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Area-depth relations for frequency values of rainfall

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ABSTRACT- Based on rainfall data of 11 dense networks of raingauges, area-depth curves for frequency values of rainfall for Indian regions, have been drawn and are presented. These curves are for durations of 1, 3, 6 and 24 hours and for small basins upto 1000 sq. km. An equation giving the area-depth relation for any duration, has also been worked out.

1. Introduction

Area-depth relations are of many kinds. Some are for storm-centred data and others for fixed areas. Storm-centred area-depth curves are much steeper than the fixed-area curves. A useful discussion of storm-centred area-depth curves is given by Court (1961). The area-depth curves in this paper are based on fixed networks of raingauges, but they are for frequency values of rainfall and are derived from data that are processed in a manner consistent with their application.

Frequency analysis of point rainfall values is required in the design of small hydraulic structures such as bridges, culverts, storm-sewers, airfield drainage etc. These values are generally obtained from the rainfall frequency charts based on point rainfall values and can be used as they are when the catchment area is very small. For catchment areas larger than a few square miles, these values have to be suitably reduced, to get the average depth over the entire drainage area and a reduction factor for converting point rainfall to areal rainfall has to be computed. Hershfield (1961) has determined from several dense networks, the average area-depth relationship as a percentage of the point values, for small basins upto 400 sq. miles for regions in the United States.

In India dense network of self-recording raingauges is not adequate for preparing area-depth curves for periods less than 24 hours. However, some attempts have been made in this direction. Areal and time distribution of storm rainfall for small durations in respect of the Damodar valley catchment has been found by Shenoy and Changraney (1969). This is a storm-centred study based on 4 actual storms for areas upto 12950 sq. km and for the durations of 1, 2, 3, 6, 12 and 24 hours. Relationship between the rainfall recorded at a point and over the surrounding area in association with short duration thunderstorm rainfall over the lower Gangetic basin has been determined by Harihara Ayyar and Mukherjee (1970). This relationship is for an area of 2000 sq. km and above and for durations of 6 hours or less.

In the present paper an attempt has been made to determine area-depth relations for 2-yr values of rainfall for durations of 1, 3, 6 and 24 hours for small basins upto 1000 sq. km for Indian regions.

2. Data

A survey of all available dense networks of self-recording raingauges of surface and hydromet observatories of India Meteorological Department was made. Networks of ordinary raingauges which are read every one hour, were also examined. These raingauges have been installed in some of the bridge catchments by Research Designs and Standards Organisation, Ministry of Railways. Out of these networks eleven were selected on the following criteria :

(1) A minimum of 3 gauges in an area of 800 sq. km or less.

(2) The minimum length of record considered was 5 years in order to ensure an estimate of the 2-yr areal rainfall within allowable limits of error.

Number of gauges and length of records for the networks used in this study are given in Table 1. The locations of the networks are shown in Fig. 1. The networks A to I are in bridge catchments, J is in Delhi and K is in Damodar valley catchment.

3. Method

Maximum rainfall amounts in one hour from each year of record for a particular station in a network were listed and the series so selected—the annual

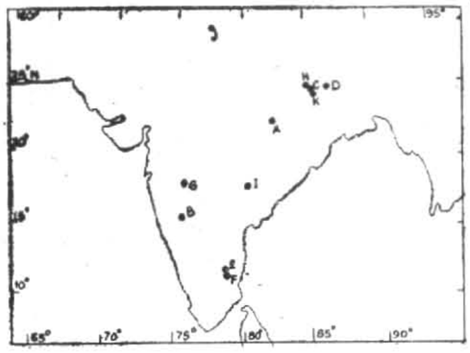

Fig. 1 Index map of dense network

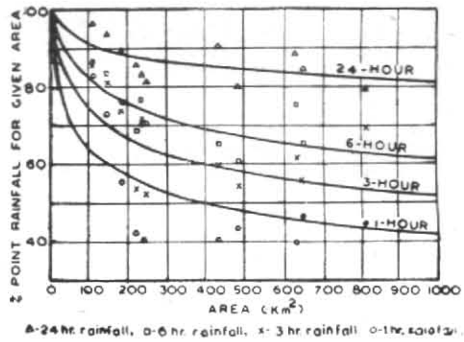

Fig. 2. Area-depth curves

TABLE 1

Net-work	No. of rain-gauges	Approx. location		Period of data (yrs)	Area (km²)
		Lat (°N)	Long. (°E)		
A	5	22°02′	82°25′	5	482·5
B	6	15 10	75 15	5	247·9
C	3	24 15	85 35	9	431·0
D	5	24 15	85 35	6	635·3
E	4	11 35	78 35	5	183·4
F	6	11 10	78 55	5	220·9
G	3	17 53	75 35	7	147·6
H	4	24 30	85 15	7	651·6
I	3	17 30	80 15	5	235·7
J	3	28 35	77 12	5	110·1
K	3	24 00	85 51	8	812·0

maximum series, was treated by Gumbel's (1954) extreme value technique using the method of least squares and 2-yr 1-hr rainfall value for that station was obtained. Similarly 2-yr 1-hr rainfall values for other stations in the same network were calculated. The mean of these values was taken to be the representative 2-yr 1-hr point rainfall for that network.

To estimate the areal depth, the arithmetic mean of the station values of rainfall occurring simultaneously at all the stations in the network was taken. As the area is small and the network is more or less uniform, arithmetic mean is assumed to be representative of areal rainfall. The maximum areal rainfall in one hour estimated in this way for the concerned network was noted for each year and from the annual series so formed the 2-yr 1-hr areal rainfall was obtained by Gumbel's extreme value technique. Percentage ratio of 2-yr 1-hr areal to 2-yr 1-hr representative point rainfall already found was then calculated. Table 2 shows the results for all the networks. Similarly ratios for 3, 6 and 24-hr were calculated and are also shown in Table 2.

To determine the area of each network to which the mean depth applies, the method adopted by Hershfield (1957) was followed. The area of a network having n gauges was taken to be equal to n circles having diameters equal to the average distance between the stations. The area of each network thus found, is given in Table 1.

The percentage ratios of areal to point rainfall were plotted against the areas of the networks and smooth curves were drawn. These area-depth curves are shown in Fig. 2.

4. Results

It is seen from Fig. 2 that there is large scatter of the plotted points with respect to the mean area-depth curves. The large scatter was also found by Hershfield (1957) and this was attributed to non-synchronized readings of the raingauges and to the gauges being not suitably located in sufficient number over the areas. Besides these factors, in the present study, the rainfall data of the bridge catchments consisting of ordinary raingauge observations taken every one hour, may not be very

TABLE 2

Network	Point rainfall (mm)	Areal rainfall (mm)	Percentage ratio of areal to point rainfall
	2-yr 1-hr		
A	41·3	18·0	43·6
B	26·5	10·7	40·4
C	28·7	11·4	39·7
D	37·6	15·1	40·1
E	42·8	23·6	55·1
F	37·4	15·9	42·5
G	25·0	18·2	72·8
H	36·9	17·2	46·6
I	35·4	24·8	70·1
J	43·9	36·3	82·7
K	18·2	41·0	44·4
	2-yr 3-hr		
A	83·8	45·3	54·1
B	37·5	19·5	52·0
C	51·5	31·7	61·5
D	60·6	36·3	59·9
E	69·5	51·0	73·4
F	55·5	29·8	53·7
G	40·5	32·5	80·2
H	61·4	34·0	55·4
I	57·8	41·2	71·3
J	63·3	54·5	86·1
K	61·9	43·2	69·8
	2-yr 6-hr		
A	107·6	64·7	60·1
B	45·7	32·2	70·5
C	65·3	49·1	75·2
D	73·7	47·9	65·0
E	81·9	62·5	76·3
F	62·3	42·7	68·5
G	54·4	45·5	83·6
H	77·7	50·6	65·1
I	73·6	56·3	76·5
J	76·9	66·7	86·7
K	77·8	62·1	79·8
	2-yr 24-hr		
A	156·9	124·9	79·6
B	65·6	53·2	81·1
C	103·4	91·9	88·9
D	118·0	106·8	90·5
E	100·9	89·9	89·1
F	85·4	72·9	85·4
G	80·3	75·3	93·8
H	137·0	115·8	84·5
I	104·4	85·8	82·2
J	109·3	97·5	92·7
K	115·1	91·1	79·1

reliable. There may also be regional variations of the ratios.

The area-depth curves of Fig. 2 are seen to be steeper than those given by Hershfield for the regions in the United States. This may be due to the rainfall variability in space being comparatively larger for Indian regions.

None of the dense networks considered here has sufficient length of record to see the effect of return period or magnitude on the ratios. Hershfield tentatively accepted that for areas of less than 400 sq. miles, return period was not a parameter in the area-depth relationship.

The following empirical equation can be fitted to the mean area-depth curves :

$$P = 100 \exp\left(-A^{1/3}/8T^{\cdot 56}\right) \tag{1}$$

where P is the percentage ratio of areal to point rainfall, A is the area of the basin and T is duration.

To illustrate the use of Fig. 2 and the equation given above, let us assume that 5-yr 3-hr point rainfall of 120 mm is obtained for a particular place, from a point rainfall frequency chart. To estimate the 5-yr 3-hr rainfall over 400 sq. km at that place, the 120 mm value from the chart is to be multiplied by a factor of 60 per cent obtained from Fig. 2 for 3-hr and 400 sq. km which gives 72 mm. From the equation also, the multiplying factor

$$P = 100 \exp\left(-400^{1/3}/8 \times 3^{\cdot 56}\right) = 60 \cdot 78$$

seems to be approximately the same as found from Fig. 2. As the return-period is not taken as a parameter in the area-depth relations, the 2-yr relation holds good for 5-yr also.

5. Conclusion

The area-depth curves of Fig. 2 or Eq. (1) may be used for Indian regions, to have a rough estimation of the percentage ratio of frequency values of areal to point rainfall for any return period. The ratios so obtained may be taken to be only approximate and used only till we have more and denser networks of self-recording raingauges with sufficient length of record.

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