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Area-Intensity relationship of Storm Rainfall

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ABSTRACT. From the analysis of rainfall distribution of a number of storms in different parts of India, the area-intensity relationship of storm rainfall has been derived as $Y=100-C\sqrt{A}$ where Y is the percentage ratio of the rainfall over an area A surrounding the storm centre to the maximum rainfall at centre of storm and C is a constant varying with geographical location, but within narrow limits. A possible use of this relation in the rainfall intensity frequency computations for local drainage designs is suggested.

1. Introduction

In a separate study* the rainfall data of available recorder and non-recorder raingauge stations in India have been analysed and generalised charts covering the whole of India showing station rainfall intensities of different return periods for different durations have been derived. In order to obtain from these charts of station rainfall, the average rainfall of different return periods over specified areas, which are the essential basic data required for purposes of local drainage design, it is necessary to know the relation between area and intensity of rainfall. The object of this study was to derive such a relation.

The maximum intensity of rainfall in a storm occurs at a point or over a small area at the centre of the storm. Outside this the intensity gradually decreases so that the average intensity over a larger area becomes less with increase in area. Various workers have proposed different formulae connecting the intensity at the centre with the average intensity over an area round the centre. All these formulae have been based on the observed distribution of intensities in a few actual storms. Most of these are of the general form $I_A = I.f(A)$, where I_A is the average intensity over an area A, and I is the maximum intensity at the centre. Only the nature of $f(A)$ is different in these different formulae.

Horton (1924) proposed the formula

$$I_A = Ie^{-mA^q}$$

where I_A is the average intensity over an area A surrounding the centre, m and q are constants varying with geographical locations. Glasspoole (1929) discussed some notable rainfalls in Great Britain and established certain relations between rainfall intensity and area. Based on the data compiled by Glasspoole the Institution of Civil Engineers Floods Committee deduced a curve showing the average intensity over an area expressed as a percentage of the maximum intensity for areas upto 50 sq. miles. Similar curve extending upto 6000 sq. miles, again based on Glasspoole's data is shown in Fig. 1, in which are also shown for purposes of comparison, the curves for the Eastern U.S.A., Western Australia and S. Rhodesia. This figure has been reproduced from Richards' book '*Flood Estimation and Control*'. The curve for Eastern U.S.A. has been based on the data of 34 storms taken from the exhaustive studies of storm rainfall carried out in connection with the Miami Floods Project and published in *Technical Report* No. 5 of the Miami Conservancy District (1917). Hazen (1930) taking the maximum 24 hours rainfall of seventeen great storms in Southern U.S.A. found that the total water falling in catchments of areas of 500 to 6000 sq. miles increased as the $0{\cdot}87^{th}$ power of the area.

* Paper presenting these results is under preparation

TABLE 1

Average rainfall over different areas as percentage of rainfall at centre of storm

Storm (Region and dates)	Area in thousand sq. miles 0·5	1	2	4	6	8	10	15	20	30	40	Value of C in the fitted curve $Y = 100 - C\sqrt{A}$
UTTAR PRADESH												
18—19 Sep 1914	97	94	88	82	77	74	71	66	62	..	..	0·275
21—24 Sep 1923	94	91	85	77	71	66	61	54	49	42	..	0·356
27—30 Sep 1924	96	92	86	79	73	70	67	62	58	51	45	0·296
24—25 Sep 1932	93	91	86	81	76	72	69	63	..	..	..	0·307
27—28 Jul 1936	93	88	81	72	66	62	..	..	..	..	..	0·422
15—16 Sep 1939	92	87	81	72	67	62	59	51	44	37	..	0·420
8—12 Jul 1953	96	92	85	76	70	66	63	57	54	50	..	0·326
Average of 7 storms	94	91	85	77	71	67	65	59	53	45	..	0·331
BIHAR												
29 Sep 1942	95	89	79	68	62	57	53	..	..	..	..	0·474
8—10 Jul 1946	90	83	76	68	62	58	55	50	48	..	..	0·440
13—15 Aug 1954	93	88	81	71	64	..	..	..	..	..	..	0·440
Average of 3 storms	93	87	79	69	63	57	54	..	..	..	..	0·468
GUJARAT												
1 — 3 Jul 1941	92	87	79	70	63	57	52	..	..	..	..	0·471
GODAVARI BASIN												
12—14 Aug 1953	95	91	85	78	73	68	64	57	52	45	..	0·336

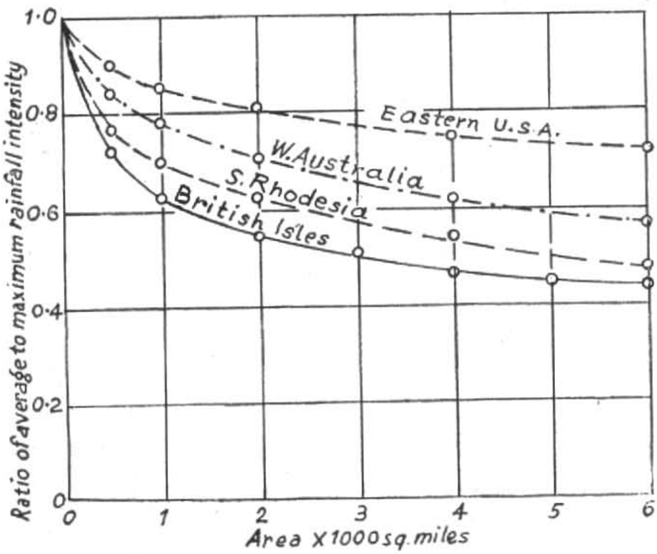

Fig. 1. Intensity-Area relation of storm rainfall

From this we obtain the relation

$$I_A = I \times A^{-0 \cdot 13}$$

which is similar in form to the formula proposed by Horton.

2. Present analysis

Recently systematic study of the major rain storms that have occurred in different parts of India over the past 50 years was undertaken in the Hydromet. Branch of the Meteorological Office at New Delhi. From the total isohyetal map of each of the storm analysed, a curve was derived for each storm showing the average intensity of rainfall over different areas upto the maximum area defined by the outer-most isohyet. The average rainfall over different areas were then converted as percentages of the maximum rainfall at the centre. These percentage values for the various storms studied are given in Table 1. Seven of these storms were in the Uttar Pradesh area, 3 in Bihar, one over the Godavari basin and one in Western India over south Gujarat and neighbourhood. It will be noted from the table that for all storms in the same region the percental rainfall for any specific area is nearly the same irrespective of the duration of the storm, its total areal extent and the actual rainfall amounts associated with it. This suggested that if a general expression was fitted to the curve obtained for the average storm (by averaging out the values of percentages of all storms over the same area), that expression could be applied satisfactorily to the individual storms in that region.

As the curve connecting percentage rainfall Y with area A had the shape of a second degree curve, the equation

$$Y = C\sqrt{A} + B$$

was fitted to the data of each storm. The goodness of fit of the equation when tested by the method of χ^2 showed that in 10 out of the 12 storms analysed, the fit was good at the 0·9995 P level. In the other 2 cases the fits were good at 0·995 and 0·975 P levels. The values of B obtained for the different storms were found to be nearly 100 (the actual values ranging from 97 to 104). The closeness of B to 100 suggested the fitting of the curve $Y = 100 - C\sqrt{A}$ to the storm data. In such a case Y becomes 100 when A is zero which it should be theoretically. Also, it is of practical advantage to have a minimum number of constants whose values vary with geographical locations. The values of C obtained when the curve $Y=100-C\sqrt{A}$ was fitted to different storms are also given in Table 1. For the average Uttar Pradesh storm, the expression $Y = 100-0\cdot331\sqrt{A}$ was found to fit the data well, the probability corresponding to the χ^2 value being greater than $0\cdot9995$. Similarly, $Y = 100-0.468\sqrt{A}$ fits the Bihar data based on the average of 3 storms at the same probability level. For the Godavari storm of 12 to 14 August 1953, C comes as $0\cdot336$ and for the south Gujarat storm of 1 to 3 July 1941, it has a value of $0\cdot471$. In these 2 cases also, the fit is found to be good at $0\cdot9995$ P level. The observed and fitted curves for the four cases are shown in Figs. 2 and 3. From this it will be seen that the intensity-area relationship of storm rainfall is very well represented by the equation

$$Y = 100 - C\sqrt{A}$$

when Y is the percental rainfall over area A and C is a constant.

3. Comparison with the model storm

Richards (1955) has derived an expression for the intensity as a function of area for a model storm circular in shape in which the intensity of rainfall is assumed to decrease uniformly in a straight line from the maximum at the centre to zero at the circumference. He got the expression

$$i = I\ (1 - 2/3\sqrt{A_1/A}),$$

where I is the intensity at the centre, i is the average intensity over the circular area A_1 round the centre and A is the total area of the storm. This equation in effect means that the decrease in rainfall from the maximum is proportional to the sq. root of the area. The equation $Y = 100 - C\sqrt{A}$ which has been fitted to the observed storm data in this paper is thus in accord with Richards' expression for the model storm, though in the storms studied the shapes of the isohyets were very different from the model circular storm.

4. Discussion

The value of C in the equation

$$Y = 100 - C\sqrt{A}$$

is found to vary slightly from storm to storm in the same region. For the 7 storms in the Uttar Pradesh area, C varies from $0\cdot275$ to $0\cdot442$, the value for the average storm being $0\cdot331$. If we adopt $0\cdot331$ as a constant value for C in the Uttar Pradesh area, the average rainfall over an area for any individual storm derived by using this value of C will be within ±10 to 15 per cent of the true value upto areas of 10,000 sq. miles. This latitude in the estimate of average rainfall over an area may be permissible for many purposes. We may, therefore, divide the country into a few zones and determine the values of C in the above equation which will be applicable to these zones on the basis of analysis of a good number of storms over each of these zones. When such an analysis is carried out, we may even find that the variation of the values of C for the different zones is within such narrow limits that with a good degree of approximation, a single value for C can be adopted for the whole country.

5. Use of the suggested relations

Let us suppose that for design purposes it is required to estimate the rainfall which may be expected to occur once in 30 years over a particular drainage basin, located in Uttar Pradesh. From the generalised charts of station rainfall of 30 years return period (mentioned in the Introduction), the station rainfall value R for the basin in question can be estimated. Using the relevant value of C and substituting for C and A in the equation, $Y = 100 - C\sqrt{A}$, the percentage ratio p of the average rainfall over the basin to the maximum rainfall at the centre can be computed. As heavy falls of rain at individual stations usually occur in association with storms of finite areal extent and not as sporadic phenomenon confined to the station, the station rainfall values of long term return period can reasonably be taken as being associated with storms. Therefore the estimated value R may be taken as the rainfall at

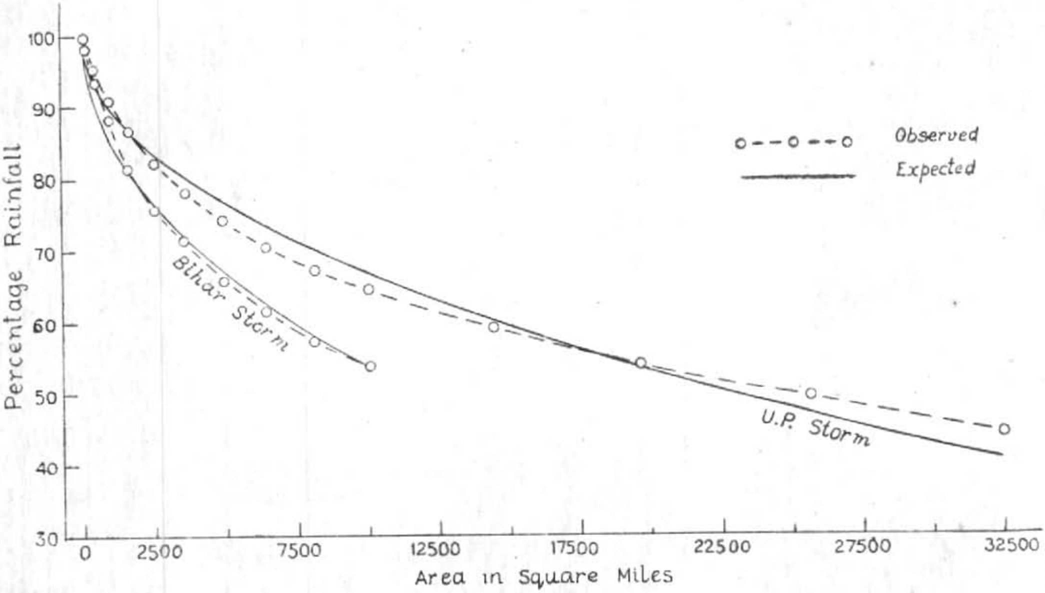

Fig. 2. Area *versus* Intensity of storm rainfall (Bihar and U. P. Storms)

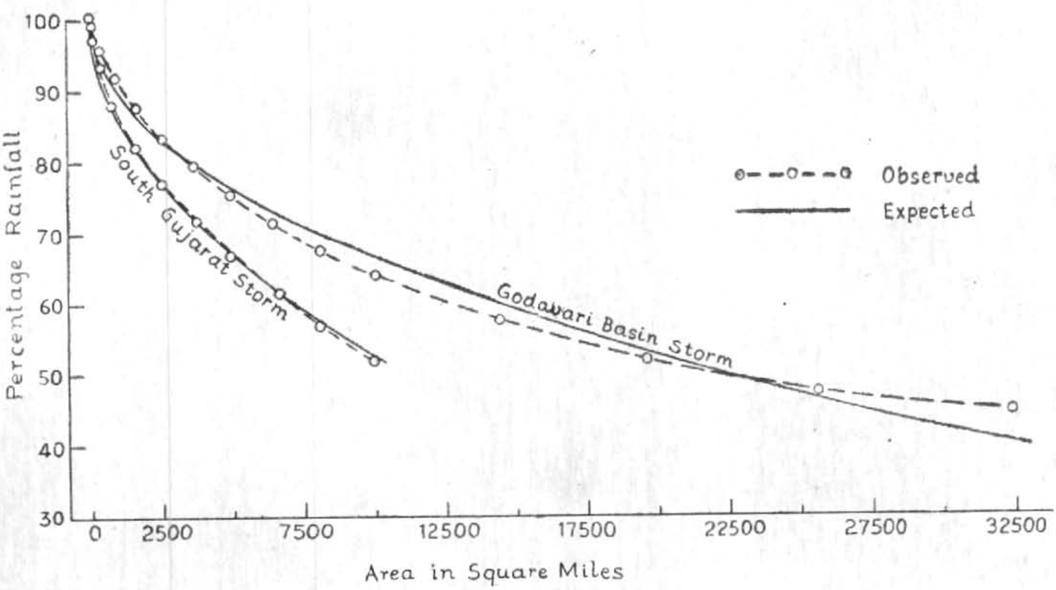

Fig. 3. Area *versus* Intensity of storm rainfall (Godavari Basin and South Gujarat Storms)

the centre of a storm located over the basin. Then $R \times p$ will be the required average rainfall of 30 years return period for the basin.

As an example may be mentioned the derivation of the 30-year storm for the Kaddam river basin in the Godavari catchment. The drainage area of this basin is about 1000 sq. miles and the time of concentration will be 6 to 8 hours. Taking this as 6 hours, a reference to the generalised rainfall charts for 6-hour duration gives the 6-hour rainfall of 30-year return period as 6″·0. From Table 1, it is seen that in the Godavari basin the average intensity over 1000 sq. miles is 90 per cent of the intensity at the centre of the storm. Thus, the 30-year storm for the Kaddam basin works out to be 9/10 of 6″·0, *i.e.*, 5″·4 nearly. This compares well with the estimates by other methods mentioned by Parthasarathy (1958).

6. Conclusion

The area-intensity relationship of storm rainfall over India is found to be of the form $Y = 100 - C\sqrt{A}$ where Y is the percentage ratio of the average rainfall over an area A surrounding the centre of the storm to the maximum rainfall at the centre and C is a constant, whose value depends mainly upon the geographical location. Further, it is seen that C varies within narrow limits over the regions covered by this study.

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