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Development of Intensity Duration Frequency (IDF) Curves for Upper and Lower Kuttanad, Kerala

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Abstract: ***Rainfall extremes such as their magnitude and duration are basically used in intensity duration frequency curves (IDF) relationships and this will be helpful in design of hydraulic structures, drainage systems, water resource projects etc. The aim of this study is to define IDF curves for upper and lower Kuttanad region of Kerala using Gumbel distribution. Historical hourly rainfall data obtained from Indian meteorological department, Trivandrum is used in this study. Many distributions are available to obtain the intensity duration frequency curve but Gumbel distribution is used here as it takes extreme values. This relationship is determined by means of statistical analysis of rainfall data. The distributions were carried out with return periods of 2, 5, 10, 50 and 100 years with durations of 1, 2, 3, 6, 12 and 24 hours. The obtained results were compared with the values obtained from empirical equations.***

Keywords: ***Intensity-Duration-Frequency Relationships Return Period, Gumbel's Distribution, Empirical equations.***

I. INTRODUCTION

In hydrologic risk analysis and design, quantification of the extreme precipitation is an important factor. This will be helpful in safe planning toward weather emergencies, engineering structure design, management of reservoirs etc. Thus evaluation of extreme rainfall plays a major role in hydrologic studies. A major means of this assessment is IDF analysis which is an empirical relationship between the rainfall intensity, duration and return period. It is a curve in which duration is taken as abscissa, intensity as ordinate and return period as third parameter. It has a variety of applications in land use planning, roads, soil conservation practices, sewer management, routing of storm water etc. Many studies have been done in the past to obtain IDF curves for various parts of the world. Koutsoyiannis (1998) have done a study to establish IDF curve using data from recording and non-recording gauges. The existing IDF curves are updated by means of newly developed Regional frequency analysis techniques. Al-Khalaf (1997) has said that IDF relationships are based on regions and should be done separately for different regions. Kim et al (2002) have improved the accuracy of IDF curves by using a method which divided long and short duration. IDF was derived using cumulative distribution function of the study area and using multi- objective genetic algorithm. When rainfall data is not available easily, this can be done using empirical equations. The rainfall intensities are obtained based on the geographical locations (Ram Babu et al. 1979).

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II. STUDY AREA

The study area is considered as the region covering Alappuzha and Kottayam districts of Kerala called as upper and lower Kuttanad. This is a well-known area for the paddy fields and geographical locations which has the lowest altitude (4 to 10 feet below sea level). Major river basins in the study area include achankovil, pamba and manimala. The hourly rainfall data were obtained for Alappuzha station from Indian meteorological department, Trivandrum. Kuttanad is known as the rice bowl of Kerala because of the vast extends of paddy cultivation. Kuttanad is basically divided into three components namely Upper, Lower and North Kuttanad. In this study we take into account Upper and Lower Kuttanad. This land is continuously affected by floods which occur during most south west monsoon season. A channel to transport water from this area to the sea is called as the thotapally spillway.

III. METHODOLOGY

Probability density function (PDF): it suggests whether a random variable lies within a particular range. Here the random variable is the rainfall intensity (mm/hr). The equation is as follows:

$$P[x_1 < X < x_2] = \int_{x_1}^{x_2} f(x)dx$$

Where f(x) is the function of distribution and X is the intensity of rainfall. Cumulative distribution function (CDF): It suggest the probability of a random variable less than a particular value (f(x))

$$F(x) = P[X \leq x] = \int_{-\infty}^{x} f(x)dx$$

Here x is the threshold value which is considered as flood. If f(x) is considered as probability of non exceedance then

$$F(x) = 1 - P$$

Where, P is the exceedance probability.

$$F(x) = 1 - \frac{1}{T}$$

Gumbel distribution: There are many distributions for generating IDF curve but Gumbel distribution uses the extreme values.

The PDF of this distribution is given by

$$f(x) = \frac{1}{\alpha} e^{\left\{-\frac{(x-\beta}{\alpha} - e^{\left\{-\frac{(x-\beta)}{\alpha}\right\}}\right\}}$$

The CDF is obtained as

$$F(x) = e^{-e^{-\left(\frac{x-\beta}{\alpha}\right)}}$$

It has two parameters which are location parameter μ and scale parameter $\beta > 0$.

Parameter estimation: In order to estimate the parameters, the method of moments is used. The n^{th} moment is

$$\mu_n = \int_{-\infty}^{\infty} (x-c)^n f(x)dx$$

The zeroth and first moments are taken as origin and so the value of c is 0. Since the mean of the distribution is taken as first moment, the values of c and n can be taken as 0 and 1 respectively.

$$\alpha = \frac{\sqrt{6}}{\pi}(S_d) \text{ and } \beta = \mu - 0.5772\alpha$$

Where, S_d is the standard deviation and μ is the mean

The transformation $y = \frac{x-\beta}{\alpha}$ can be used to simplify the expression of the PDF and CDF.

The CDF may be rewritten as,

$$F(y) = e^{-e^{-y}}$$

The above function is invertible.

$$y = -\ln(-\ln(F(x)))$$

$$y = -\ln\left(-\ln\left(1 - \frac{1}{T}\right)\right)$$

$$y = -\ln\left(\ln\left(\frac{T}{T-1}\right)\right)$$

The above can be written as $x = \beta + \alpha y$

$$x = \mu - 0.5772\frac{\sqrt{6}}{\pi}(S_d) - \frac{\sqrt{6}}{\pi}(S_d)\ln\left(\ln\left(\frac{T}{T-1}\right)\right)$$

$$x = \mu - \frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right)S_d$$

The Gumbel distribution uses the following equation proposed by chow:

$$x = \mu + K_T S_d$$

Where x is the intensity in mm/hr and K_T is the is the frequency factor. This can be obtained from comparing both the equations

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

Where, T is the return period.

IV. RESULTS AND DISCUSSION

From the hourly rainfall measurements of Alappuzha station, the cumulative values for the durations 1, 2, 3, 6, 12 and 24 hours were obtained. The maximum values for each duration was to found out for the available years. The intensity was calculated by dividing the rainfall depths with the durations. The mean (μ) and standard deviation (S_d) of each of the durations are calculated. The frequency factor is obtained as

Table 1: Value of Frequency Factor for different Return Periods

Duration (hrs)	Intensity values (mm/hr) for Return Period of				
	2 Years	5 Years	10 Years	50 Years	100 Years
K_T	-0.16427	0.71945	1.304563	2.59228	3.13661

Once the frequency factor was calculated, the rainfall intensity has to be calculated using the equation for Gumbel distribution

$$x = \mu + K_T S_d$$

The following table depicts the variation of rainfall intensity with duration for the given return periods. For any given storm, the intensity increases with the return period. The shortest duration event shows the highest intensity. Sherman (1983) devised a method by which the intensity can be calculated without the rainfall data. An empirical equation was obtained for this which depends on the return period and duration.

$$i = \frac{k \times T^a}{(t+b)^n}$$

Where k, a, b and n are constants which depend on the geographical location, I is the rainfall intensity in cm/hr and T is the return period. Ram Babu et al. (1979) found the value of these constants for 42 stations. The values were obtained as 6.672, 0.1536, 0.5 and 0.8158 for k, a, b and n respectively. The estimated values are obtained as follows

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Table 2: Intensity-Duration-Frequency Relations obtained using Gumbel's method

Duration (hrs)	Intensity values (mm/hr) for Return Period of				
	2 Years	5 Years	10 Years	50 Years	100 Years
1H	51.317	59.37	64.701	76.43	81.396
2H	36.146	41.43	44.93	52.63	55.89
3H	26.22	30.085	32.65	38.274	40.653
6H	16.228	18.605	20.179	23.643	25.1076
12H	9.62	11.047	11.97	14.0715	14.96
24H	5.369	6.179	6.716	7.897	8.3963

Table 3: Intensity-Duration-Frequency Relations obtained using the Empirical Equation

Duration (hrs)	Intensity values (mm/hr) for Return Period of				
	2 Years	5 Years	10 Years	50 Years	100 Years
1H	53.317	61.37	68.27	87.41	97.23
2H	35.14	40.46	45	57.62	64.09
3H	26.71	30.75	34.2	43.79	48.71
6H	16.12	18.55	20.54	26.43	29.4
12H	9.45	10.88	12.11	15.5	17.24
24H	5.46	6.28	6.99	8.95	9.95

While comparing the results, it was seen that the values obtained from the Gumbel distribution and the empirical equations are more or less the same. The relationship between the rainfall intensity and the duration can be represented in the form of a graph known as intensity duration frequency curve.

The development of IDF curves requires that a frequency analysis be performed for each set of annual maxima, one each associated with each rainfall duration

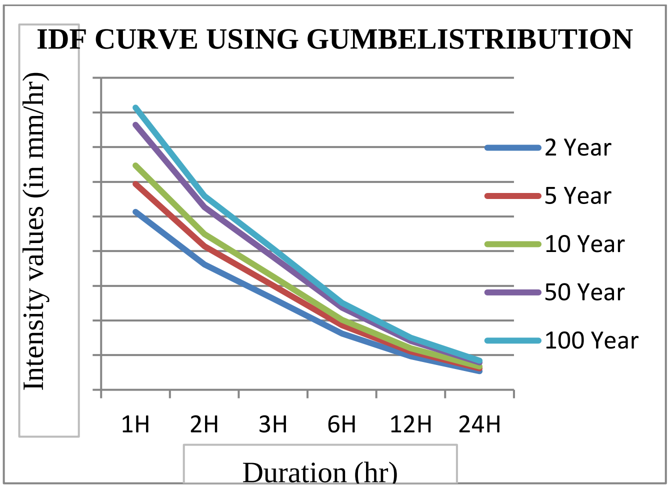

Fig 1: Intensity-Duration-Frequency Curve for the Study Area using Gumbel's method

The rainfall intensities obtained for different durations can be used to calculate the flood hydrographs for different design floods. A flood of higher return period can cause more damage and hence it is considered for hydrologic design of flood. Hydraulic modeling of flood for the generation of inundation maps can be done using this method.

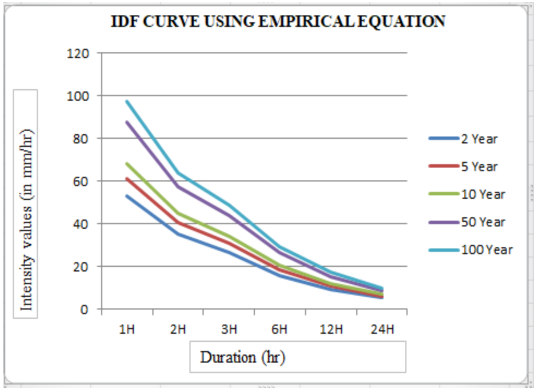

Fig 2: Intensity-Duration-Frequency Curve for the Study Area using Empirical Equation

V. CONCLUSIONS

The intensity duration frequency curve for the upper and lower Kuttanad region of Kerala were analyzed using the hourly rainfall data obtained from Indian meteorological department, Trivandrum. The results obtained from Gumbel distribution and those from the empirical equations were more or less the same. The floods with higher return period were considered to be severe when compared to that of lower return period.

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