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Rainfall intensity duration frequency analysis

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सार — इस शोधपत्र में, लघु अवधि वर्षा की तीव्रता के आकलन के लिए सामान्य सम्बन्ध विकसित करने के लिए भारत के अनेक भागों पर फैले अस्सी स्टेशनों से एकत्र किए गए वर्षा आंकड़ों का विश्लेषण किया गया है ।

ABSTRACT. In the present study the analysis of rainfall data compiled for eighty stations spread over several parts of India has been carried out for developing a general relationship for the estimation of short duration rainfall intensity.

1. Introduction

Rainfall intensity-duration-frequency relationship is required for many purposes such as the hydrologic design of railway and road bridges and their protection works, design of culverts in highways, design of airfield drainage, design of storm sewers in urban areas and in flood control and flood forecasting problems. At present the design engineers in the country do not have a simple and reliable method for estimation of rainfall intensity, particularly for short durations (*i.e.*, less than 24 hours).

The charts published by India Met. Dep. (Harihara Ayyar and Tripathi 1974) give estimates of rainfall for different durations and return periods. However, due to limited amount of data used the charts do not show finer variations of values and give only their rough estimate for a particular location. Analysis of short duration rainfalls have also been carried out by Dhar and Kulkarni [1970 (a), 1970 (b), 1971 and 1972]. Ram Babu *et al.* (1979) have tried to give separate relationships for different regions of India based on data than available. These relationships need to be refined using the additional data which have now become available. Keeping this in view it was thought desirable to analyse all the available data regarding rainfall intensity. Through rainfall analysis a general relationship has been developed for rainfall intensity of short durations (*i.e.*, less than 24 hours). The details of present investigation are presented herein.

2. Rainfall data used

Data on rainfall intensity, duration and recurrence interval have been compiled for the rainfall stations located in various parts of India. Sources of data used in the present study are furnished through the references (Dhar and Kulkarni 1971, Harihara Ayyar and Tripathi 1974, Raman and Bandyopadhya, 1969, Ram Babu *et al.* 1979). Fig. 1 shows the locations of the raingauge stations used in present study on a map of India.

In all data for 80 stations spread uniformly over several parts of India have been collected. The period of data varied from 10 years to 33 years. For 73 stations the rainfall intensities of different durations and return periods were directly available from the references of Dhar and Kulkarni (1971), Harihara Ayyar and Tripathi (1974), Raman and Bandyopadhya (1969) and Ram Babu *et al.* (1979). For these stations, the estimates of rainfall intensity of given duration and having different recurrence interval have been obtained using Gumbel's frequency distribution with the method of moments. Same procedure has been also adopted for estimating these values for the remaining stations. This is described below.

From the available hourly rainfall records the storms having durations of 3 hours or more were selected. The rainfall intensity values for each of these stations for durations of 1 hr, 2 hr, 3 hr, 4 hr and 5 hr, etc. were calculated for all selected storms as shown in the example given in Table 1.

Rainfall intensity values, thus calculated for each station and for each duration, were plotted on Gumbel frequency distribution curve. In Fig. 2, such a plot for the rainfall station, New Delhi is shown. It was confirmed from this and similar plots for other stations that rainfall intensities of given duration follow Gumbel's frequency distribution. Using the method of moments,

Fig. 1. Map of India showing the locations of the recording raingauge stations and zonal boundaries

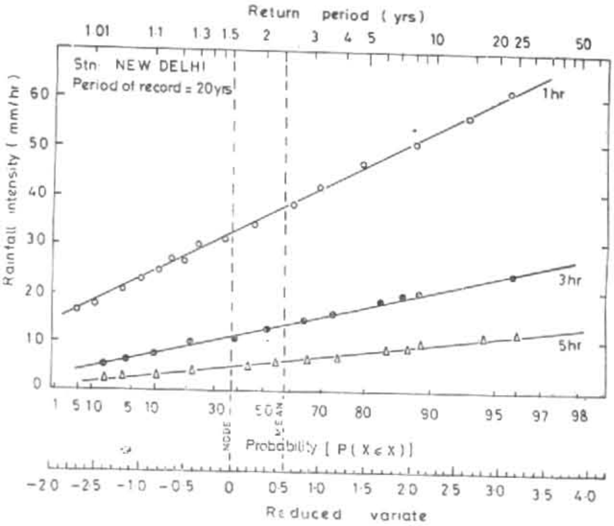

Fig. 2. Gumbel frequency distribution curve

TABLE 1

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

Duration of rainfall (hr)	Rainfall depth in successive 1 hr intervals (mm)	Cummulative rainfall (mm)	Average intensity (mm/hr)
1	7.0	8.9	8.9
2	8.9	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

the rainfall intensites for each station for different return periods of 2, 5, 10, 25, 50 and 100-year were then obtained for each duration. Since the length of record for the data used is always more than 10 years, therefore, the data have been deemed suitable for estimating rainfall intensities having small recurrence interval *i.e.*, up to 100 years.

The mean annual rainfall and the maximum mean monthly rainfall for each station have been obtained from the maps given in the reference, India Met. Dep. (1971). The 24-hour, 2-year rainfall has been obtained for each station from the IMD monograph (Harihara Ayyar and Tripathi 1974). The range of data used is given below :

Variable and symbol used	*Range*
Duration (t)	1 hr-24 hr
Return period (T)	2 yr-100yr
Mean annual rainfall (P)	300 mm-2500 mm
Max mean monthly rainfall (P_{max})	70 mm-700 mm
Ratio of P to P_{max} (P/P_{max})	0.1-0.5
Max 24 hr, 2 yr, rainfall (P_{24})	50 mm-165 mm
Rainfall intensity (I)	4.17-135 mm/hr
Period for which data are available	10 yr-33 yr

3. Analysis

In general, it has been observed that larger rainfall intensities occur for shorter duration and higher intensity rains occur, less frequently. Based on these observations the conventional form of intensity-duration frequency relationship is given by Chow (1964) :

$$I = K_t \frac{T^a}{t^b} \qquad (1)$$

where K_l, a and b are constants, t is the duration of rainfall in hr, T is the return period in years and I is the intensity in mm/hr. As a first step in the analysis the effect of duration and return period on the intensity of rainfall has been studied using the data from all the eighty stations together. The following relationship was obtained using the multiple regression analysis :

$$I = 40.10 \frac{T^{0.20}}{t^{0.70}} \tag{2}$$

The multiple correlation coefficient for Eqn. (2) is 0.90. In order to check the accuracy, the I values computed using Eqn. (2) were plotted against the observed I values. Eqn. (2) was found to predict results within ± 30 per cent error for about 90 per cent data. This error was considered as too large.

In general, the raingauge stations lying in a meteorologically homogeneous region only are grouped together for evolving the intensity-duration-frequency relationship in the form of Eqn. (2). If the rainfall stations selected for evolving the relationship are not from the meteorologically homogeneous areas, then the constant appearing in the relationship can be a function of other hydrometeorologic variables that cause and influence the rainfall. However, the short period rainfalls appear to be almost free from geographical dependence. The extreme values of short period rainfalls are associated with local convective rainfall cells which have similar physical properties in most part of the world (Raudkivi 1979). Therefore, grouping of data from different meteorological regions is justifiable if only short duration, *i.e.*, less than 24-hr rainfall intensities are considered.

The accuracy of Eqn. (2) is not considered to be satisfactory. Therefore, to establish the relationship for rainfall intensities which is more accurate, the effect of some other meteorologic variables on rainfall intensity need to be taken into account.

Rainfall amounts observed during different durations are not independent events. There is pronounced dependence between the rainfalls observed during consecutive hours. This relationship can be illustrated with estimates of certain conditional probabilities. Such relationship is often used in the synthesis of hourly rains to obtain larger duration rains (Pattison 1965) and also is segregation of larger duration rains into smaller duration rains (Hershenhorn & Woolhiser 1987). Hence 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 the other (Gert *et al.* 1987, Rao *et al.* 1983). In order to study the effect of meteorologic variables on short duration rainfall intensity of given return period, the variables, *viz.*, mean annual rainfall (P), mean maximum monthly rainfall (P_{max}), Ratio (P/P_{max}) and 24-hour, 2-year rainfall (P_{24}) have been considered, as these variables are also found to take into account effect of other hydrologic variables as indicated by investigators in earlier studies (Kothyari *et al.* 1985, Garde and Kothyari 1987 and Garde and Kothyari 1989). In Table 2 the relationships obtained for I in terms of these variables are given. In all, 953 data points have been used to obtain relationships given in Table 2.

In Table 2, P, P_{max} and P_{24} are in mm. A close study of the relationships shown in Table 2 reveals that inclusion of the meteorologic variables as selected above results in improvement in the accuracy of relationship for rainfall intensity. The exponents of variables T and t have not changed significantly by inclusion of other meteorologic variable selected above. Also, it can be mentioned that the following relationship gives the most realistic estimates of rainfall intensity amongst the relationships given in Table 2 :

TABLE 2

Relationships for rainfall intensity

Relationship	M.C.C.	Error
$I = 20.65 \frac{T^{0.2}}{t^{0.71}} P^{0.15}$	0.94	85% points have less than ± 30 % error
$I = 24.45 \frac{T^{0.2}}{t^{0.72}} P_{max}^{0.16}$	0.92	83% points have less than ± 30 % error
$I = 46.80 \frac{T^{0.19}}{t^{0.70}} \left(\frac{P_{max}}{P}\right)^{0.10}$	0.92	83% points have less than ± 30 % error
$I = 8.31 \frac{T^{0.2}}{t^{0.71}} P_{24}^{0.33}$	0.96	95 % points have less than ± 30 % error

M.C.C. — Multiple correlation coefficient

$$I = C \frac{T^{0.20}}{t^{0.71}} P_{24}^{0.33} \tag{3}$$

where C is a constant having value equal to 8.31. I is in mm/hr, T is in years, t is in hours and P_{24} is in mm.

In order to study the change in the value of constant C appearing in Eqn. (3) for different geographical regions, the rainfall intensities predicted using Eqn. (3) with $C=1.0$, have been plotted against the observed rainfall intensity values for five different regions, *viz.*, south India, central India, north India, western India and eastern India. These geographical divisions have beed directly adopted from the reference Ram Babu *et al.* (1979). Such plot, revealed that use of different values of C in Eqn. (3) as given in Fig. 1 in these geographical regions gives better results. Fig. 3 shows comparisons of I values computed using Eqn. (3) with value of constant C as given in Fig. 1 with the observed I values. It can be seen from this figure that Eqn. (3) with C as given in Fig. 1 predicts the results with less than $\pm$ 18 per cent error for most of the data points.

3.1. *Comparison with other studies*

A comparison of Eqn. (3) with the relationships for rainfall intensity given by Chow (1964), Raudkivi (1979), Gert *et al.* (1987), Tung (1986), Sharma (1987), Hargreaves (1988) and Chen (1983) revealed that the values of exponents of variables t and T do not vary much from place to place. The exponent of T ranges between 0.18 & 0.26 and that of t ranged between 0.7 & 0.85. This gives more confidence in the results obtained from present study.

4. Verification of proposed relationship

In order to verify Eqn. (3), additional data of two stations, *viz.*, Roorkee and Calcutta, which were not used for establishing Eqn. (3) have been used. The I computed using Eqn. (3) with value of C taken from Fig. 1, have been plotted against the I observed values

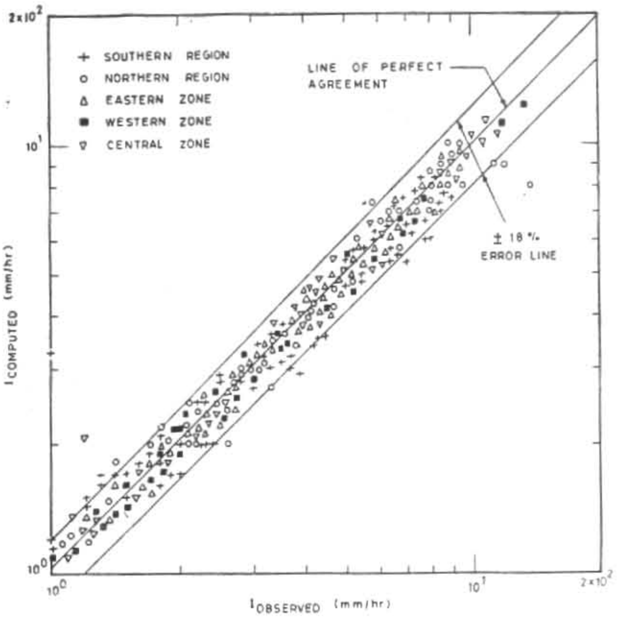

Fig. 3. Comparison of observed and computed values of I using Eqn. (3)

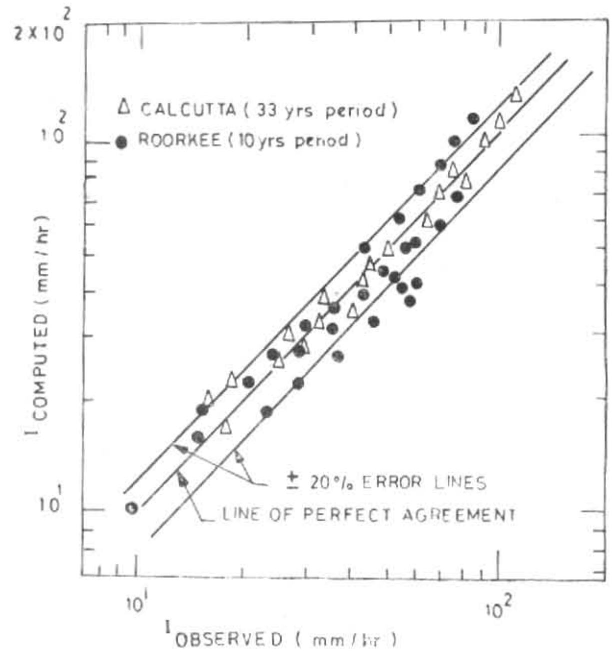

Fig. 4. Verification of Eqn. (3)

for these two stations as shown in Fig. 4. This figure reveals that Eqn. (3) with value of C as given in Fig. 1 gives results with less than $\pm$20 per cent error for the independent data. Thus Eqn. (3) with the value of constant C as given in Fig. 1 is considered to be satisfactory for prediction of I for known t and T values if P_{24} is known.

5. Conclusions

Use of data from 80 raingauge stations spread uniformly over several parts of India has been made to establish a general relationship for rainfall intensity as given by Eqn. (3) with different values of constant C as given in Fig. 1 for different geographical regions. The geographical regions as shown in Fig. 1 are able to predict the rainfall intensity with less than $\pm$ 18 per cent error. A comparison of Eqn. (3) with the relationships commonly used in other parts of the world revealed that the exponents of the variables t and T do not vary much from place to place.

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