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Interpolation of short duration rainfall from 24-hour rainfall in lower Godavari basin

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सार — अभिकल्पना हेतु बाढ़ आकलन संबंधी अनेक समस्याओं में विभिन्न प्रत्यर्पण अवधियों की अल्पावधिक वर्षा के आकलों की आवश्यकता होती है । स्वलेखी वर्षामापी (एस० आर० आर० जी०) के अपर्याप्त संजाल और उपलब्ध प्रलेखों में सभी अवधियों के प्रलेख उपलब्ध न हो पाने से जल स्रोत विषयक योजनाकारों ने उक्त कमियों को दूर करने के लिए बैकल्पिक विधियों का विकास किया है । शोधपत्र में साधारण अन-भिलेखी वर्षामापियों के 24 घंटों के आंकड़ों से ज्ञात प्रत्यागमन अवधि के लिए अल्पावधि अधिकतम वर्षा के आकलन का प्रयास किया गया है। इस अध्ययन में अपनायी गई प्रक्रिया इस प्रकार है :

गोदावरी बेसिन के निचले भाग में लगे 17 स्वलेखी वर्षामापियों के विद्यमान संजाल में से यादृच्छिक रूप से चुने हुए 14 स्वलेखी वर्षा-मापियों के आंकड़ों का उपयोग करके अल्पावधि वर्षा के आकल और ज्ञात प्रत्यागमन अवधि के लिए 24 घंटों की वर्षा के बीच समाश्रयण समीकरण फिट किया गया है । बेसिन को एक इकाई मानकर न्यूनतम वर्ग विधि से समाश्रयण वक्र के गुणांकों को हल किया गया है ।

उक्त स्थिरांकों और गुणांकों का उपयोग करके एक समस्या प्रधान क्षेत्र में अल्पावधि वर्षा का आकलन किया गया । शेष तीन स्वलेखी वर्षामापी स्टेशनों जिन्हें समाश्रयण गुणाकों के अभिकल्पन में उपयोग में नहीं लाया गया और उस क्षेत्र में और उसके आसपास के चार साधारण वर्षामापी स्टेशनों के आंकड़ों से 2 और 50 वर्ष की प्रत्यागमन अवधियों की अल्पावधि वर्षा के आकल निर्धारित किए गए । तुलना करने पर उनकी त्रुटियां उचित सीमा के भीतर पाई गई । अस्तु शोधपत्र में प्रस्तुत प्रविधि से किसी भी क्षेत्र की दैनिक वर्षा के आंकड़ों से अल्पावधि वर्षा का आकलन किया जा सकता है ।

ABSTRACT. Short duration rainfall estimates for different return periods ore required in many problems concerning flood estimation for design purposes. A general paucity of data in the form of inadequate network of self recording raingauges (SRRG) and also the inadequacy of available period of records often necessitated the water resource planners to develop alternate techniques to overcome this deficiency. An attempt has been made in this paper to estimate short duration extreme rainfall for a given return periods from a knowledge of 24-hour data of ordinary non-recording raingauges. The procedure adopted in the study is as follows :

Using data of randomly selected 14 SRRGs out of already existing network of 17 S.R. raingauges in lower Godavari basin regression equation was fitted between a short duration rainfall estimate and 24-hr rainfall estimate for a given return period. The coefficients of regression curve were worked out by the least squares method with basin as a unit.

Using these constants and coefficients, estimates of short duration in a problem area were made. The short duration rainafll estimates for 2 and 50-year return periods were computed for three existing SRRG stations which were not used in the computation of regression coefficients and four ordinary raingauge stations in and around the sub-zone. The errors, on comparison are found to be within reasonable limits. The technique presented in the paper can be employed to estimate short duration rainfall from daily rainfall records for any area.

1. Introduction

The short duration rainfall estimates of less than 24 hrs are essential for the design of spillways, culverts, road and railways bridges over small and medium catchments etc. These estimates are determined by the analysis of autographic rainfall charts. However, the network of autographic record stations in a catchment is generally inadequate, in most of the catchments in many

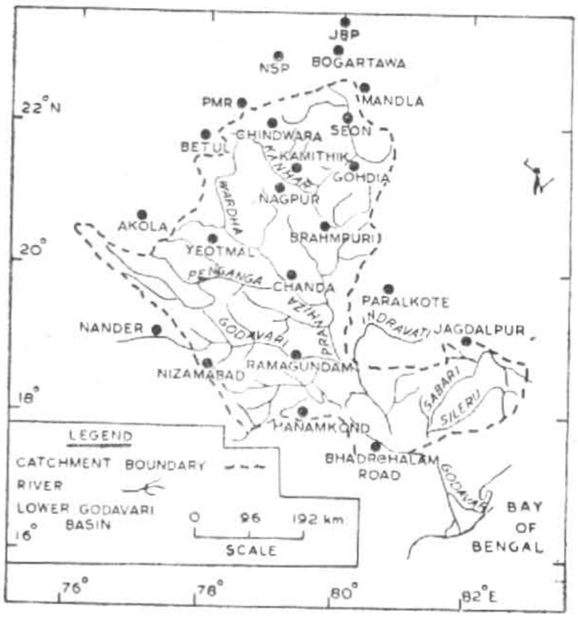

Fig. 1. Location of self recording raingauges in lower Godavari basin

countries. On the other hand, there are many ordinary raingauge stations recording daily rainfall in catchment areas whose data can be used. A huge amount of daily rainfall data are also recorded by the stations maintained by various States and central agencies. This data could not be used directly so far for want of a suitable application method for estimation of short duration rainfall required for design purposes.

In USA (1967) precipitation frequency maps for different regions using the rainfall data of recording and non-recording raingauges, were prepared. Different regression equations for the estimation of rainfall amounts for 24 hrs duration over various return periods were used for the regions of sparse or no data. Various parameters like annual normal rainfall, elevation and topography of the place were used as independent variables in the regression equation. The short duration rainfall, in particular 6-hr rainfall, was estimated by using the regression equation of the form

$$y = a + b \log x + cz,$$

where, y is the 6-hr precipitation amount for particular return period, x is the corresponding 24-hr precipitation amount and z is the elevation of the place. The regression coefficients a, b and c were determined using the data of a number of stations in the region considered.

In this paper the authors have presented a similar procedure to compute short duration rainfall estimate for a given return period from the daily rainfall. The hourly rainfall data of 17 stations existing in the lower Godavari basin were analysed by Gumbel's method and rainfall estimates for different return periods and for various durations were computed. The short duration rainfall estimates (dependent variables) were related to 24 hrs maximum rainfall estimates (independent variables) by a regression equation of 2nd order. The regression coefficients were computed based in the short duration data of randomly selected 14 (S. No. 1-14 Table 1) out of 17 existing SRRG stations by using the least square method. The resulting regression equation, were used to compute 1 hour, 3 hours, 6 hours, 9 hours, 12 hours and 15 hours rainfall estimates for 4 non-recording and 4 recording raingauge stations located in and around the basin. It was found that the results obtained by this method were comparable with the rainfall estimates computed from observed short duration data of the nearest autographic station.

2. Fitting of constants from sample of existing values

The first part of the approach is to fit the constants based on an existing sample of data. The data chosen should be dense enough to define the constants accurately. After the constants are fitted, then in the second part they are tested on a fresh set of data. In the third step, the values tested are compared with the known values of the nearest recording stations.

2.1. *Derivation of constants*

The hourly SRRG rainfall data as available varied from 7 years to 30 years for 17 stations in lower Godavari basin. These data were utilised in the present study which is a good spatial coverage. The stations are shown in Fig. 1.

According to Gumbel's (1958) extreme value distribution the probability density function $F(x)$ is given by :

$$F(x) = \exp[-e^{-\alpha(x-u)}],$$

where x is the extreme rainfall likely to occur or be exceeded once in a given return period on the average. The parameters α and u are estimated by the method of moments and are given by :

$$u = \bar{x} - 0.58/\alpha, \tag{2}$$

and

$$\alpha = \frac{1}{0 \cdot 78\, s} \tag{3}$$

where, $\bar{x}$ and s are the mean and standard deviation respectively of the extreme rainfall data series. The value of x for a given return period T can now be estimated from

$$x = u + y_T/\alpha, \tag{4}$$

where, y_T the reduced variate is a function of return period T and is given by :

$$y_T = -l_n\, l_n \left(\frac{T}{T-1}\right), \tag{5}$$

Eqn. (4) was used to estimate the rainfall values for different durations and return periods. The rainfall estimates as computed using above equations, for chosen return period of 2-year and 50-year for different durations are given in Table 1.

2.2. *Interpolation of rainfall estimates*

The rainfall estimates may be interpolated into two different categories, namely :

2.2.1. *Over different return periods*

According to Gumbel's extreme value distribution the relation between different return period estimates and the corresponding reduced variates can be shown as straight line on the Gumbel's probability paper (Double exponential linear). The values of rainfall estimates of 2-year and 50-year return periods may be plotted and estimates of rainfall of other return periods can be made directly from this graph.

2.2.2. *Over different durations*

A long duration rainfall event is supposed to cover all short duration events and is likely to be related with them in some form or other. As an example 24-hr rainfall event is bound to be related to short duration event of 1-hr, 3-hr, 6-hr, 12-hr etc. and this 24-hr event will account fractionally for these short duration events. Several trial mathematical relationships were used to establish a relation between 24-hr rainfall estimate and a short duration estimate. The following regression equation of second order is found best suitable, on the basis of highest degree of correlation between observed and expected events, to relate short duration rainfall with the 24-hr rainfall :

$$y = a + bx + cx^2 \tag{6}$$

where x is the rainfall estimate for 24-hr duration for any given return period and y is the rainfall estimate of any short duration for that return period. The constants a, b & c were estimated by using the least square technique of minimising the errors. If S denotes the sum of squares as :

$$S = \Sigma\,(y - a - bx - cx^2)^2, \tag{7}$$

then the least square method demands

$$\frac{\partial S}{\partial a} = \frac{\partial S}{\partial b} = \frac{\partial S}{\partial c} = 0 \tag{8}$$

Using Eqns. (7) & (8) we get

$$\Sigma\, y - an - b\,\Sigma\, x - c\,\Sigma\, x^2 = 0$$
$$\Sigma\, x\, y - a\,\Sigma\, x - b\,\Sigma\, x^2 - c - c\,\Sigma\, x^3 = 0$$
$$\Sigma\, xy^2 - a\,\Sigma\, x^2 - b\,\Sigma\, x^3 - c\,\Sigma\, x^4 = 0 \tag{9}$$

The set of three equations given by (9) are solved to get three unknowns a, b, c. After knowing the constants a, b, c a relationship is established between 24-hr rainfall estimate of a given return period and the required short duration rainfall estimate. The relationship can be used to compute short duration rainfall estimate of a required design return period from the analysis of daily rainfall data in the subzone.

3. Testing of regression coefficient

The standard error in the estimation of regression coefficient, S. E., is given by:

$$S.\,E. = \left[\frac{R^2\,(1 - r^2)}{(N-2)\,r^2}\right]^{\frac{1}{2}} \tag{10}$$

where 'r' is the coefficient of correlation between the observed and computed rainfall estimates.

TABLE 1

Rainfall estimates (mm) computed by Gumbel's distribution for 2 and 50 years

Station	No. of yrs of data	2-yr							50-yr						
		1-hr	3-hr	6-hr	9-hr	12-hr	15-hr	24-hr	1-hr	3-hr	6-hr	9-hr	12-hr	15-hr	24-hr
Akola	7	44.0	63.5	74.8	81.5	85.3	90.0	101.7	77.8	114.3	118.8	146.7	151.1	165.4	213.8
Brahampuri	8	46.6	79.7	102.0	119.9	128.6	136.3	161.2	80.8	128.9	167.6	217.8	251.8	290.0	367.3
Betul	9	39.3	59.6	79.8	98.3	111.0	119.5	147.0	70.7	136.5	196.8	254.2	269.0	277.9	327.6
Bagartawa	23	38.9	66.7	86.9	99.8	110.8	120.3	140.2	74.8	121.5	172.0	202.8	218.2	240.5	297.5
Gondia	9	50.9	78.0	102.5	118.3	131.0	142.0	169.8	88.9	152.9	214.7	259.2	269.1	287.6	310.8
Jabalpur	27	40.2	64.8	81.3	88.6	96.0	102.2	119.4	81.0	129.7	176.0	190.3	194.3	221.0	245.0
Jagdalpur	25	40.7	58.7	75.4	86.5	92.6	103.5	120.0	77.1	112.8	130.1	145.1	156.8	179.3	206.8
Mandla	9	47.8	75.2	87.1	95.4	106.8	114.1	138.1	107.8	174.6	192.3	199.9	204.1	214.9	258.8
Narsinghpur	7	39.7	65.4	91.0	106.8	123.6	132.4	149.6	66.9	110.8	165.7	195.4	219.8	238.9	289.8
Nizamabad	7	32.0	46.9	57.5	66.8	73.8	77.7	95.9	57.6	90.3	102.5	113.1	134.3	161.0	188.8
Paralkote	8	43.7	62.9	78.9	94.6	107.0	117.5	154.2	77.0	118.2	151.2	191.3	239.5	273.0	344.0
Pachmarhi	8	43.9	84.1	104.3	124.9	141.0	157.4	211.6	58.3	125.6	176.7	243.4	300.6	371.2	510.8
Ramagundam	10	47.9	66.0	78.1	83.5	86.4	87.2	99.0	72.4	114.5	131.3	145.8	151.7	152.5	173.8
Yeotmal	7	38.5	51.6	77.1	87.0	93.5	100.4	106.9	70.6	145.2	168.5	179.5	184.5	197.5	224.8
Chanderpur	10	45.8	70.7	84.5	92.1	103.5	113.9	134.5	84.4	130.9	153.9	180.4	203.0	221.8	229.5
Hanamkonda	7	34.3	50.3	63.4	73.0	77.1	78.2	85.1	61.9	88.3	113.7	143.2	160.3	169.7	180.1
Nagpur	30	41.7	59.4	71.9	78.9	85.3	90.9	104.0	77.9	113.3	131.4	150.0	157.7	165.2	196.3

The significance of the regression coefficient is tested by student's t-test given by :

$$t = r\sqrt{\frac{N-2}{1-r^2}} \tag{11}$$

4. Results and discussions

The hourly rainfall data of the 17 autographic stations located in lower Godavari basin were analysed and annual series of different durations were computed. The Gumbel's extreme value distribution was applied to these annual series of each station and the rainfall estimates for different duration and different return periods were computed by using Eqn. (4). The rainfall estimates as computed by using Eqn. (4) for all the 17 stations for different durations for 1, 3, 9, 12, 15 and 24-hr and of 2-year and 50-year return periods are tabulated in Table 1.

Different relations to interpolate the short duration rainfall from 24-hr annual maximum rainfall were tried. It was found that the relation given by Eqn. (6) showed best fitting as the highest correlation coefficient between the observed and computed rainfall estimates for all durations was observed. The values of the regressions coefficients based on 14 out of 17 SRRG stations for different durations for 2-year and 50-year return periods are given in Table 2. The standard errors in the computation of regression coefficients b & c were computed by

TABLE 2

Values of regression coefficients and errors of estimates for 2-yr & 50-yr return periods

	1-hr		3-hr		6-hr		9-hr		12-hr		15-hr	
	Regression coefficient	S Error	Regression coefficient	S Error	Regression coefficient	S Error	Regression coefficient	S Error	Regression coefficient	S Error	Regression coefficient	S Error
						2-year return period						
a. —	26.77	—	39.38	—	30.97	—	24.77	—	5.72	—	—3.31	—
b. 10^{-2} X	17.86	11.28	15.93	3.60	47.56	7.60	62.72	6.62	93.18	7.44	107.54	6.43
c. 10^{-4} X	—4.33	2.74	2.62	0.59	—5.72	0.92	—6.69	0.71	—13.29	1.06	—14.62	0.87
						50-year return period						
a. —	27.18	—	38.15	—	—25.60	—	—34.85	—	—36.92	—	—17.88	—
b. 10^{-2} X	34.88	15.95	54.75	32.48	110.12	30.35	121.88	21.90	122.11	11.59	109.51	6.21
c. 10^{-4} X	—5.68	2.60	—7.57	4.49	—14.08	3.88	—13.31	2.39	—10.96	1.04	—6.58	0.37

TABLE 3 (a)

Rainfall estimates (mm) computed by regression equation for 2-year return period

Stations	1-hr	3-hr	6-hr	9-hr	12-hr	15-hr
Akola	40.4	58.3	73.4	81.7	86.8	90.9
Brahampuri	44.3	71.9	92.8	108.5	121.4	132.0
Betul	43.7	68.5	88.5	102.5	114.0	123.2
Bagartawa	43.3	66.9	86.4	99.6	110.3	118.7
Gondia	44.6	74.0	95.2	112.0	125.6	187.1
Jabalpur	38.8	54.8	67.3	73.3	75.4	77.6
Jagdalpur	41.9	62.1	79.6	90.1	98.0	104.2
Mandla	42.0	62.3	79.8	90.4	98.4	104.7
Narsinghpur	43.2	66.4	85.7	98.6	109.1	117.3
Nizamabad	43.8	69.1	89.3	103.6	115.4	124.8
Paralkot	44.0	70.2	90.7	105.6	117.8	127.7
Pachmarhi	45.2	84.8	106.0	127.5	143.4	158.8
Ramagundam	40.2	57.7	72.4	80.3	84.9	88.8
Yeotmal	40.9	59.4	75.3	84.2	90.2	94.9
Corr. Coeff.	0.42	0.74	0.88	0.94	0.96	0.98
T-values	1.58	4.42	6.26	9.47	12.52	16.72

TABLE 3 (b)

Rainfall estimates (mm) computed by regression equation for 50-year return period

Stations	1-hr	3-hr	6-hr	9-Hr	12-hr	15-hr
Akola	75.8	120.6	145.5	164.9	174.0	186.4
Brahampuri	78.7	137.1	188.9	233.3	263.7	296.2
Betul	80.4	136.2	184.0	221.6	245.4	270.7
Bagartawa	80.6	134.0	177.4	209.9	229.3	250.0
Gondia	80.7	135.2	180.6	215.4	236.7	259.3
Jabalpur	71.6	112.2	127.0	141.5	147.4	155.1
Jagdalpur	78.5	126.8	159.7	183.9	196.4	211.2
Mandla	75.0	119.0	141.9	160.3	168.7	180.6
Narsinghpur	79.4	129.1	165.1	191.4	205.7	221.8
Nizamabad	80.6	133.2	175.3	206.6	224.9	244.6
Paralkot	79.9	136.9	186.6	226.9	253.6	281.5
Pachmarhi	56.9	120.2	169.5	240.4	300.7	370.9
Ramagundam	70.6	110.4	123.3	136.8	142.2	152.7
Yeotmal	76.9	123.0	150.8	171.9	182.2	195.3
Corr. Coeff.	0.53	0.44	0.72	0.85	0.96	0.98
T-values	2.186	1.69	3.63	5.56	10.53	17.64

using Eqn. (10) and are also listed in Table 2. The value of coefficient '*a*' is also simultaneously determined. The significance of correlation coefficient between the observed and computed series was tested by student's *t*-test. The *t* values thus obtained were found to be statistically significant at 5% level of significance. This implies that the fitting of curvi-linear regression Eqn. (6) can be used to estimate a short duration rainfall knowing 24-hr rainfall estimate for a given return period, in this subzone. The rainfall estimates based on the regression equation for different durations and for 2-year and 50-year return periods for various stations used in the study are given in Tables 3(a) and 3(b).

In general, the available length of record of autographic rainfall data for short duration estimates of 50-year or 100-year return periods is inadequate for the purpose of return period analysis. For instance Gumbel's form of distribution assumes $\underset{n\to\infty}{\mathrm{Lt}} \left(1 - \frac{x}{n}\right)^n = e^{-x}$ when $n \to \infty$, where n is the number of observations in the annual series, *i.e.*, number of years of data used. If the data used are for a short period, it does not satisfy the condition for Gumbel distribution. The authors therefore suggest here that a relationship of the type of Eqn. (6) may be first established between 24-hr rainfall estimate and the desired duration estimate of the design return period. Thereafter daily rainfall records for all available stations and periods of records should be involved in the process of computation of desired estimates. For the purpose a daily rainfall estimate should be first converted into any 24-hr estimate by multiplying by a factor of 1.15 (Harihara Ayyar *et al.* 1973) and then the relationship already established should be used to deduce short duration rainfall estimate for each station. All stations in a catchment and sub-catchment or in a railway bridge catchment may be used to evaluate final estimates.

TABLE 4

Verification of results for 2 & 50-year return period estimates

Station	No. of yrs of data	1-hour			3-hour			6-hour			9-hour			12-hour			15-hour		
		I	*C*	% Error	*I*	*C*	% Error	*I*	*C*	% Error	*I*	*C*	% Error	*I*	*C*	% Error	*I*	*C*	% Error
(a) 2-year return period																			
Warora (ORG)	30	41.7	41.6	<1	59.4	56.2	5	71.9	78.1	−6	78.9	87.1	−10	85.3	95.3	−12	90.9	101.3	−11
Seoni (ORG)	30	40.2	42.6	−6	64.8	59.3	8	81.3	82.8	−2	88.6	94.6	−7	96.0	103.8	−8	102.2	111.0	−9
Hinganghat (ORG)	30	45.8	42.3	7	70.7	58.4	17	84.6	81.5	4	92.1	92.7	−1	103.5	101.4	2	113.9	108.3	5
Katol (ORG)	30	41.7	40.7	2	59.4	53.8	9	71.9	74.3	−3	78.9	82.8	−5	85.3	88.3	−4	90.9	92.8	−2
Begumpet (SRRG)	22	78.4	71.0	9	124.9	109.8	12	145.9	124.7	15	158.2	140.6	11	163.0	149.3	9	167.6	162.1	3
Chanderpur (SRRG)	10	45.8	42.9	6	70.7	65.5	7	84.6	84.6	0	92.1	97.0	−5	103.5	107.0	−3	113.9	114.9	<1
Nagpur (SRRG)	30	41.7	40.7	2	59.4	58.8	1	71.9	74.3	−3	78.9	82.8	−5	85.3	88.3	−3	90.9	92.7	−2
Hanamkonda (SRRG)	7	34.3	38.8	−13	50.3	49.8	1	63.4	67.3	−6	73.0	73.2	<1	77.1	75.4	2	78.2	77.6	1
(b) 50-year return period																			
Warora (ORG)	30	77.9	74.35	4	113.3	119.20	−5	131.4	142.38	−8	150.0	160.31	−7	157.7	169.42	−7	165.2	181.20	−10
Seoni (ORG)	30	81.0	78.55	3	129.7	130.3	<1	176.0	163.01	7	190.3	195.65	−3	194.3	210.92	−9	221.0	227.53	−3
Hinganghat (ORG)	30	84.4	74.78	11	130.9	120.15	8	153.9	143.87	6	180.4	163.58	9	203.0	171.31	16	221.8	184.54	17
Katol (ORG)	30	77.9	70.18	10	193.3	114.79	−1	139.4	132.69	−1	150.0	148.52	1	157.7	155.36	2	165.2	166.27	<1
Begumpet (SRRG)	22	78.4	70.56	9	124.9	113.55	9	145.9	129.99	11	158.2	145.15	8	163.0	151.55	7	167.6	162.23	3
Chanderpur (SRRG)	10	84.4	77.32	8	130.9	123.93	5	153.9	152.97	<1	180.4	174.76	3	203.0	192.76	5	221.8	198.78	10
Nagpur (SRRG)	30	77.9	73.77	5	113.3	116.45	−3	131.4	136.31	−4	150.0	153.11	−2	157.7	160.55	−2	165.2	171.72	−4
Hanamkonda (SRRG)	7	61.9	70.9	14	88.3	112.2	−27	113.7	127.1	12	143.2	141.5	+1	160.3	147.3	8	169.7	158.0	7

I = Short duration estimates from records.

C = Short duration estimates computed from regression equations.

$$\% \text{ Error} = \frac{I-C}{I} \times 100$$

I = Values of Nagpur are used for comparison for Warora & Katol.

I = Values of Jabalpur area used for comparison for Seoni.

I = Values of Chanderpur are used for comparison for Hinganghat.

5. Conclusions

The following inferences may be drawn in the present study :

(*i*) The rainfall estimate for 2-yr and 50-yr return periods as computed by using the regression equation for 14 SRRG stations are between 5-15% of the estimates made using actual autographic data.

(*ii*) The short duration records of three existing stations (of Table 1 No. 15-17) which were not used for the computation of regression coefficients were utilized for the verification of the above method. Using the coefficients of regression equation for different durations for 2-yr and 50-yr return periods, rainfall estimates for 1-hr, 3-hr, 6-hr, 9-hr, 12-hr and 15-hr were computed from 24-hr values and compared with those obtained from frequency analysis of original records. The results were found to agree within ± 15% [Table 4(a & b)].

(*iii*) Also daily rainfall records of five stations for a period of 30-year has been utilized in the study to verify the results. Annual series for observational day were made and were converted into any 24-hr rainfall series & return period estimates of any 24-hr rainfall computed. Using the coefficients of regression equation (Table 2) for different durations, rainfall estimates for 1-hr, 3-hr, 6-hr, 9-hr, 12-hr and 15-hr were computed for these stations [Table 4(a & b)]. Thus an observational day record of rainfall measured through ordinary raingauges has been used to work out short duration rainfall return periods. The short duration estimates were compared with those obtained at nearest autographic station. The estimates are found to agree within ± 15% [Table 4(a & b)].

(*iv*) Similar studies may be done for different zones all over India and the required regression coefficients may be computed. Once these coefficients are known, any non-recording ordinary rainfall data can also be used for design purposes where short duration rainfall estimate is required.

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