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Depth area duration analysis of short duration rainfalls

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सार — जल संसाधन निर्माण कार्यों के लिए, जलविज्ञान संबंधी डिजाइन तैयार करने में, चरम वर्षा की घटनाओं का ''डेप्थ एरिया ड्यूरेशन'' (डी. ए. डी.) विश्लेषण एक महत्वपूर्ण चरण है। इस क्षेत्र में साहित्य की समीक्षा करने पर ज्ञात होता है कि अधिक अवधि (एक या अधिक दिन) के झंझावतों के लिए डी. ए. डी. विश्लेषण से संबंधित बहुत ज्यादा कार्य हुआ है। यद्यपि इस दिशा में अल्पावधि (एक दिन से कम) वाले झंझावातों के लिए किसी प्रकार के अध्ययन का उल्लेख नहीं है।

डी. ए. डी. के सरल संबंधों के विकास हेतु वर्षा रिकार्ड करने वाले 36 केन्द्रों के लिए वर्षा के एक-एक घंटे की अवधि के आंकड़ों का विश्लेषण किया गया है। यह विश्लेषण राम गंगा, गोमती, यमुना एवं घाघर नदियों के जलग्रहण क्षेत्रों से संबंधित है।

ABSTRACT. Depth Area Dûration (DAD) analysis for the extreme rainfall events forms an important step in the hydrological design for the water resources structures. Review of literature reveals that enormous amount of work has been done concerning the DAD analysis for large duration (*i.e.*, one day or more) storms. However, no work is reported so far on this aspect for storms having shorter duration, *i.e.*, less than one day.

Hourly rainfall data for 36 rainfall stations have been analysed to develop simple DAD-relationship. This analysis pertains to the catchments of the rivers, namely *Ramganga*, *Gomati*, *Yamuna* and *Ghaghara*.

Key words — Depth Area Duration (DAD) analysis, Catchment, Design storm, Correlation coefficient.

1. Introduction

For the estimation of design flood for any river valley project, a hydrologist needs to have a fairly reliable estimate of the design storm. A file of data on the depths of rainfall corresponding to different areas in respect of each of the historically severe storms is important for examining and studying storms suitable for the design purposes. Such an information is derived from Depth Duration or Depth Area Duration (DAD) analysis. Incorrect estimation of design storm leads to wrong estimation of the design flood. Over-estimation of the design storm results in uneconomic structure while its under-estimation may lead to failure of the structure causing loss of life and property.

Dhar and Rakhecha (1975), in their review article, have given the state of art on studies related to DAD analysis. On the basis of rigorous analysis of data from various parts of the country, a relationship in the form of a nomogram was proposed between maximum rain-depth (P_m), area (A) and return period (T) for a 3-day duration storm. Conversion factors were also worked out by them for obtaining 1-day and 2-day maximum rain depths for different areas and return periods from the 3-day rain depths. Various other studies on DAD analysis carried out by different investigators are also reported by Dhar and Rakhecha (1975).

On the basis of forty two severemost storms in north India, Dhar and Bhattacharya (1975) determined the values of regional constants K and n for storms of different durations using the following formula :

$$P_A = P_m \exp(-KA^n) \quad (1)$$

Here, P_A is the average rain depth over an area A and P_m is rainfall at the storm centre. Values of the constant K and n were found to increase and decrease respectively with the storm duration.

Various studies carried out elsewhere on DAD analysis are reported by Court (1961). However,

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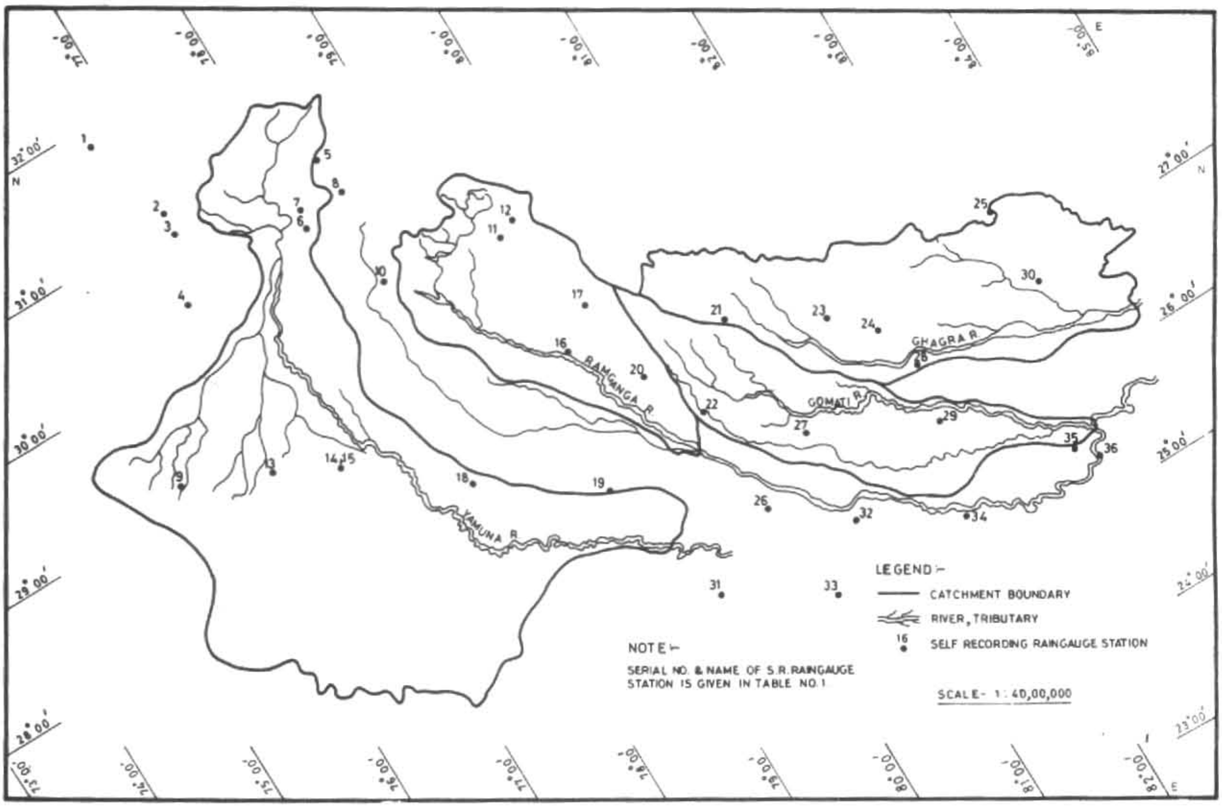


Fig. 1. River catchments with the locations of self-recording rainguage stations

TABLE 1

List and the location of SR raingauges

S. No.	Station	Period of data (years)	State/Basin	S. No.	Station	Period of data (years)	State/Basin
1	Dharamshala	10	Himachal Pradesh (H.P.)/c	19	Mainpuri	15	U.P./a. b. c. d
				20	Shahjahanpur	13	U.P./a. d
2	Shimla	10	H.P./c	21	Lakhimpur (Kheri)	15	U.P./a. b. c. d
3	Dharampur	11	H.P./c				
4	Ambala	11	Haryana/c	22	Hardoi	13	U.P./a. b. c. d
5	Uttar Kashi	9	U.P./a	23	Bahraich	14	U.P./a. b, d
6.	Dehradun	15	U.P./a. c	24	Gonda	13	U.P./b, d
7	Mussoorie	14	U.P./a	25	Nautanwa	14	U.P./a, b. d
8	Tehri	12	U.P./a. c	26	Kanpur	15	U.P./a, b. d
9	Hissar	15	Haryana/c	27	Lucknow (Amausi)	15	U.P./a. b. c. d
10	Najibabad	11	U.P./a. c	28	Faizabad	15	U.P./a. b, c. d
11	Nainital	15	U.P./a. b. c	29	Sultanpur	14	U.P./a. b, d
12	Mukteswar	14	U.P./a. b. c. d	30	Gorakhpur (P.B.O.)	14	U.P./a, b. d
13	Rohtak	15	Haryana/c	31	Orai	14	U.P./a, b. c. d
14.	Palam	15	Delhi/c	32	Fatehpur	13	U.P./a. b. c. d
15	Safdarjang	13	Delhi/c	33	Banda	12	U.P./b. c. d
16	Bareilly	15	U.P./a. b. c. d	34	Allahabad	15	U.P./a. b. c. d
17	Pilibhit	11	U.P./a. c	35	Varanasi (Babatpur)	15	U.P./b. c. d
18	Aligarh	15	U.P./a. c. d	36	Varanasi (BHU)	13	U.P./b, c, d

– Ramganga. b—Gomati. c — Yamuna and d — Ghaghara.

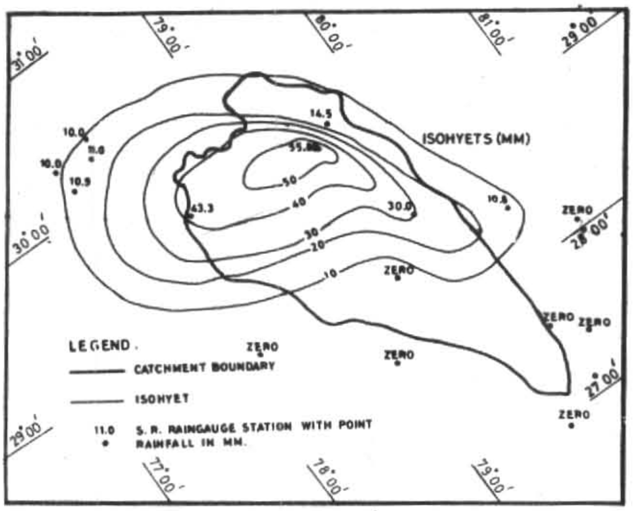


Fig. 2. 6-hr rainstorm (20-21 July 1970) over Ramganga catchment

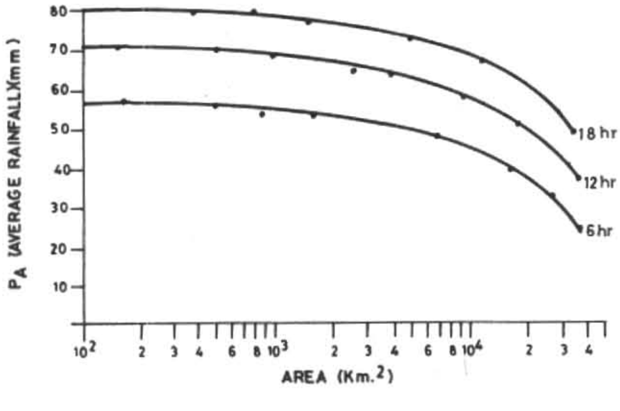


Fig. 3. Depth area duration curves for Ramganga catchment (20-21 July 1970)

little or no work has been reported in the literature on DAD analysis of rain storms having duration less than one day.

Keeping this in view, in the present investigation, it has been attempted to conduct DAD analysis for rain storms having durations less than one day.

2. Data used

Hourly rainfall data for the monsoon months, *i.e.*, June to September were collected from the India Meteorological Department (IMD), Pune for 36 stations. The list of the Self Recording Rain Gauges (SRRGs) is given in Table 1 alongwith the number of years for which the rainfall record is available. The period for which the data are used is from the year 1969 to 1985. The rainfall stations considered lie in the catchments of *Ramganga, Gomati, Yamuna* and *Ghaghara*. Locations of the rainfall stations are shown in Fig. 1 alongwith the boundaries of these river basins. In all, nineteen severemost storms having duration less than one day were selected for the DAD analysis. Out of these, one storm from each catchment is used only for verification of the results obtained.

3. Methodology

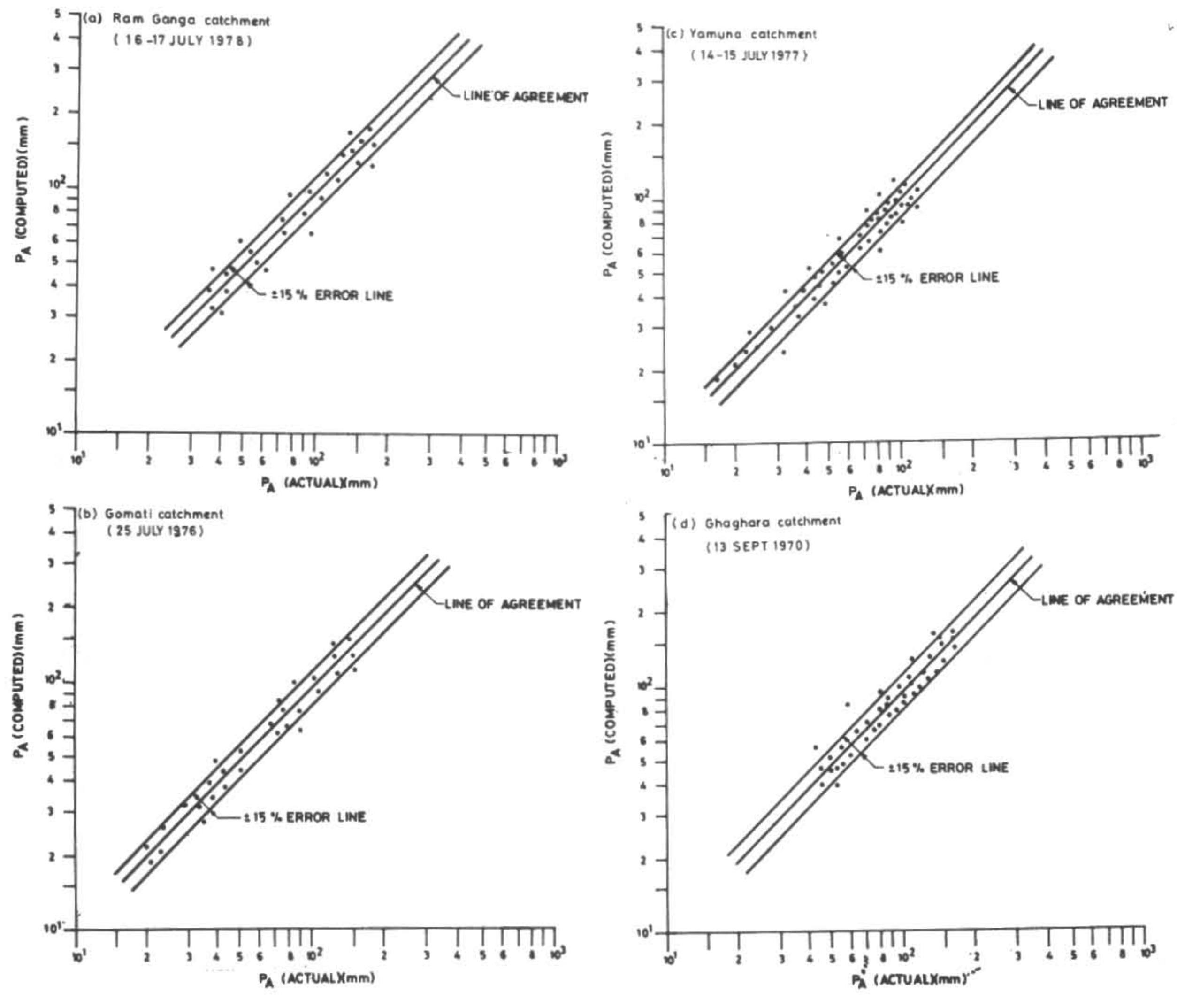
As an illustration, the rainfall measurements available at eighteen self recording raingauge stations in the *Ramganga* catchment are used. Using these, the isohyets are drawn in Fig. 2 at an interval of 10 mm for the 6-hour storm during the storm period 20-21 July 1970. For this storm duration the areal rainfalls (P_A) were computed and plotted against logarithms of the selected storm thus obtained. This exercise is then repeated for other durations of the storm. The depth area relation for different duration of this storm is shown in Fig. 3. Such relations are obtained for all the storms for 6, 12 and 18-hour durations. These relations (Garg 1992) are then used for further analysis.

4. Analysis and results

Review of the literature suggested that Eqn. (1) can appropriately be used to describe the DAD-relationship. As a first step in the analysis, values of the coefficients K and n were derived for each storm in each catchment for the durations of 6, 12 and 18-hour.

Values of the coefficients K and n in Eqn. (1) were derived using the method of two dimensional grid search (Kothyari and Garde 1991). In this method, for a set of K and n values, the P_A value was computed using Eqn. (1) for each storm in each catchment. The correlation coefficient between the P_A values so computed and corresponding observed P_A values was also obtained. The values of K and n giving the highest correlation coefficient were adopted.

A close study of the values of K and n as obtained in the above step revealed that these values vary systematically with geographical location of the station and the storm duration. Use of all the



Figs. 4 (a-d). Comparison of P_A (computed) and P_A (actual) for verification of Eqn. (6) for different catchments

data together is made to derive following DAD-relationship :

$$P_A = C.\ P_m \exp(-KA^n) \quad (2)$$

Here, C is another coefficient. K and n are found to be related to the storm duration as given below :

$$K = (0.07\ t + 1.54) \times 10^{-3} \quad (3)$$

and

$$n = -0.01\ t + 0.69 \quad (4)$$

Eqns. (3) and (4) were derived using the method of regression analysis. The correlation coefficients for Eqns. (3) and (4) were 0.92 and 0.91 respectively. In Eqns. (3) and (4), t is in hours. P_A and P_m are in mm and A is in km^2. P_A values computed from Eqn. (2), with $C = 1.0$, were graphically compared with the corresponding observed values for 6, 12 and 18-hour durations. Such comparison revealed that the value of constant C appearing in Eqn. (2) varies systematically with the storm duration. Graphical plotting of values of C with the duration revealed that these are inversely related with one another. Substitution of the relation for C in Eqn. (2) produces following relationship for P_A :

$$P_A = C_1\ .\ C\ .\ P_m \exp(-K\ A^n) \quad (5)$$

Here, C_1 is another coefficient and C is found to be related to the storm duration as below :

$$C = -0.03\ t + 1.31 \quad (6)$$

TABLE 2

Values of empirical constant C_1

Catchment	Value of C_1
Ramganga	1.150
Gomati	1.023
Yamuna	1.204
Ghaghara	1.290

In Eqn. (6) t is in hours. The correlation coefficient for Eqn. (6) was 0.93. Values of P_A were computed using Eqn. (5) with C_1 = 1.0 for all the data. In this, C was computed using Eqn. (6) and Eqns. (3) and (4) were used for the computation of K and n respectively. Analysis of data indicated that when values of C_1 as given in Table 2 are used in Eqn. (5) alongwith Eqns. (3), (4) and (6), it produces the estimates of P_A with a maximum error of ±10%, ±13%, ±15% and ±10% for about 90% data from the catchments of *Ramganga, Gomati, Yamuna* and *Ghaghara* respectively.

4.1. *Verification of proposed relationships*

Eqn. (5) was verified using independent data for one storm each from the catchments of *Ramganga, Gomati, Yamuna* and *Ghaghara*. Values of P_A were computed using Eqn. (5) with value of constant C_1 taken from. Values of K, n and C were computed using Eqn. (3), (4) and (6) respectively. Figs. 4 (a-d) graphically show this comparison. It can be seen from these figures that the above procedure produces results with a maximum error of ±15% for the independent data considered for the verification. Hence these equations have been considered as satisfactory.

Example 1. In order to show how the areal rainfall can be estimated using the point rainfall, consider example of the storm in Ramganga catchment shown in Fig. 2.

Here t = 6 hr, P_m = 55.80 mm and A = 34600 km^2. Therefore,

$K = 1.96 \times 10^{-3}$ [from Eqn. (3)]

$n = 0.63$ [from Eqn. (4)]

$C = 1.13$ [from Eqn. (6)]

C_1 = 1.15 (from Table 2 for Ramganga catchment)

Hence, P_A = 18.0 mm [from Eqn. (5)]

Actual P_A = 22.6 mm

Thus, it is obvious that for estimation of the areal rainfall, one would need to make use of Eqns. (3)-(6) alongwith Table 2, when t and P_m are known.

4.2. *Comparison with other studies*

No study on DAD relationship for rainfall storms having duration less than 24-hour is presently available in the country. However, the values of coefficients K and n have been compared with the studies on larger duration rainfall. Dhar and Bhattacharya (1975) had shown K values to increase with t and n values to decrease with t for t > 24 hours. Similar trend has been observed in the present analysis for t < 24 hours. Hence it is considered that the results obtained in the present study are in agreement with those reported previously by other investigators.

5. Conclusions

DAD relationship for various storms in the Gangetic plains has been studied. A relationship, *i.e.*, Eqn. (5) has been established for describing the rainfall having different durations over varying areas. The coefficient C_1 appearing in the relationship is found to vary with the geographical location of the station. This relationship produces satisfactory results when verified using an independent set of data. The results obtained in the present study compare well with those obtained from previous studies on larger duration rainfalls.

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