DEVELOPMENT OF RAINFALL INTENSITY-DURATION-FREQUENCY RELATIONSHIPS FOR PARTS OF WESTERN GHATS IN KARNATAKA STATE, INDIA

B. Venktesh

Scientist, Regional Centre,
National Institute of Hydrology, Hanuman Nagar,
Belgaum, Karnataka – 590 001

1.0. Introduction

The intensity duration frequency relationship (IDF) of heavy storms is one of the most important hydrologic tools utilised by engineers for designing flood alleviation and drainage structures. Local IDF equations are often estimated on the basis of records of intensities abstracted from rainfall depths of different durations, observed at a given recording rainfall gauge stations. In some regions, there may exist number of recording rainfall gauging stations operating for a time period sufficiently long to yield a reliable estimation of the IDF relationships. In many other regions, especially in developing countries, these stations are either non-existent or their sample sizes are too small. Because daily precipitation data is the most accessible and abundant source of rainfall information, it seems natural, at least for the regions where data at higher time resolution are scarce, to develop and apply methods to derive the IDF characteristics of short-duration events from daily rainfall statistics.

Uttarakannada district is one of the forest rich district of Karnataka state and falls in the region of the Western Ghats. It is considered to be very resourceful in terms of abundant natural resources and constitutes an important district in Karnataka. In the recent times, there are several infrastructural project have been implemented for effective use of natural resources and are being planned to implement in the coming years. The implementation of these projects has created a complex mosaic of land cover in the district. In view of the ongoing environmental and ecological changes in the Western Ghats, it is important to understand the environmental parameters pertaining to the sustenance of the region. Rainfall is one such parameter governing the hydrological processes crucial to agriculture planning, afforestation and eco-system management. Due to the large scale changes in the land cover and enhanced afforestation activities in the region, it is essential to understand rainfall distribution and its variation in relevance to such activities. More so, are the properties of shorter duration rainfall, which can be utlised to understand the runoff producing mechanism in view of large scale land cover changes and their impact on the hydrologic regime of the region.

Therefore present study is aimed at developing rainfall intensity-duration-frequency relationships using the short-term data of rainfall stations covering Uttara Kananda district of Karnataka which forms parts of Western Ghats. The relationships are developed for 5 different duration (ranging from 1hr to 5hrs) and 5 different return periods. The developed relationship will further used to understand the changed runoff producing mechanism and their possible impact on the runoff regime of the region.

2.0.**Study Area**

The Uttarakannada district in Karnataka state has the biggest share of moist tropical forest (Figure 1). Geomorphology the district reflects the complex geology by resulting in a sharp, contrasting topography. Within Uttar Kannada district, there are gentle undulating hills which rise steeply from a narrow coastal strip bordering the Arabian Sea to a plateau at an altitude of 500 m with occasional hills rising above 600–860 m. The study area can be thus broadly categorised into three distinct blocks that is, i) the Coastal Lands ii) the mostly forested Sahyadrian interior corresponding to the Western Ghats proper (Malnad) and iii) the Eastern Margin where the table land or plateau begins that merges with the Deccan plateau. Following the landscape groupings of Gunnell and Radhakrishna (2001), these blocks are termed respectively as Coastal, Mid-Ghat/Mid-lands and Up-Ghat.

Gunnell (1997) outlined the climatic features of the Western Ghats in some detail, which is distinctly monsoonal. The rainfall is dominated by the orographic uplift of moist, southwest monsoon airflow with the topographic barrier of the "Western Ghats-Central Sahyadri" during the months June – September. Spatially annual rainfalls are highly variable and range from 1150mm to greater than 5000mm over the highest topography. There is a distinct drying gradient on the eastern slopes and onwards towards the Deccan plateau.

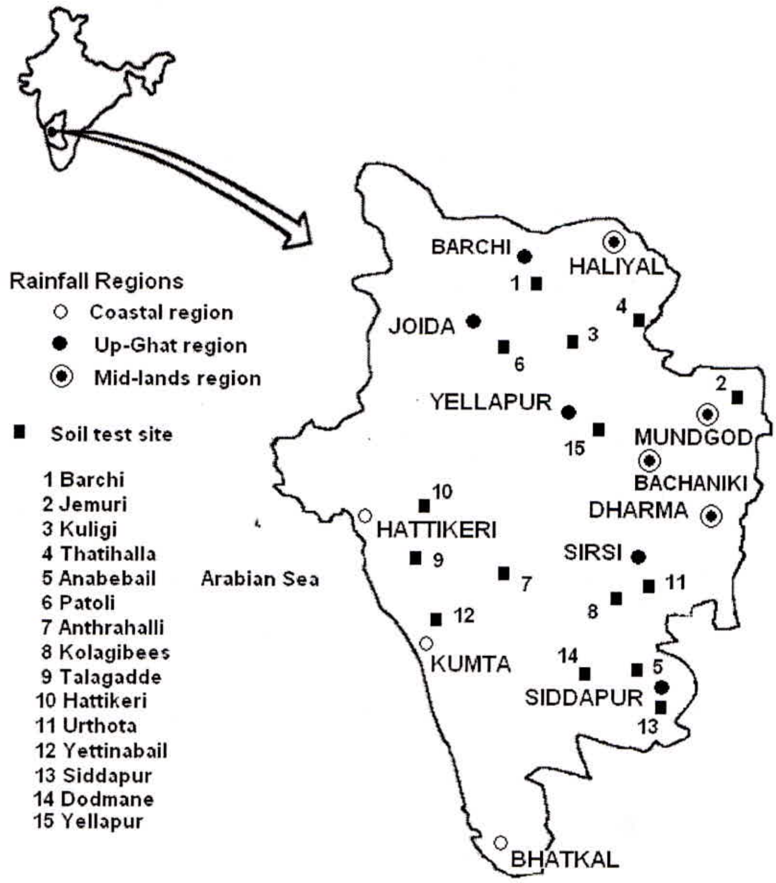

Figure.1. Study area showing the location of Raingagues used for the study.

2.1. Rainfall data used

Data on rainfall intensity and duration have been compiled for the rainfall stations located in the different parts of the Uttara Kannada district (Figure.1). The daily charts of recording raingauge stations were collected from the Water Resources Development Organisation (WRDO) Dharwad. There are 12 are the recording raingauges with data length varies from 16 years to 32 years. From the available hourly rainfall records the storms having duration of upto 5 hours or less were selected to evaluate the impact of organised rain producing systems (Raman et al, 1969). The rainfall intensity values for 1hr, 2hr, 3hr and 5hr duration were calculated for all selected storms as shown in the example given in Table.1.

Table.1. Example for computation of rainfall intensity (Raman et.al. 1969)

Duration of rainfall (hr)	Rainfall depth in successive 1 hr intervals (mm)	Cumulative rainfall (mm)	Average intensity (mm/hr)
1	8.9	8.9	8.9
2	7.0	15.9	7.95
3	4.9	20.8	6.93
4	3.5	24.3	6.08
5	2.0	26.3	5.26
6	1.8	28.1	4.68

3.0.Methodology

In order to establish a relationship between rainfall intensity-duration - frequency, the rainfall intensity values were regressed against duration for the set of data available.

$$I = a\, t^{b}\, T^{c} \qquad \text{Eq............ (1)}$$

where I = intensity of the rainfall mm/hr
t = duration in minutes
T = return period in years
a,b,c are the empirical constants

A comparative analysis will be done to find out which method is more suitable for this region.

3.1. Probability distributions used in the study

The present study is carried out using the most commonly used distributions like Gumbel (EV-I) distribution to the corresponding annual maximum series of the available rainfall data (Sharma, 1987).

The density function is defined by :

$$P(x) = \exp[- \exp - (x-u)/\alpha)] \qquad \text{Eq............. (2)}$$

Where P(x) is the probability of an event not exceeding x, and u and α are the location and scale parameters of the distribution. The above equation may be written conveniently in terms of a reduced variate y:

$$P(x) = \exp[-\exp(-y)] \qquad \text{Eq................(3)}$$

where

$$x = u + \alpha y \qquad \text{Eq................(4)}$$

By inversion of above equation, the relationship may be written in terms of the return period T (the reciprocal of the probability of exceedence):

$$y = -\ln[\ln\{T/(T-1)\}] \qquad \text{Eq................ (5)}$$

The L-moment method of parameters estimation of Gumbel distribution found to be superior in many respects to the conventional moment and maximum-likelihood estimators. Hence, this method is employed for the determination of parameters in the distribution.

4.0.Results and Discussion

In the present study, the available data were extracted in 5 durations, i.e., 1hr, 2hr, 3hr, 4 hr and 5hr intervals. Most of the literature depicts that the Extreme Value- Type I distribution explains the characteristics of the rainfall significantly compare to the other methods. Hence, in the present study, the Gumbel Distribution is used. As the length of the data were not sufficient to represent the variability with in the study area, 3 meteorologically homogeneous regions were identified, namely, Coastal region, Up-Ghat region and mid-land region. The data of all the stations which falls under these three regions were pooled together to fit Gumble distribution.

The basic statistical parameters estimated for stations selected for analysis are presented in Table.2. Table.2. indicate that the mean annual rainfall varies between 940 mm to 4000 mm. The stations namely, Mundgod, Dhrma, Bachaniki falls on the lee ward side of the Western Ghats and are about 80-100 kms away from the west coast. From the Table.2, it can be noticed that there is a large variation in the values of coefficient of skewness and coefficient of Kurtosis, which indicates that the sample which is considered for the study may exhibit a large sampling error.

Table.2. Basic statistical parameters of individual stations

Stations	Elevation (mts)	Sample size (years)	Statistical Parameters Mean	Std.Dev	Cv	Cs	Ck
Barchi	490.00	14	1521.17	355.27	0.23	0.31	0.41
Yellapur	540.86	7	2429.23	493.16	0.20	1.28	2.64
Aversa	22.80	8	3709.43	510.60	013	0.35	-0.92
Sirsi	617.83	23	2488.66	364.93	0.41	0.51	-0.30
Bhatkal	63.66	6	4192.81	616.68	0.14	1.48	1.90
Mundgod	563.88	7	1148.68	456.25	0.39	2.59	7.20
Siddapur	703.15	5	2734.94	586.14	0.21	0.06	-1.85
Haliyal	549.86	7	1210.76	228.14	0.18	-0.21	-0.74
Bachaniki	565.60	7	940.92	153.12	0.16	-0.44	0.13
Joida	668.12	3	2444.14	403.45	0.16	0.86	1.91
Dhrma	596.04	5	1413.01	361.85	0.25	0.71	-0.38
Kumta	30.50	6	3090.45	1078.01	0.34	-2.17	5.92

A plot of elevation with the average rainfall intensity (Figure.2) show the intensity of rainfall decreases as the altitude increases. As illustrated in the Figure.2, the average rainfall intensity is poorly correlated with the elevation for 1hr duration. However the correlation increases with the duration. The plot of the average rainfall intensity and mean annual rainfall forms two distinct groups. The first group are the values belong to the stations which are closed to the coastal line of the district. As we move in-land, there is a decrease in the intensity (Figure.3). However, the second group contains the values observed at up-ghat and the plains. The higher intensity values in the plains are observed during the pre-monsoonal rains. On the contrary, similar values in the up-ghat region are observed during the monsoon period.

4.1. Derivation of Intensity-Duration-Frequency Relationships

Since the individual station record are relatively short (less than 25 years) the derived IDF relationships cannot be used for high return period (greater than 50 years) with very much confidence (Bell, 1969). This lack of confidence, together with the inadequate coverage of the study area provided by the available stations, promoted a regional rainfall intensity-duration-frequency study. The individual station data sets were compounded to yield larger regional data samples, i.e., by station-year concept. In this method, the data of all stations are pooled- together to form a larger data set (Baghirathan and Shaw, 1978).

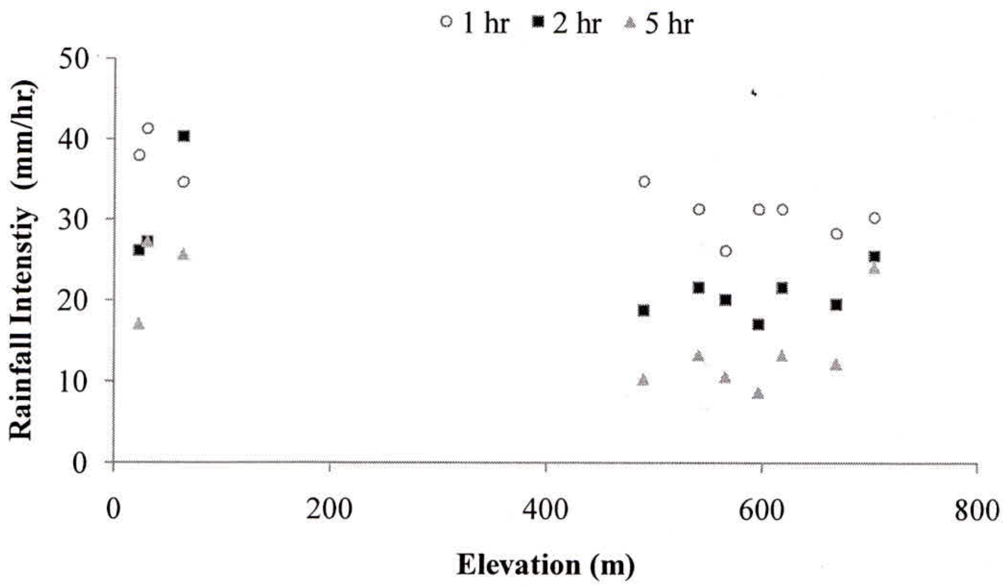

Figure.2. Relationship between elevtion and rainfall intensity for selected duration

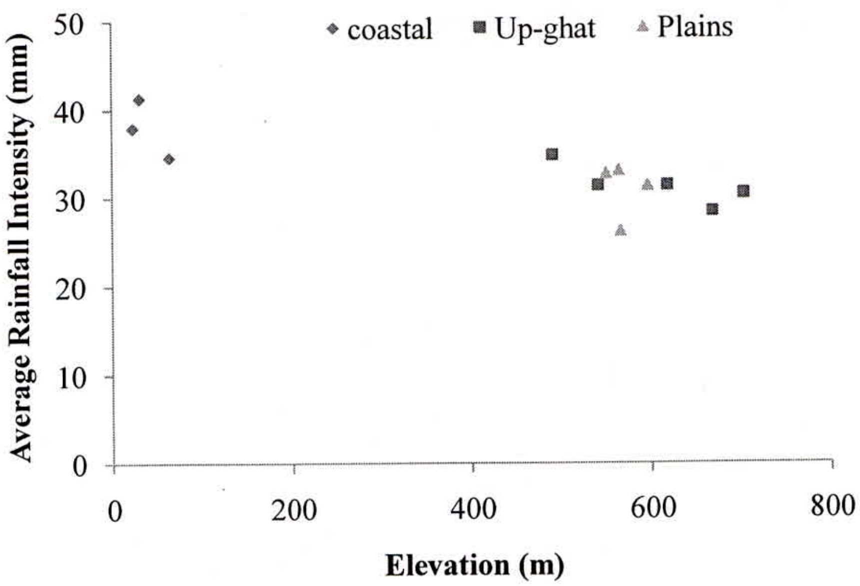

Figure.3. Relationship between elevtion and rainfall intensity for regions considred for analysis

In this study, the regions are identified mainly based on the elevation hence, the study area was divided into three regions, namely, Coastal, up-ghats and Plains. The stations falling under thes groups are, Kumta, Aversa and Bhatkal in Coastal region, where as Sirsi, Yellapur, Joida and Siddapur falls under Up-ghats region, finally, the mid-land region comprises of Mudgod, Dharma, Barchi, Bachaniki and Haliyal raingauge stations.

Once the regions were recognised, the respective individual station records were compounded. The records from the rain-gauge stations in each region were taken together to give regional record totals in station-years. This compounded value of annual maximum series assumes that they are independent and that the stations are representative of their regions defined from the criteria. These compounded records were then subjected to an analysis similar to that executed for the individual satins. The fitted EV-I distribution for different regions in the form of Eq.(4) are tabulated in Table.3. The rainfall estimated for different return periods are tabulated in Table.4.

Table.3. Fitted relationships for different regions

Regions	1hr	2hr	3hr	5hr
Region 1	32.07+6.886Y	24.29+11.23 Y	25.98+8.77 Y	16.71+9.72 Y
Region 2	22.91+10.07 Y	18.83+6.84 Y	11.77+6.81 Y	9.98+5.44 Y
Region 3	25.19+11.04 Y	14.40+7.55 Y	10.04+5.47 Y	7.96+4.57 Y
All the regions together	25.85+9.233Y	17.92+8.69Y	13.75+7.17Y	10.24+6.09Y

Table.4. Rainfall intensity-duration estimates for different regions for selected return period.

Return Period	Region I				Region II				Region III			
	1 hr	2 hr	3 hr	5hr	1hr	2hr	3hr	5hr	1 hr	2 hr	3 hr	5hr
2	34.06	28.41	29.19	20.27	26.06	21.34	14.27	11.98	29.23	17.17	12.04	9.64
5	42.40	41.14	39.14	31.30	38.01	29.09	22.00	18.14	41.75	25.73	18.25	14.82
10	47.57	49.57	45.73	38.60	45.57	34.23	27.11	22.22	50.04	31.40	22.37	18.26
25	54.10	60.22	54.05	47.82	55.12	40.72	33.57	27.38	60.51	38.56	27.56	22.60
50	58.94	68.12	60.23	54.66	62.20	45.53	38.37	31.21	68.28	43.87	31.41	25.82
75	61.76	72.71	63.81	58.64	66.32	48.33	41.15	33.44	72.80	46.96	33.65	27.69
100	63.75	75.96	66.35	61.45	69.23	50.31	43.13	35.01	75.99	49.14	35.24	29.02

Table.4. reveal that the 1 hour duration rainfall intensities of all the return periods for the region 1 and region 3 are more than the region 2. This difference indicates that, the rainfall intensity is high in the coastal region. This could be, as region 1, has very close proximity with the maritime origin pertubation in south-west monsoon. In the region 3, the higher intensity rainfall events sometimes observed during the month of April or May, i.e, the pre-monsoonal showers, these rainfall occurs due to the convectional (thunder storms) processes and can deliver upto 80 mm/hr (Gunnell, 1997). Normally, south-west monsoon is associated with the high wind speeds, which may be other reason that could cause a lower intensity

rainfall in the Up-Ghat region, the same is carried to the plains where the observed intenisties are higher than the Up-Ghats. Also, the duration of rainfall in the Up-Ghat region is longer with the mild intensity than the coastal and plains, where the rainfall is with high intensity for shorter duration. The rainfall intensities for other duration (i.e., 2hr, 3hr and 5 hr) are comparable.

4.2. Development of Empirical formulae

As the first step of the analysis the values of maximum intensities for 1hr, 2hr, 3hr and 5hr duration from all 14 stations were considered. The frequencies of all these maximum intensity values were computed using the weibull plotting position procedure. A multiple regression model is used to develop a relationship of intensity versus duration and frequency of the form of

$$I = 112.47\, D^{-0.341}\, T^{0.210} \qquad \text{Eq..................(6)}$$

The multiple correlation coefficient of 0.80.

In order to check the accuracy, the rainfall intensity values computed using the developed empirical equation are compared with that of the values obtained by the fitted distribution previously and also with the observed rainfall intensity values. The comparison indicates that the values predicted using the above equation results are with in ± 15% error in most cases. The values obtained are tabulated in Table.5.

Table.5. Comparison of rainfall intensities estimated from fitted EV-1 Distribution with that of Empirical Formula derived considering all the regions as single unit.

Return Period	Computed using Empirical formulae				Computed using the fitted distribution			
	1hr	2hr	3hr	5hr	1hr	2hr	3hr	5hr
2	32.19	25.42	22.13	18.58	29.23	21.10	16.37	12.44
5	39.02	30.81	26.83	22.53	39.69	30.95	24.50	19.53
10	45.12	35.64	31.04	26.06	46.62	37.47	29.89	23.76
25	54.72	43.21	37.62	31.59	55.39	45.71	36.69	29.45
50	63.27	49.96	43.50	36.53	61.87	51.82	41.73	33.68
75	68.92	54.42	47.39	39.79	65.65	55.37	44.67	36.14
100	73.20	57.80	50.34	42.26	68.32	57.89	46.74	37.88

From Table.5. it is noticed that, the regional rainfall estimates are comparable with the individual station estimated for return period up to 50 years. The longer the lengths of the regional data samples, except for the region III, allow more confidence to be attached to rainfall estimates for the higher return periods obtained from the regional intensity-duration-frequency relationships.

5.0.Summary

In this study, the product moment method and the L-moment method with regional analysis were investigated for developing IDF relationship for Uttara Kannada district of Karnataka. From the above analysis, the following important points are observed;

1. The rainfall intensity decreases with the increase in elevation, on the contrary, it increases with increase in mean rainfall
2. Up-ghat region receive lower intensity rainfall in comparison to the other two regions for 1hr and 2hr duration.

6.0.REFERENCES

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