MODELLING OF INTENSITY DURATION FREQUENCY CURVES FOR UPPER PALAR WATERSHED USING PROBABILITY DISTRIBUTIONS

Chalapathi K[1], Dr.M. Inayathulla[2],

Research Scholar, Department of Civil Engineering, Bangalore-560056., Karnataka, India.

Professor, Department of Civil Engineering, UVCE, Bangalore-560056.Karnataka, India

Key Words: *Watershed, Short duration rainfall, Probability Distribution, Empirical equation.*

ABSTRACT

Quantification of short duration high intensity rainfall is generally done using IDF (Intensity-Duration-Frequency) curves, based on historic rainfall data of significant years. Due to non-availability of short duration rainfall data, an attempt is made to derive short duration empirical reduction formula to understand urban hydrology. Daily rainfall data of 5 stations for the years 1995 to 2019 collected from Indian Meteorological Department (IMD) were used in the study. The missing rainfall data, during this period was interpolated by Normal Ratio method. The IMD empirical reduction formula was used to estimate the short duration rainfall. The rainfall depth for various return periods were predicted using different probability distributions and analyzed. The Chi-Square goodness of fit was used, to arrive at the best statistical distribution among Normal, Log-Normal, Gumbel and Pearson. Chi-Square test showed that log-normal is the best probability distribution for the 5 stations considered. The IDF curves were plotted for short duration rainfall of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes for a return period of 2, 3, 5, 10, 25, 50, 100 and 200 years for stations with peak rainfall values. The use of IDF curves becomes cumbersome; hence a generalized empirical relationship was developed for the Upper Palar Watershed, Kolar Taluk through method of least squares.

Introduction

Extreme environmental events, such as floods, droughts, rainstorms, and high winds, have severe consequences for human society. Planning for weather related emergencies, design of engineering structures, reservoir management, pollution control, and insurance risk calculations, all rely on knowledge of the frequency of these extreme events (Hosking and Waallis, 1997). The rainfall Intensity Duration Frequency (IDF) relationship is one of the most commonly used tools for the design of hydraulic and water resources engineering control structures. The establishment of such relationship was done as early as 1932. The rainfall intensity-duration-frequency (IDF) relationship is commonly required for planning and designing of various water resource projects (El-sayed, 2011). The statistical characteristics of high-intensity, short-duration, convective rainfall are essentially independent of locations within a region and are similar in many parts of the world. Analysis of short-term rainfall data suggests that there is a reasonably stable relationship governing the intensity characteristics of this type of rainfall.

Study area

The study area chosen was Kolar Taluk Sub watersheds, Kolar District. The study area geographically lies between North latitude 12° 46' to 13° 58' and East Longitude 77° 21' to 78° 35'. The watershed area geographically covers an area of 793.20 Sq. km. The types of soils distributed range from red loamy soil to red sandy soil and lateritic soil. The topography of the district is undulating to plain. The central and eastern parts of the district forming the valley of Palar Basin, are well cultivated. The present study is intended to classify the land for its best suitability based on the various parameters which are derived from Survey of India (SOI) Toposheet 57 K/4, 57K/8, 57K/3,57G/15 and 57 G/16 on 1: 50,000 scale.

The Location map of the study area is shown in Fig 1

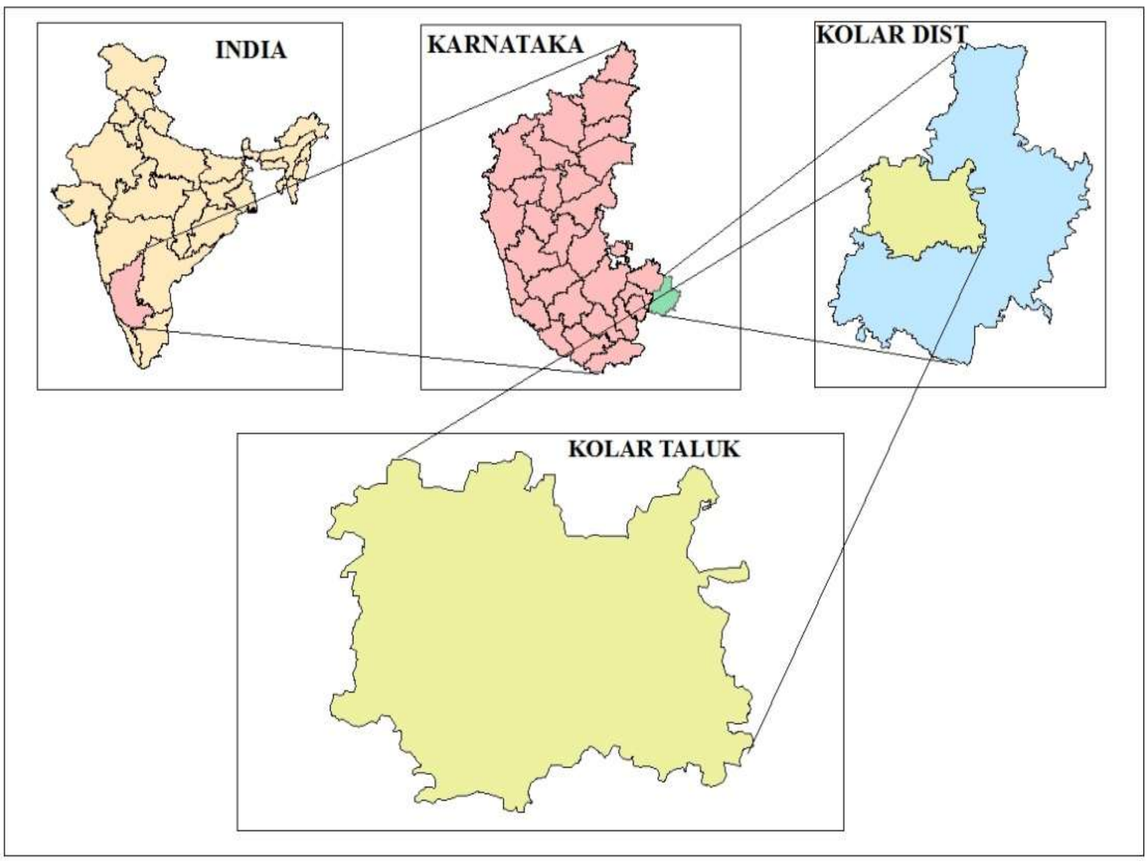

Fig1. Location Map of the Study Area

Estimation of Missing Precipitation Values by Normal Ratio Method

This method is used if any surrounding gauges have the normal annual precipitation exceeding 10% of the considered gauge. This weighs the effect of each surrounding station. In the normal ratio method, the rainfall P at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and those of the neighboring stations for the period of missing data at the station under question.

$$P_A = \left(\Sigma_{i-1}^{n} \frac{NR_A}{NR_i} * P_i\right)/n \quad 1$$

Table 1: - Specimen Calculation for Missing Rainfall Values

Year	**Kolar Tq office**	**Kolar City RLY**	**Muduvadi**	**Narasapura**
1996	58.6	68.82	97.6	84
1997	49.4	57.7	83.8	68
1998	107.8	122.7	135	187
1999	67	66.3	100.6	62.6
2000	68	65.8	62	100
2001	86	81	67	108.5
2002	82.6	77.6	58.4	72
2003	47	43.8	60.2	45
2004	180	122	91.4	116.2
	79.2	71.5	82.9	86.6
	0.902	1.000	0.862	0.825

Estimation of Short Duration Rainfall

The following IMD Empirical Reduction formula is used to estimate the short duration rainfall

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \quad (2)$$

Table 2: - Short duration rainfall by using IMD empirical formula for Kolar Tq Office station

Year	Rainfall (mm)	$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}}$ in mm where, time t is in hours							
Duration in Minutes		5	10	15	30	60	120	720	1440
1995	120	18.17	22.89	26.21	33.02	41.60	52.41	95.24	120
1996	58.6	8.87	11.18	12.80	16.12	20.32	25.60	46.51	58.6
1997	49.4	7.48	9.42	10.79	13.59	17.13	21.58	39.21	49.4
1998	107.8	16.32	20.57	23.54	29.66	37.37	47.09	85.56	107.8
1999	67	10.15	12.78	14.63	18.44	23.23	29.26	53.18	67
2000	68	10.30	12.97	14.85	18.71	23.57	29.70	53.97	68
2001	86	13.02	16.41	18.78	23.66	29.81	37.56	68.26	86
2002	82.6	12.51	15.76	18.04	22.73	28.64	36.08	65.56	82.6
2003	47	7.12	8.97	10.26	12.93	16.29	20.53	37.30	47
2004	180	27.26	34.34	39.31	49.53	62.40	78.62	142.87	180

2005	83.6	12.66	15.95	18.26	23.00	28.98	36.52	66.35	83.6
2006	80.8	12.24	15.42	17.65	22.23	28.01	35.29	64.13	80.8
2007	69	10.45	13.16	15.07	18.99	23.92	30.14	54.77	69
2008	87.4	13.23	16.67	19.09	24.05	30.30	38.18	69.37	87.4
2009	57	8.63	10.87	12.45	15.68	19.76	24.90	45.24	57
2010	71.4	10.81	13.62	15.59	19.65	24.75	31.19	56.67	71.4
2011	74.8	11.33	14.27	16.34	20.58	25.93	32.67	59.37	74.8
2012	98.4	14.90	18.77	21.49	27.08	34.11	42.98	78.10	98.4
2013	70	10.60	13.35	15.29	19.26	24.27	30.58	55.56	70
2014	70.5	10.68	13.45	15.40	19.40	24.44	30.79	55.96	70.5
2015	70	10.60	13.35	15.29	19.26	24.27	30.58	55.56	70
2016	70.1	10.62	13.37	15.31	19.29	24.30	30.62	55.64	70.1
2017	85.5	12.95	16.31	18.67	23.53	29.64	37.35	67.86	85.5
2018	65.8	9.96	12.55	14.37	18.11	22.81	28.74	52.23	65.8
2019	58.6	8.87	11.18	12.80	16.12	20.32	25.60	46.51	58.6

Table 3: - Mean and Standard Deviation of Short Duration Rainfall for Kolar Tq Office, Kolar City Rly and Muduvadi.

Duration in minutes	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
	Kolar Tq Office		**Kolar City Rly**		**Muduvadi**	
5	11.99	4.08	10.84	3.35	12.56	2.79
10	15.10	5.14	13.66	4.22	15.82	3.51
15	17.29	5.89	15.64	4.83	18.11	4.02
30	21.79	7.42	19.70	6.09	22.82	5.07
60	27.45	9.34	24.83	7.68	28.75	6.38
120	34.58	11.77	31.28	9.67	36.22	8.04
720	62.84	21.39	56.84	17.57	65.82	14.61
1440	79.17	26.95	71.61	22.14	82.93	18.41

Table 4: - Mean and Standard Deviation of Short Duration Rainfall for Vemgal and Narasapura.

Duration in minutes	Mean	Standard Deviation	Mean	Standard Deviation
	Vemgal		**Narasapura**	
5	12.39	4.27	13.11	4.40
10	15.61	5.38	16.52	5.55
15	17.87	6.16	18.91	6.35
30	22.52	7.77	23.82	8.00
60	28.37	9.78	30.01	10.08
120	35.74	12.33	37.81	12.70
720	64.95	22.40	68.71	23.07
1440	81.83	28.22	86.57	29.07

Frequency Analysis using Frequency Factor

The magnitude of x_T of a hydrologic event may be represented as the mean μ plus the departure Δx_T of the variate from the mean i.e., $x_T = \mu + \Delta x_T$ (Chow et al, 1988). The departure may be taken as equal to the product of σ and a frequency factor K_T are functions of the return period and the type of distribution to be used in the analysis. The above equation may be expressed as $x_T = \mu + k_T\sigma$which may be approximated by$x_T = \bar{x} + k_T s$. (Chow et al, 1988). In the event the variable analysed is y = In(x), then the same method is applied to the statistics for the logarithms of the data using $y_T = \bar{y} + k_T s_y$and the required value of $x_T$is foundby taking the antilog of y_T(Chow et al, 1988).

Probability distribution

In this study the maximum rainfall intensity for various return periods were estimated using different theoretical distribution functions. Normal, Two-Parameter Lognormal, Pearson Type III, Extreme Value Type I (Gumbel) etc were used for probability distribution of the daily rainfall data. (Chow et al, 1988).

Log - Normal distribution

Variables in a system sometimes follow an exponential relationship as y = exp(x). If the exponent is a random variable, say X, Y= exp (X) is a ramdom variable and the distribution of X is of interest. An important special case occurs when X has a normal distribution.

In that case, the distribution of X is called a lognormal distribution. The name follows transformation ln (X) = Y. That is, the natural logarithm of X is normally distributed.

Probabilities for x are obtained from the transformation to X, but we need to recognize that the range of X is (0,∞). Suppose that X is normally distributed with mean θ and variance σ^2 ; then the cumulative distribution function for x is

$$f(x) = \int_0^x \frac{1}{xb\sqrt{2\pi}} \exp\left\{-\frac{(\ln x - a)^2}{2b^2}\right\} dx \ ; \qquad 0 < x < \infty \tag{3}$$

Since the random variable X is log normally distributed, then the random variable

$$Y = \ln X \tag{4}$$

is normally distributed. With transformation

$$Z = \frac{Y-a}{b} \tag{5}$$

Lognormal distribution becomes the standard normal distribution.

The frequency factor for lognormal distribution is same as normal distribution except that it is applied to the logarithms of the variables and their mean and standard deviations are used in $y_T = \bar{y} + k_T s_y$

Where $\bar{y} = \mu_y = \frac{1}{2}\ln\left[\frac{\mu_x^4}{\mu_x^2 + \sigma_x^2}\right]$ and $\sigma_y^2 = \ln\left[\frac{\sigma_x^2 + \mu_x^2}{\mu_x^2}\right]$

Table 5: - Rainfall intensity values by Log-Normal Distribution for Kolar Tq Office Station.

Log-Normal Distribution	**Rainfall intensity (mm/hr)**							
	Return period							
Duration in (min)	2 year	3 year	5 year	10 year	25 year	50 year	100year	200year
5	171.23	174.50	176.80	178.43	179.35	179.65	179.80	179.80
10	107.87	109.93	111.38	112.41	112.99	113.17	113.27	113.27
15	82.32	83.89	85.00	85.78	86.22	86.37	86.44	86.44
30	51.86	52.85	53.54	54.04	54.32	54.41	54.45	54.45
60	32.67	33.29	33.73	34.04	34.22	34.27	34.30	34.30
120	20.58	20.97	21.25	21.45	21.56	21.59	21.61	21.61
720	6.23	6.35	6.44	6.49	6.53	6.54	6.54	6.54
1440	3.93	4.00	4.05	4.09	4.11	4.12	4.12	4.12

The Chi-Square goodness of fit was used to arrive at the best statistical distribution among Normal, Log-Normal, Gumbel and Pearson. IDF curve was plotted for short duration rainfall of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes for a return period of 2, 3, 5, 10, 25, 50, 100 and 200 years for station with peak rainfall values. The use of IDF curves becomes cumbersome and hence a generalized empirical relationship was developed through method of least squares.

Rainfall depth and intensity

The short duration rainfall depths were calculated for the years 1995 to 2019 from IMD empirical reduction formula. Then the mean and standard deviations of short durations of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes were estimated. These estimated mean and standard deviations were used in Normal, Log-Normal, Gumbel and Pearson probability distribution methods to determine the rainfall depths and intensity for standard return periods of 2, 3, 5, 10, 25, 50, 100 and 200 years for 5 stations. It was found that the rainfall depths increased with the increasing time duration. But the rainfall intensity decreased appreciably with increasing duration. These distributions were subjected to chi-square goodness of fit test to find the best distribution. The table4 shows specimen calculations for Kolar Tq Office station

Table 6: Specimen calculations for Kolar taluk office station

Duration in minutes	Observed values	NORMAL DISTRIBUTION		LOG-NORMAL DISTRIBUTION		GUMBELS DISTRIBUTION		PEARSON TYPE III DISTRIBUTION	
		Expected values	Chi-square values	Expected values	Chi-square values	Expected values	Chi-square values	Expected values	Chi-square values
5	11.99	15.25	0.70	14.79	0.53	18.91	2.53	17.51	1.74
10	15.10	19.21	0.88	18.63	0.67	23.83	3.19	22.07	2.20
15	17.29	21.99	1.00	21.33	0.76	27.28	3.66	25.26	2.51
30	21.79	27.71	1.27	26.87	0.96	34.37	4.61	31.82	3.16
60	27.45	34.91	1.60	33.85	1.21	43.30	5.80	40.10	3.99
120	34.58	43.98	2.01	42.65	1.53	54.55	7.31	50.52	5.03
720	62.84	79.92	3.65	77.51	2.78	99.13	13.29	91.80	9.14
1440	79.17	100.7	4.60	97.65	3.50	124.89	16.74	115.66	11.51

IDF curve

It was found from chi-square test that log-normal distribution gave the best results with minimum deviations from the observed values. Hence the IDF curve was plotted from log-normal values for each station considered. The IDF curve is plotted with duration in minutes on the abscissa and rainfall intensity in mm/hr on the ordinate for standard return periods.

Figure 3 represents the rainfall IDF curves for five stations in the study area i.e., rainfall intensity-duration-frequency curve for short durations of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes and return periods of 2, 3, 5, 10, 25, 50, 100 and 200 years for Log-normal distribution. The use of IDF curves becomes more cumbersome and hence a generalized empirical relationship of the form $i = x * (t_d)^{-y}$ was developed for each station, for the various return period considered. Rainfall IDF empirical equation constant x and y were calculated for different return period by the method of least-squares. IDF empirical equation was formed by putting the value of x and y in the mentioned equation format for each return period separately. Table 5 gives the empirical constant x for 5 stations for the return periods considered.

Table 7: Empirical constant x for 5 stations for different return periods

Station	Return Periods							
	2	3	5	10	25	50	100	200
Kolar	511	521	528	532	535	536	537	537
Kolar Rly	457	465	471	475	477	478	478	478
Muduvadi	511	517	522	525	527	527	528	528
Narasapura	558	568	576	581	584	585	585	585
Vemgal	529	539	546	551	554	555	556	556

It is seen that the empirical constant y remains constant for all return period and for all stations with a value of 0.6667 or 2/3. The empirical constant x varies at lower return periods and tends to become constant with higher return periods. These IDF empirical equations will help to estimate the rainfall intensity for any specific return period in Urban in a short time and more easily for the locations considered.

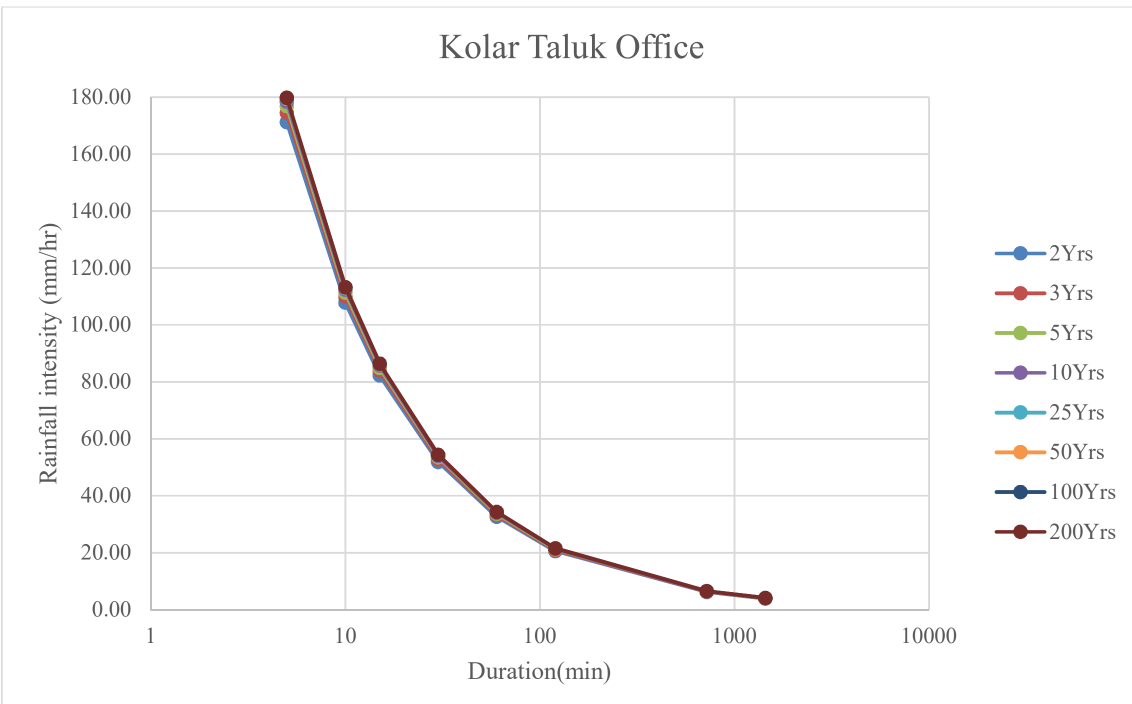

Figure 2:- Rainfall IDF curves for various Return Periods by Log-Normal Distribution for Kolar Tq Office Station

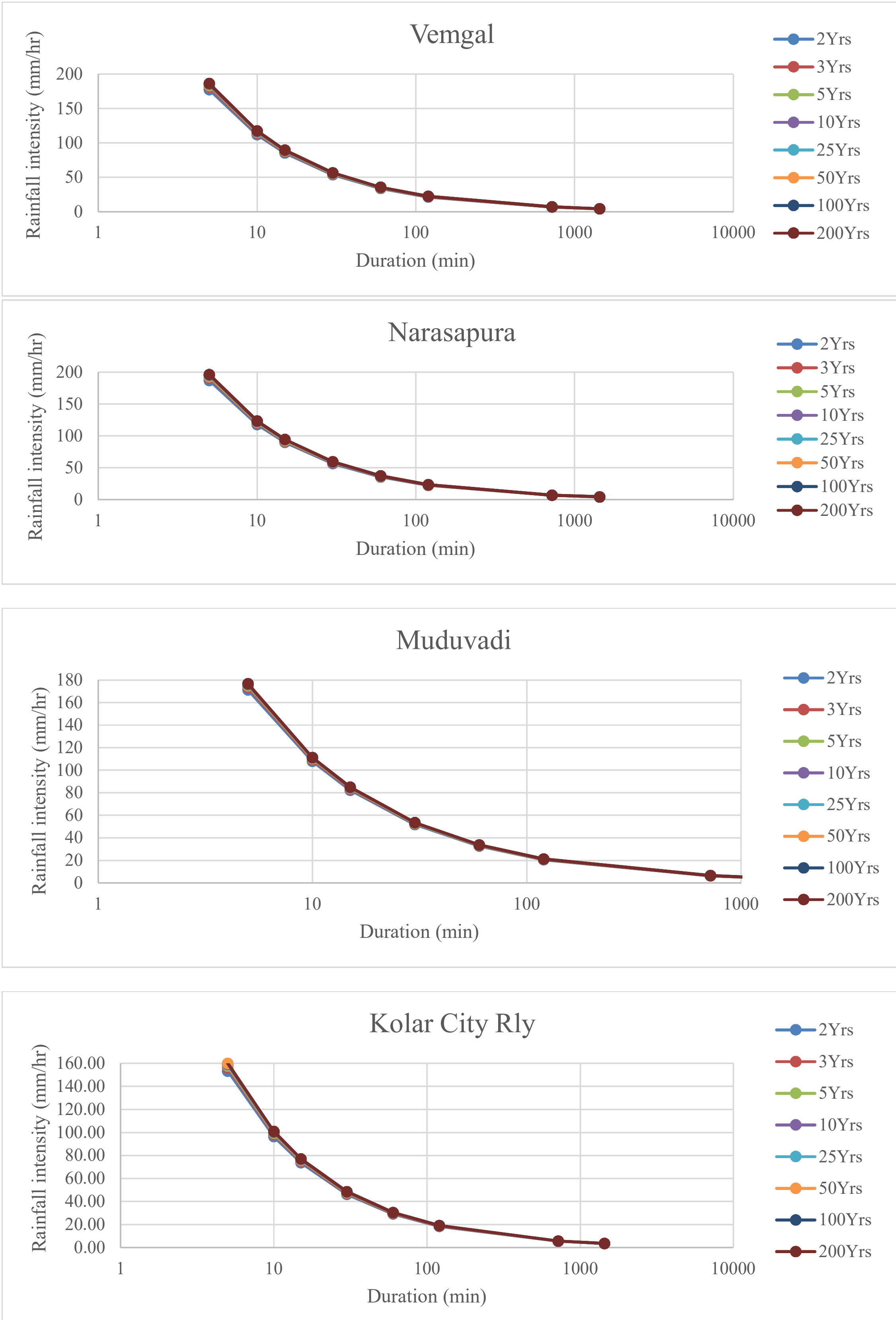

Figure 3:- Rainfall IDF curves for various Return Periods by Log-Normal Distribution

CONCLUSIONS;

- IDF curves are developed for annual maximum series of 25 years from 1995 to 2019 of the data set for annual maximum series for 5 stations of Kolar Taluk. It is observed that the station Narasapura has high intensities of rainfall compared to other stations. Its shows that the maximum intensity occur at short duration with large variations with return period.
- As per the Chi-square goodness of fit test Log-Normal distribution method is best fit for study area compared to other distributions, by using this distribution rainfall intensity and rainfall depth can be estimated for the selected standard short duration and return period.
- Study showed that $i = x * (t_d)^{-y}$ was the best form of IDF empirical equation for Kolar Taluk.
- These IDF equations will help to estimate the rainfall intensity for any specific return period in Kolar Taluk in a short time and more easily.

References

- Chalapathi K and Mohammed Inayathulla “Ground Water Prospects Map for SuryanagaraWatershed” in IJRIT VOL 6 ISSUE 2 JULY 2019.
- Chalapathi K and Mohammed Inayathulla “Estimation of crop water requirement for Kolar taluk subwatershed” in IJRIT VOL 6 ISSUE 2 JULY 2019 impact factor 5.86.
- Parvez, Inayathulla and Chalapathi K Analysis of Landforms of a Mini Watershed of Manvi Taluk, Raichur District Karnataka” in IJIRT Vol 6 Issue 4, September 2019 ISSN:2349-6002.
- M. M. Rashid, 1 S. B. Faruque and 2 J. B. Alam (2012), “Modeling of Short Duration Rainfall Intensity Duration Frequency (SDRIDF) Equation for Sylhet City in Bangladesh.
- USDA, 1972, United states department of agriculture.
- Ven Te Chow (1964) Handbook of applied Hydrology, McGraw-Hill Book Company.