Development of intensity duration frequency relationships for Port Blair, Andaman and Nicobar Islands, India

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सार – भारी वर्षा के कारण बाढ़ के खतरे का आकलन करने के लिए और जल संसाधन परियोजनाओं का डिजाइन करने के लिए वर्षा तीव्रता अवधि आकृति संबंध आवश्यक है। इस अध्ययन में पोर्टब्लेयर के 1969 से 2000 तक के स्वतः रिकार्डिंग वर्षा मापी के प्रति घंटे वर्षा आँकड़ों का उपयोग करके पोर्टब्लयर, अंडमान और निकोबार द्वीपसमूह के लिए भारत में वर्षा तीव्रता अवधि आवृति संबंध को विकसित किया गया है। पहले चरण में विभिन्न अवधियों की वर्षा के परिमाण की वार्षिक श्रृखला तैयार की गई है और भारित क्षेणों की विधी का प्रयोग करके अनुमानित प्राचल के साथ गमबेल ईवी 1 सामान्य उच्चतम मान, समान्यीकृत लॉजिस्टिक एवं लॉग नार्मल वितरणों का प्रयोग करके अच्छी तरह विस्तृत सटीक अध्ययन किया गया। सामान्य तौर पर अधिकतम मानकों में विभिन्न अवधियों (अर्थात, 24) की वार्षिक अधिकतम वर्षा श्रृखला के लिए गमबेल ईवी 1 वितरण पूर्ण रूप सटीक पाया गया था। इसलिये पोर्टब्लेयर के लिये वर्षा तीव्रता अवधि आवृति संबंध की सामान्यीकृत समीकरण तैयार करने के लिए ईवी 1 वितरण को चुना गया है। डिजाइन के उद्धेश्य के लिये इस सामान्यीकृत समीकरण सिफारिश की गई है। ऑप्टीमाईजेशन तकनीकी का प्रयोग करके 24 घंटे वर्षा से छोटी अवधियों के लिये वर्षा तीव्रता की अनुमान के लिये संबंध भी स्थापित किया गया है।

ABSTRACT. Rainfall intensity duration frequency relationships are required for planning and design of water resources projects and for assessing the risk of floods caused by heavy rainfall. In the present study rainfall Intensity Duration Frequency (IDF) relationships for Port Blair, Andaman and Nicobar Islands, India have been developed utilizing hourly rainfall data of self-recording rain gauge from 1969-2000 at Port Blair. As a first step, annual maximum series of rainfall depths of different durations were derived and detailed goodness of fit studies were conducted using Gumbel EV1, General Extreme Value, Generalized Logistic and Lognormal distributions with parameter estimation using probability weighted moments method. In general for most of the cases, Gumbel EV1 distribution was fitting well for the annual maximum rainfall series of different (*i.e.*, 24) durations. Hence EV1 distribution was selected for deriving the generalized equation for rainfall intensity duration frequency relationship for Port Blair. This generalized equation is recommended to be used for design purpose. The relationships for estimation of rainfall intensities for smaller durations from 24 hour rainfall have also been established using optimization technique.

Key words – Rainfall intensity duration frequency (IDF) curves, Smaller duration rainfall intensity.

1. Introduction

Andaman and Nicobar Islands are situated in the Bay of Bengal (Fig. 1) and Port Blair is the capital city of Andaman and Nicobar Islands. Lot of developmental activities, like development and strengthening of drainage plan of the city, extension of International airport etc. are being undertaken in the area. For these developmental activities, flood frequency estimates are often needed. These flood frequency estimates, in turn require, intensity duration frequency (IDF) relationships and also the conversion of daily rainfall into shorter interval (say 1 hour, 2 hours, etc.) design rainfall. Keeping these requirements in view the present study has been undertaken with the objectives to develop IDF curves for Port Blair area, and to develop relationship for converting 24 hourly rainfall into smaller interval rainfall.

2. Review of literature

2.1. IDF relationships

Initial work on development of IDF relationship was done by Sherman in 1931. He developed the following empirical relationship:

$$i = \frac{KT^a}{(t+c)^b} \tag{1}$$

where, i is rainfall intensity, t is rainfall duration and T is return period. K, a, b and c are all constants which depend on the geographical region.
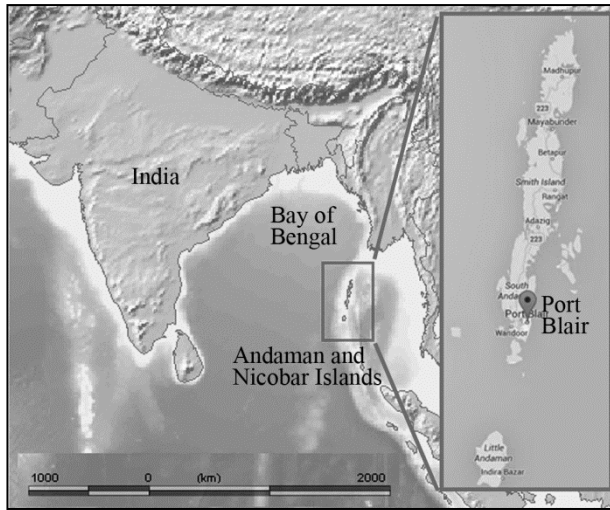
Fig. 1. Port Blair, Andaman and Nicobar Islands, India

Bernard (1932) developed an equation of the following form:

$$I_t^T = \frac{KT^x}{t^b} \qquad (2)$$

where, I_t^T is rainfall intensity of duration t and return period of T. K, x and b are constants depending on the region.

Many studies have been carried out for development of the relationships for different parts of the world such as Bilham (1935) for U.K. and Yarnall (1935) for U. S. Bell (1969) provided a Depth - Duration - Frequency (DDF) formula for United States. Baghirathan & Shaw (1978) developed DDF relationship for Sri Lankan conditions. Chen (1983) proposed a general formula of IDF relation for United States. Yu and Cheng (1998) developed a general regional IDF relation obtained by pooling annual maximum rainfall for Taiwan. Guo (2006) studied IDF analysis considering the effect of climate change for Chicago.

Several studies have been conducted for developing the IDF relationships for different regions in India. Parthsarathy & Singh (1961) developed IDF curves for local drainage design for Indian regions. Ayyar & Tripathi (1973) developed generalized plots of 15 min to 15 hours rainfall duration for 2 to 50 years return periods. Ram Babu *et al*. (1979) utilized the relationship developed by Sherman (1931), as shown below, and estimated coefficients of the relationship for different regions of India by dividing the country into Northern zone, Central zone, Western zone, Eastern zone and Southern zone.

$$i = \frac{KT^x}{(t+a)^b} \qquad (3)$$

where, i is maximum rainfall intensity (cm/ hour) of t (hour) duration having T (year) return period. K, x, a and b are constants based on the geographical region represented by the station. They provided different values of the constants for different locations within the zones. The average values of the coefficients, K, x, a, and b for the Eastern zone are 6.933, 0.1353, 0.50 and 0.8801 respectively and for the Southern zone, the values are 6.311, 0.1523, 0.50 and 0.9465 respectively.

Kothyari & Garde (1992) proposed following generalized relation for IDF by analyzing the rainfall data of 80 rain gauge stations in India.

$$i = C \frac{T^{0.20}}{t^{0.71}} (R_{24}^2)^{0.33} \qquad (4)$$

where, i is rainfall intensity in mm/hour, T is return period in years and t is rainfall duration in hours. R_{24}^2 is rainfall depth (mm) having duration of 24 hours and return period of 2 years. C is a constant whose values are 8.0, 9.1, 7.7, 8.3 and 7.1 for Northern, Eastern, Central, Western and Southern India respectively.

Ram Babu *et al*. (1979) and Kothyari & Garde (1992) divided India into five zones, however, Port Blair is not covered in any of these zones. Hence there is need for the development of the IDF relationship suited for the area.

2.2. *Rainfall intensity of smaller duration from intensity of 24 hours duration*

Rainfall intensities of smaller durations are required for estimation of design floods of small catchments. Most of the rain gauges in India are non-recording gauges and observations are taken only once, twice or thrice in a day, mostly once in a day. So, there is need of a relationship to obtain the intensities of smaller durations from the rainfall intensity of 24 hours duration. For this purpose the following relationship has been proposed in literature:

$$\frac{i}{I} = \frac{T+C}{t+c} \qquad (5)$$

where, t is smaller duration (hour), i is rainfall intensity of t hour duration in cm/ hour, T is 24 hours, I is rainfall intensity of 24 hours duration in cm/ hour and C and c are coefficients based on the region represented by the station. Analysis of rainfall statistics of several stations has shown the value of C and c to be 1 (Richards, 1944).

Ram Babu *et al*. (1979) also developed monograph for converting rainfall intensity of one hour duration into intensities of other durations. Conversion ratios to convert 24 hours point rainfall into short duration rainfall for

different zones of India are also available in flood estimation reports published by Central Water Commission, India and India Meteorological Department. Andaman and Nicobar Islands have been classified under Subzone 6. However Flood Estimation Report for Subzone 6 has not been published yet. Keeping in view this gap in existing reports, the present study has been undertaken.

3.   Study area and data used

The study area of the present study is Port Blair which is the capital city of Andaman and Nicobar Islands. Port Blair is located around 11°40′06″ N; 92°44′16″ E. It has average ground elevation of 16 m. It has a tropical monsoon climate with average temperature of 26.2 °C. It receives substantial rainfall round the year except January, February and March with annual rainfall of 3034.8 mm. 32 years hourly rainfall data of self-recording rain gauge at Port Blair from 1969 to 2000 procured from India Meteorological Department have been used in the study.

4.   Methodology

4.1. *IDF relationships*

The steps for developing the IDF curves are explained as follows:

(*i*)   Annual maximum, 1 hourly, 2 hourly, 3 hourly … 24 hourly rainfall depths were computed for each year of the available data. Thus a total of 24 series of annual maximum rainfall depth of length 32 were obtained.

(*ii*)   The univariate frequency analyses of each of the series of rainfall depths was performed using Gumbel EV1, General Extreme Value (GEV), Generalized Logistic and Lognormal distributions with parameter estimation using probability weighted moments. The expressions for the distributions are available in a number of text books [Rao & Hamed (2000); Hosking & Wallis (1997); WMO (1989)].

(*iii*) These distributions were selected on the basis of their general acceptability world over, for extreme rainfall analysis. Moreover, three of these distributions are available in inverse form and are easy to use and are recommended distributions in many countries like Gumbel EV1 distribution for India, Generalized Extreme Value Distribution (GEV), and Generalized Logistic Distribution (GLO) for U.K. etc. Initial goodness of fit tests like Chi-square test and Kolmogorov-Smirnov test indicated the acceptability of all of these distributions for most of the rainfall intensity data sets, obtained at step (*i*). Hence, graphical comparisons of the estimated rainfall

data obtained using these distributions against the observed rainfall data were made. The distribution which gave better estimation of rainfall especially of the top values was selected for further analysis. The empirical distribution of observed rainfall was determined by using Hosking plotting position formula as given below:

$$F = \frac{r - 0.35}{n} \qquad (6)$$

where, F is probability of non-exceedance, r = 1, 2, 3 … n are the ranks of rainfall values arranged in ascending order and n is total number of rainfall data.

(*iv*)   Apart from this, D-index test for goodness of fit was also carried out for selecting the best distribution. The value of D – index was determined as follows.

$$\text{D-index} = \frac{\sum_{i=1}^{6} |R_i - R_i^c|}{\bar{R}} \qquad (7)$$

where, R_i and R_i^c are the first 6 highest observed rainfalls and corresponding computed rainfalls from distribution. $\bar{R}$ is the average of all the observed rainfalls. The distribution having less value of D-index is the fitted one.

(*v*)   In order to develop the IDF relationship, Equations (2), (3) and (4) were used. The coefficients of these equations were found out by minimizing Root Mean Square Error (RMSE) for estimation of rainfall intensities through optimization. For optimization, Generalized Reduced Gradient (GRG) Nonlinear, (Lasdon *et al*., 1974) method was used.

(*vi*) Among the three developed relationships, the relationship having least RMSE was selected for the IDF equation.

(*vii*) The rainfall intensities obtained from the best IDF equation were also compared with the relationships developed by Kothyari & Garde (1992) and Ram Babu *et al*. (1979).

4.2. *Rainfall intensity of smaller duration from intensity of 24 hours duration*

In order to derive rainfall intensity of smaller duration from intensity of 24 hours duration for Port Blair, the same datasets as used in previous analysis were used. The steps are explained as follows:

(*i*)   Annual maximum rainfall intensities of 1, 2, 3 … 24 hours durations were obtained from hourly rainfall data.

(*ii*)   In order to derive the relationship, Equation (5) was used in two different ways. Firstly, the values of C and c

TABLE 1

Statistical properties of series of rainfall depths in mm

Series	Original Series					Log transformed Series					LC_v	LC_s	LC_k
	Max	Mean	SD	C_s	C_k	Max	Mean	SD	C_s	C_k			
1 hr	122.0	55.86	19.13	1.76	3.82	2.09	1.73	0.13	0.88	0.73	0.18	0.30	0.24
2 hrs	205.2	77.19	29.72	2.76	10.60	2.31	1.87	0.13	1.22	2.68	0.19	0.33	0.28
3 hrs	249.2	89.28	35.82	2.99	12.49	2.40	1.93	0.14	1.29	3.01	0.19	0.33	0.24
4 hrs	272.1	99.19	41.77	2.42	8.57	2.43	1.97	0.15	0.98	1.23	0.21	0.33	0.19
5 hrs	272.1	103.55	42.33	2.18	7.00	2.43	1.99	0.15	0.93	0.83	0.21	0.33	0.17
6 hrs	272.1	109.74	46.32	1.66	3.46	2.43	2.01	0.16	0.79	-0.09	0.22	0.33	0.15
7 hrs	280.4	115.00	48.90	1.60	2.85	2.45	2.03	0.16	0.82	-0.14	0.22	0.35	0.15
8 hrs	280.4	118.99	49.59	1.50	2.26	2.45	2.05	0.16	0.80	-0.23	0.22	0.34	0.15
9 hrs	283.9	122.90	50.68	1.45	2.01	2.45	2.06	0.16	0.72	-0.26	0.22	0.32	0.17
10 hrs	284.0	126.30	50.61	1.44	1.94	2.45	2.07	0.15	0.72	-0.17	0.21	0.32	0.19
11 hrs	285.7	128.60	51.24	1.41	1.85	2.46	2.08	0.15	0.66	-0.21	0.22	0.30	0.19
12 hrs	285.7	131.89	51.80	1.36	1.61	2.46	2.09	0.15	0.63	-0.23	0.21	0.30	0.19
13 hrs	285.7	134.45	52.73	1.28	1.31	2.46	2.10	0.15	0.56	-0.34	0.21	0.28	0.18
14 hrs	285.9	138.27	55.07	1.26	1.02	2.46	2.11	0.16	0.61	-0.36	0.22	0.30	0.18
15 hrs	285.9	142.87	55.81	1.24	0.92	2.46	2.13	0.15	0.61	-0.40	0.21	0.29	0.17
16 hrs	295.9	146.23	58.94	1.28	0.99	2.47	2.14	0.16	0.64	-0.36	0.22	0.30	0.17
17 hrs	326.8	150.57	62.74	1.42	1.52	2.51	2.15	0.16	0.74	-0.18	0.22	0.32	0.19
18 hrs	342.0	153.91	65.48	1.46	1.69	2.53	2.16	0.16	0.76	-0.15	0.23	0.33	0.19
19 hrs	350.6	156.35	67.53	1.48	1.73	2.54	2.16	0.16	0.77	-0.15	0.23	0.33	0.19
20 hrs	366.8	158.63	70.56	1.54	2.00	2.56	2.17	0.17	0.81	-0.06	0.23	0.35	0.20
21 hrs	382.0	162.90	73.71	1.47	1.73	2.58	2.18	0.17	0.77	-0.21	0.24	0.35	0.19
22 hrs	392.0	165.58	75.34	1.50	1.77	2.59	2.18	0.17	0.81	-0.15	0.24	0.36	0.20
23 hrs	400.0	168.83	76.25	1.52	1.87	2.60	2.19	0.17	0.82	-0.09	0.24	0.36	0.20
24 hrs	404.8	171.61	77.11	1.54	1.93	2.61	2.20	0.17	0.82	-0.01	0.23	0.36	0.21

were assumed to be same, in order to have a simpler formula. Suitable value of C = c for Equation (5) to get better estimation of rainfall intensities of smaller durations from intensity of 24 hours were obtained by minimizing RMSE through optimization using Generalized Reduced Gradient (GRG) nonlinear method. The value of c which gave least RMSE for estimating the rainfall intensities of smaller durations was selected.

(*iii*) Secondly, different values for C and c were determined by applying the optimization technique by reducing the RMSE.

(*iv*) Apart from Equation (5), the following equation was also used to get the required relationship:

$$\frac{i}{I} = \left(\frac{T+c}{t+c}\right)^d \qquad (8)$$

where, i and I are rainfall intensities (cm/hour) of smaller durations of t (hour) and T (*i.e.*, 24) hours

respectively. c and d are coefficients depending on the region. The values of these coefficients were obtained through optimization technique as before.

(*v*) Rainfall intensities of durations 1, 2, 3 … 23 hours were estimated from observed intensity of 24 hours duration using Equation (5) taking conventional value of c = C that is 1, modified value of c = C obtained in step (ii), values of C and c obtained in step (iii) and using Equation (8) with corresponding values of coefficients, c and d obtained in step (iv). The estimation of rainfall intensities was compared against the observed intensities to check the performance of the relationships. RMSE and percentages of rainfall intensities lying outside 10% and 30% error bands were determined for comparison purpose.

(*vi*) Percentages of overestimation and underestimation of rainfall intensities obtained by above four approaches were determined for further comparison. The following
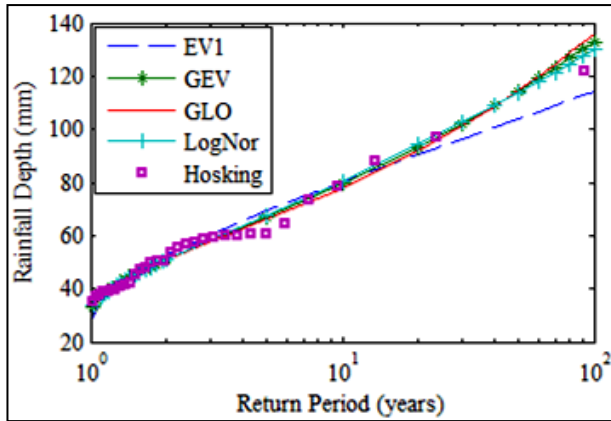
Fig. 2. Comparison of rainfall depths of 1 hour duration estimated by different distributions with the observed rainfall depths
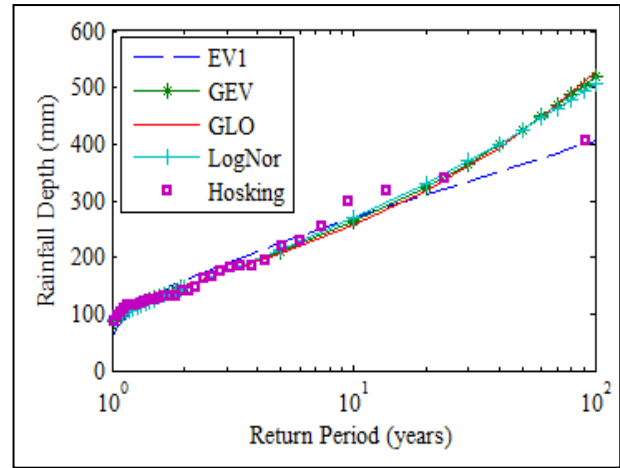

Fig. 4. Comparison of rainfall depths of 24 hours duration estimated by different distributions with the observed rainfall depths
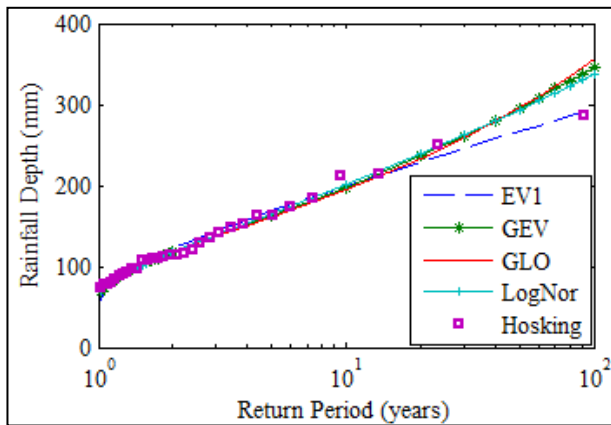

Fig. 3. Comparison of rainfall depths of 12 hours duration estimated by different distributions with the observed rainfall depths

expression was used for calculating the percentages of over and underestimations.

$$\%\text{age over or underestimation} = [\frac{i_{est} - i_{obs}}{i_{obs}}]*100 \qquad (9)$$

where, i_{obs} is observed intensity and i_{est} is corresponding estimated intensity. Positive results are overestimations and negative are underestimations.

(*vii*) Considering all these comparison processes, the better values of coefficients were selected for estimation of rainfall intensities of smaller duration for Port Blair.

5.   Results and discussion

5.1. *Rainfall intensity duration frequency curves*

Series of 32 annual maximum rainfall depths of 1, 2, 3 …, 24 hours durations were prepared. The statistical properties of series of rainfall depths are shown in the Table 1. Univariate frequency analyses were performed using Gumbel EV1, GEV, Generalized Logistic and Lognormal distributions for these series. Rainfall depths corresponding to return periods up to 100 years were estimated. Comparison plots of rainfall depths obtained from the above distributions with the empirical depths obtained from Hosking plotting position formula for duration of 1, 2, 3, …, 24 hours were plotted. Figs. (2-4) show the comparison plots for rainfall duration of 1, 12 and 24 hours only. Table 2 shows the values of D-index obtained for above distributions. The results of D-index test showed Gumbel EV1 distribution as the best fitted for the rainfall depths beyond duration of 5 hours. For duration of 1 hour, Lognormal distribution and for durations from 2 to 5 hours, Generalized Logistic distribution were found best fitted. As in most of the cases, Gumbel EV1 distribution was best fitted except for rainfall depths of smaller durations from 1 to 5 hours. To maintain uniformity, Gumbel EV1 distribution was selected for all durations and used for further analysis.

Rainfall intensities were obtained from the estimated depths. The values of coefficients of Equations (2), (3) and (4) obtained by minimizing RMSE of estimated rainfall intensities with the intensities obtained by Gumbel EV1 distribution are shown in Table 3. As the minimum RMSE was obtained by Equation (3), it has been chosen as the relationship for IDF curves for Port Blair.

The rainfall intensities obtained from the Equation (3) were also compared with the empirical intensities. Likewise, the rainfall intensities were also estimated from established IDF relationships of Kothayari & Garde (1992) and Ram Babu *et al*. (1979) assuming Southern

TABLE 2

Values of D-Index of different distributions

S. No.	Series	D Index				Remark
		EV1	GEV	GLO	Log Nor	
1.	1 hr	0.65	0.43	0.52	0.42	Log Nor
2.	2 hrs	1.21	0.71	0.55	0.88	GLO
3.	3 hrs	1.53	1.11	1.00	1.22	GLO
4.	4 hrs	1.17	0.87	0.79	0.99	GLO
5.	5 hrs	0.99	0.79	0.78	0.86	GLO
6.	6 hrs	0.76	1.06	1.13	0.96	EV1
7.	7 hrs	0.73	1.13	1.24	1.02	EV1
8.	8 hrs	0.67	1.17	1.30	1.04	EV1
9.	9 hrs	0.48	0.98	1.09	0.85	EV1
10.	10 hrs	0.31	0.75	0.90	0.64	EV1
11.	11 hrs	0.21	0.59	0.79	0.50	EV1
12.	12 hrs	0.36	0.58	0.80	0.49	EV1
13.	13 hrs	0.43	0.64	0.79	0.58	EV1
14.	14 hrs	0.66	0.91	1.08	0.79	EV1
15.	15 hrs	0.69	0.93	1.11	0.81	EV1
16.	16 hrs	0.82	1.07	1.24	0.96	EV1
17.	17 hrs	0.77	1.06	1.19	0.95	EV1
18.	18 hrs	0.78	1.11	1.24	0.97	EV1
19.	19 hrs	0.85	1.15	1.28	1.01	EV1
20.	20 hrs	0.83	1.11	1.24	1.00	EV1
21.	21 hrs	0.47	1.12	1.32	0.89	EV1
22.	22 hrs	0.54	1.23	1.41	1.04	EV1
23.	23 hrs	0.57	1.22	1.37	1.03	EV1
24.	24 hrs	0.61	1.20	1.38	1.02	EV1

TABLE 3

Values of coefficients of the equations obtained by minimizing RMSE

Equation (2)	Equation (3)	Equation (4)
b = 0.623	a = 0.529	
x = 0.232	b = 0.733	C = 9.93
	x = 0.232	
K = 4.376	K = 5.816	
RMSE = 0.255	RMSE = 0.239	RMSE = 0.358
$R^2 = 0.977$	$R^2 = 0.980$	$R^2 = 0.957$

and Eastern zones and compared with the empirical intensities. Table 4 shows RMSE, R-square and the percentage of rainfall intensities lying within ± 30% error lines obtained by comparing the empirical intensities with the intensities from Equation (3) and the IDF relationships of Kothayrai & Garde (1992) and Ram Babu *et al*. (1979).

The ± 30% error lines were taken uniformly, for comparison purpose. Figs. (5-7) show the comparison plots. The purpose of these comparisons was to assess the performance of the results obtained from Equation (3) with the results of established relationships in use. The 45° inclined line passing through the origin is the

TABLE 4

RMSE, R-square and percentage of rainfall intensities within ± 30% error lines

S. No.	Agreement between rainfall intensities	RMSE	R-square	% of intensities within ± 30% error
1.	Equation (3) & Empirical	0.238	0.974	87.11
2.	Kothyari & Garde (1992), Southern zone & Empirical	0.6705	0.9077	63.28
3.	Kothyari & Garde (1992), Eastern zone & Empirical	0.4269	0.9077	90.10
4.	Ram Babu *et al.* (1979), Southern zone & Empirical	0.7268	0.8542	39.58
5.	Ram Babu *et al.* (1979), Eastern zone & Empirical	0.5893	0.8490	74.09

TABLE 5

Root Mean Square Error (RMSE) and percentage of estimated rainfall intensities lying outside of error bands

Case	Equation used	Values of Coefficients	RMSE	% intensities outside	
				10%	30%
I	5	c = 1	1.449	59.2	34.2
II	5	c = 3.5	0.766	51.1	19.3
III	5	c = 2.8 and C = 0	0.742	60.5	13.5
IV	8	c = 0.67 and d = 0.4	0.726	49.6	12.5

line of agreement. The points lying along the line show that the estimated intensities are equal with the empirical intensities which is the desired result. Zero value of RMSE means that the estimated values are exactly equal with the empirical values. So, value of RMSE near to zero is desirable. The maximum value of R-square is "one" which means that the estimated values and empirical values are perfectly linearly correlated. Hence, the value of R-square close to one is desired.

It can be seen that the lowest RMSE and highest R-square were obtained for the Equation (3). The percentage of rainfall intensities lying within ± 30% error lines was highest for the case of the Kothyari & Garde (1992), Eastern zone than the case of the Equation (3) by very less amount. However, the RMSE of the Kothyari & Garde (1992), Eastern zone was more, it had more deviations in estimating rainfall intensities of larger durations [can be seen in the Fig. (8)]. Thus Equation (3) was taken as appropriate for development of IDF curves for Port Blair. Hence, the proposed IDF formula for Port Blair for estimating rainfall intensities of return periods up to 100 years has been proposed as follows:

$$i = \frac{5.816 \, T^{0.232}}{(t + 0.529)^{0.733}} \tag{10}$$

where, i is taken in cm/hour, T is in years and t in hours. IDF curves for Port Blair were developed using the proposed relationship, Equation (10). The final plot of IDF curves were drawn for return periods of 2, 5, 10, 25, 50, 75 and 100 years for Port Blair which are shown in Fig. (8).

5.2. *Determination of rainfall intensity of smaller duration from intensity of 24 hours duration*

The Equations (5) and (8) were used for deriving rainfall intensities of smaller durations. The conventional value of c = C in Equation (5) is 1. The rainfall intensities obtained by taking the conventional value, were compared with the observed intensities. The Case I of Table 5 shows the Root Mean Square Error (RMSE) and percentages of rainfall intensities lying outside ± 10% and ± 30% error bands. The main intension of this study was to get the values of coefficients of Equation (5) and (8) so that the estimation of the rainfall intensities of smaller durations from the intensity of 24 hour duration could be done more precisely. For this, five cases were considered, *viz.*, Equation (5) with c = C = 1 (Case I); Equation (5) with values of c = C ≠ 1 (Case II); Equation (5) with different values of c and C (Case III); and Equation (8) (Case IV). The results of different cases are shown in Table 5. The RMSE corresponding to Case IV was the least. The percentages of rainfall intensities lying outside error bands were also comparatively least for Case IV among the other Cases.

The scatter plot of estimated rainfall intensities obtained from Cases I and IV with the observed intensities is shown in Fig. (9). It can be seen that the intensities
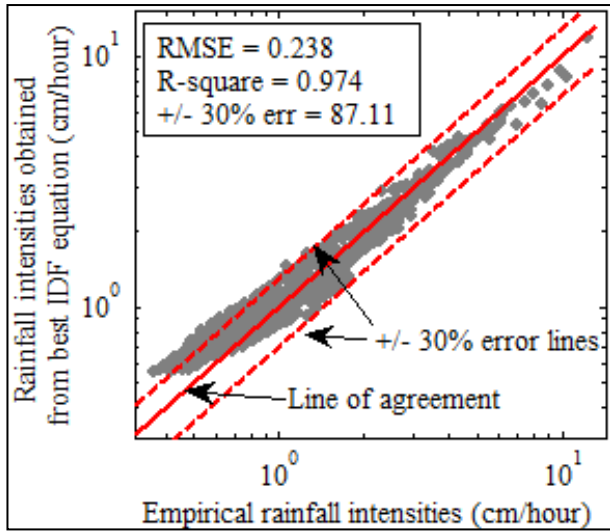
Fig. 5. Comparison of rainfall intensities obtained from the best IDF Equation (3) with empirical rainfall intensities
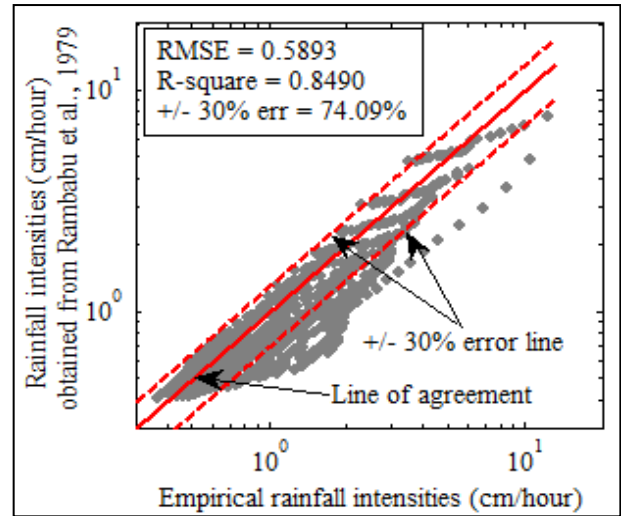

Fig. 7. Comparison of rainfall intensities obtained from Rambabu *et al*., 1979 (Eastern Zone) with empirical rainfall intensities
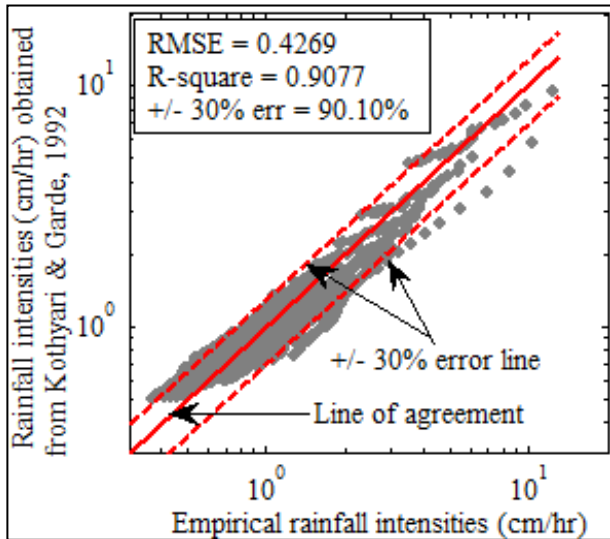

Fig. 6. Comparison of rainfall intensities obtained from Kothyari & Garde, 1992 (Eastern Zone) with empirical rainfall intensities
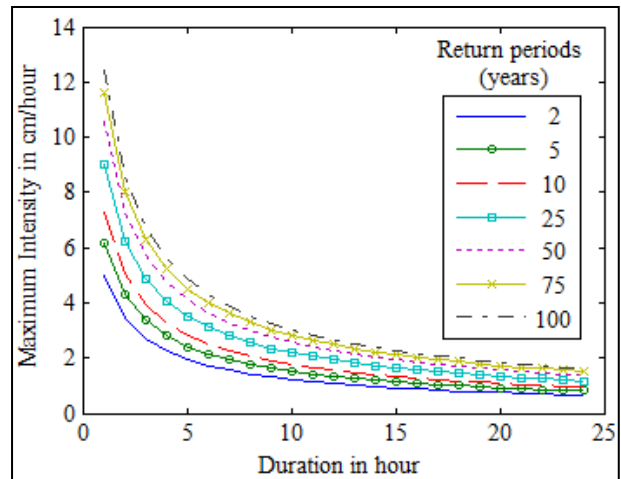

Fig. 8. IDF Curves obtained from the best equation for Port Blair

estimated from Case IV are more close to the line of agreement and less intensities lie outside the error bands due to lesser RMSE. Figs. (10 & 11) show the scatter plot of rainfall intensities obtained from Cases II and IV; and Cases III and IV respectively. The main intention of these plots were to compare graphically the performance of Case IV with other Cases. The graphical comparisons also showed Case IV to be best among the other cases.

The points which are lying above of the line of agreement in Figs. (9-11) are overestimations of
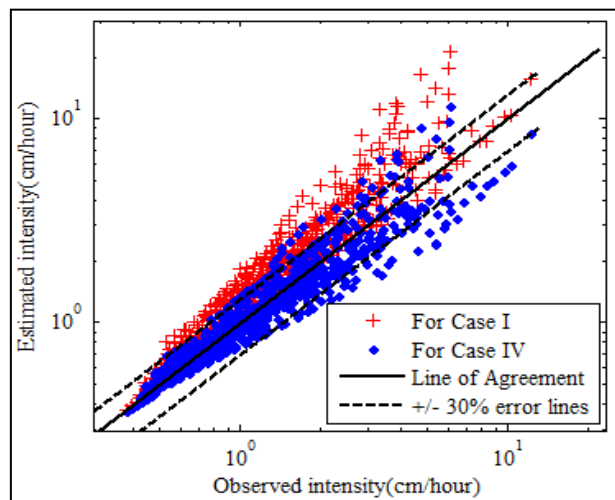
Fig. 9. Comparison of estimated rainfall intensities obtained from cases I and IV with the observed intensities
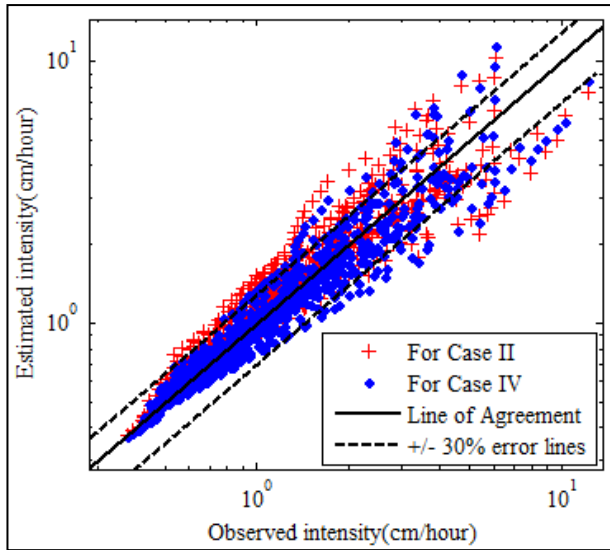
Fig. 10. Comparison of estimated rainfall intensities obtained from cases II and IV with the observed intensities
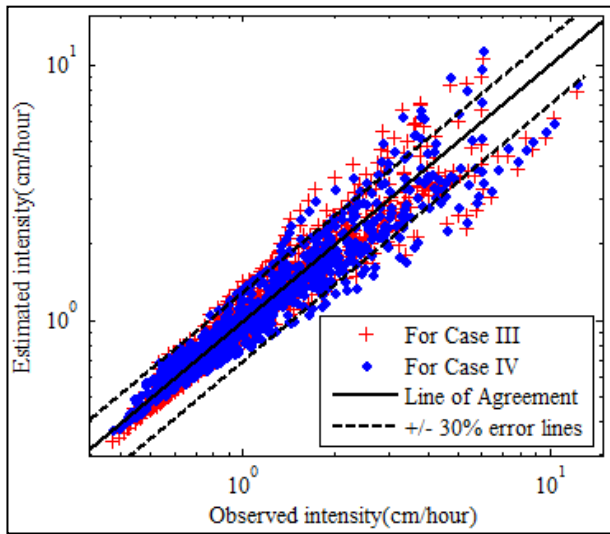

Fig. 11. Comparison of estimated rainfall intensities obtained from cases III and IV with the observed intensities
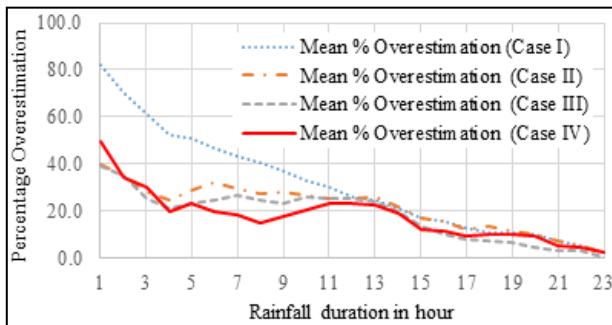

Fig. 12. Comparison of mean percentages of overestimation of rainfall intensities obtained for different cases versus rainfall durations
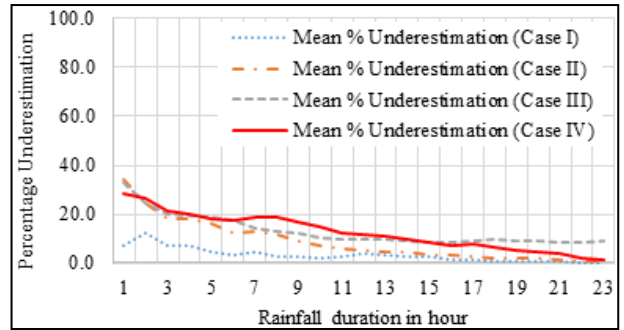

Fig. 13. Comparison of mean percentages of underestimation of rainfall intensities obtained for different cases versus rainfall durations

rainfall intensities while the points lying below are underestimations. It is desirable to have less value for both over and underestimations. Percentages of over and underestimations were determined by using Equation (9). The percentages of over and underestimations for different cases were determined corresponding to different values of rainfall durations. Means of such over and underestimations were plotted against the rainfall durations for comparison purposes as shown in Figs. (12&13) respectively. Fig. (12) shows that the percentages of overestimations for Case IV are the lowest for most of the rainfall durations. The percentages of underestimations, as shown in Fig. (13), are comparatively higher for Case IV. Case IV reduced overestimations by great amount as compared to little increase in underestimations. So in this perspective, Case IV was taken as the best among the cases.

Hence, considering all above comparative studies, Equation (8) used in Case IV has been proposed for estimating rainfall intensities of smaller durations from the intensity of 24 hours duration for Port Blair. The final form of the required equation after substituting the values of the coefficients is given as below:

$$\frac{i}{I} = \left(\frac{T + 0.67}{t + 0.67}\right)^{0.4} \tag{11}$$

where, i and I are rainfall intensities of smaller duration, t (hour) and duration of 24 hours (*i.e.*, T) respectively.

6. Conclusions

Three general Equations (2)-(4), were used for development of IDF relationship for Port Blair applying best fitted Gumbel EV1 distribution. Optimizing technique was used to find the values of constants involved in the equations by minimizing the RMSE for estimating the rainfall intensities. Among the three,

Equation (3) was found to have least RMSE and hence, it was selected for IDF relationship for Port Blair. Performance of the Equation (3) was also compared with other established relationships of Kothyari & Garde (1992) and Ram Babu *et al.* (1979) considering Southern and Eastern zones. The comparisons also showed better estimation of IDF relationship by the Equation (3). The final form of the relationship, *i.e.*, Equation (10) which is obtained by replacing the coefficients with the respective numerical values in Equation (3), has been proposed for IDF relationship for Port Blair. Similarly, for estimating rainfall intensities of smaller durations from intensity of 24 hours duration for Port Blair, Equation (11) has been proposed.

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