general equation of IDF is write on the logarithmic scale

$$\text{Log } I = x\text{Log } T - n \text{ Log } t$$

The limits of the nomograph will fixed (T vary from 5 to 100 years and t from 1 to 24 hours)

1) The length of outer scale is selected and functional modulus for T and t is workout with the help of the equations given below:

$$M_T = \frac{10}{x \text{ Log } T_{max} - x \text{ Log } T_{min}}$$

$$m_t = \frac{10}{n \text{ Log}(t_{max}) - n \text{ Log}(t_{min})}$$

Determine the plotting equation for Ta $T_p = M_T \, x \text{ LOg} T$, $t_p = m_t n\text{Log}(t)$

Determine functional modulus and plotting eq. I

$$m_I = \frac{M_t \times m_t}{M_T + m_t}$$

$$I_P = m_t \text{Log}_I$$

The length of I will check, which is same or not as in case of T and t scale

$$I_L = m_I \text{ Log } I_{max} - m_I \text{ Log } I_{min}$$

Determine the scale spacing ratio using equation

$$S_R = \frac{M_T}{m_t}$$

Steps followed:

At first collected the intensity data of some severe most storm (annually) of rainfall for 1, 2, 3, 6, 12 and 24 h.

– Perform Chi-square and Kolmogorov-smirnov test statistics in order to get best fit distribution.

– Then evaluate intensity of rainfall for various return periods using best fit probability distribution Same procedure is adopted for various durations.

– Then develop a graph on a simple arithmetic paper showing the relationship between these parameters and also establish a relationship between these parameters using graphical method discussed above.

– Develop a nomograph using the procedure explained above using scale developed in AUTOCAD software.

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Goodness of fit result summary:

Both the tests are carried out at 10 per cent significance level for various durations. Critical values of both the test for a particular degree of freedom and at particular significance level obtained from standard tables

Out of 03 distribution models, Gumbel distribution found to be have least critical values in both the test for all durations. Hence considered as the best fit for given analysis.

Developed equation:

By substituting the constants, IDF equation has developed.

Table 1 : Goodness of fit test result for max. Intensity of rainfall for various durations for Udaipur

Sr. No.	Rainfall duration in hr.	Calculated and critical values	Distribution Model					
			Gumbel (DOF=2)		Logpearson type III (DOF=2)		Normal (DOF=3)	
			Chi-square test	Kolmogorov-Smirnov Test	Chi-square test	Kolmogorov-Smirnov Test	Chi-square test	Kolmogorov-Smirnov Test
1.	01 Hr. max.	Calculated values	1.300	0.105	11.022	0.166	4.533	0.174
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
2.	02 Hr. max.	Calculated values	1.223	0.086	8.321	0.173	5.266	0.146
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
3.	03 Hr. max.	Calculated values	4.720	0.065	13.809	0.147	14.357	0.181
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Rejected	Accepted	Rejected	Accepted
4.	06 Hr. max.	Calculated values	7.376	0.112	8.193	0.213	9.468	0.123
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
5.	12 Hr. max.	Calculated values	4.193	0.064	9.197	0.230	4.710	0.087
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Accepted	Rejected	Accepted	Accepted
6.	24 Hr. max.	Calculated values	0.826	0.052	2.939	0.247	8.965	0.127
	intensity	Critical Values	9.210	0.228	9.210	0.228	11.345	0.228
		Result	Accepted	Accepted	Accepted	Rejected	Accepted	Accepted

Table 2 : Observed data of maximum intensity of rainfall in mm/hr for different time duration and return period using Gumbel's probability distribution for Udaipur

Sr. No.	Duration in hr.	Return period in years									
		5	10	25	50	100	200	300	400	500	1000
1.	1	51.04	61.94	75.70	85.91	96.05	106.15	112.05	116.23	119.47	129.54
2.	2	28.70	34.54	41.92	47.40	52.83	58.24	61.41	63.65	65.39	70.79
3.	3	22.01	26.57	32.33	36.60	40.84	45.06	47.53	49.28	50.63	54.84
4.	6	12.42	14.86	17.95	20.23	22.51	24.77	26.09	27.03	27.75	30.01
5.	12	7.41	8.98	10.98	12.45	13.92	15.38	16.24	16.84	17.31	18.77
6.	24	4.05	4.86	5.89	6.66	7.42	8.18	8.62	8.93	9.18	9.93

Table 3 : Calculations of determining the constants for IDF relationship for Udaipur

Sr. No.	Return period 1	LogT 2	n (slope) 3	Log C (Intercept) 4	Parameters
1.	5	0.699	0.789463	1.708238	01. n (average of column 3) = 0.793
2.	10	1.000	0.79095	1.790542	
3.	25	1.398	0.79222	1.876216	02. x (Slope of Log T V/s Log C graph) = 0.167
4.	50	1.699	0.792905	1.930372	
5.	100	2.000	0.793444	1.978179	03. k (Antilog of intercept of Log T V/s Log C graph) = 42.088
6.	200	2.301	0.79388	2.021092	
7.	300	2.477	0.7941	2.044323	
8.	400	2.602	0.794242	2.044323	
9.	500	2.699	0.794345	2.071906	
10.	1000	3.000	0.794634	2.106716	

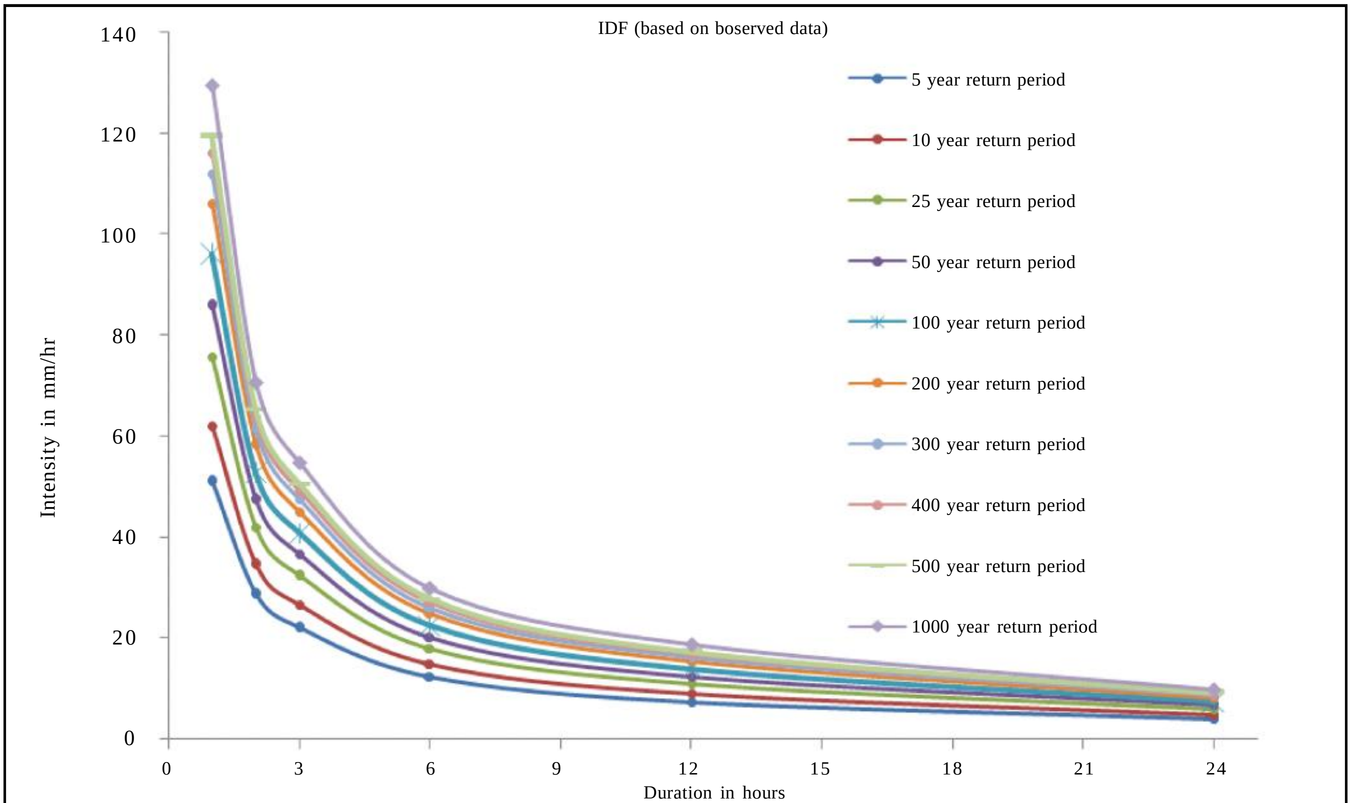

Fig. 1 : Intensity-duration-frequency curve based on observed data for Udaipur

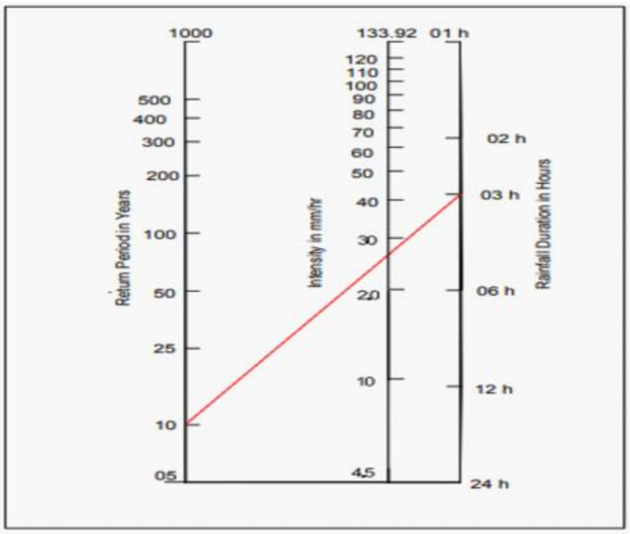

Fig. 2 : Nomograph of established IDF equation for Udaipur

$$I = \frac{42.088T^{0.167}}{d^{0.793}}$$

where d is the duration of rainfall in hour, T is the return period in years and I is the maximum intensity of rainfall in mm/hr.

Conclusion:

28 years is collected from CTAE farm meteorological station Udaipur. The data were analyzed to get intensity in mm/hr for the duration of 01, 02, 03, 06, 12 and 24 hr. The sample data were checked to get best probability distribution using chi-square and KS tests. Gumbel distribution found to be best fit for this analysis. Designed value of rainfall intensity were evaluated using Gumbel's distribution model for 05, 10, 25, 50, 100, 200, 300, 400, 500, and 1000 years return period for each durations separately. A curve is drawn between maximum intensity of rainfall versus rainfall duration for various return periods. A relationship was derived (IDF equation) using graphical method (Ibrahim, 2012). Based on the developed equation, nomograph has developed using AUTOCAD 2017 software. Babu (2001) developed IDF equation for multiple locations in India based on observed records. Same trend was observed but magnitude is less as compare to Babu's data from equation derived for Jodhpur. So such study is very necessary and need to be revised for this area and can be used for entire southern part of Rajasthan.

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