NOTE

Severe rainstorms in the Vidarbha subdivision of Maharashtra State, India

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ABSTRACT: This paper discusses the results of Depth-Area-Duration (DAD) analysis of the 8 most severe rainstorms that affected the Vidarbha subdivision of Maharashtra State, India, during the 100 yr period from 1891 to 1990. It was found from this analysis that rainstorms in June 1908, July 1930 and August 1912 yielded greater raindepths for smaller areas, i.e. $\leq 1000 \text{ km}^2$ and $\leq 25\,000 \text{ km}^2$, and that the August 1986 rainstorm yielded greater raindepths for all the larger areas, for measurement periods of 1 to 3 days. The DAD raindepths of these severe rainstorms for different durations will be useful for the design storm estimates of different water resources projects in the Vidarbha region, as well as for checking the spillway capacity of existing dams.

KEY WORDS: Rainstorm · Depth-Area-Duration (DAD) · Probable maximum precipitation (PMP)

1. Introduction. Dhar et al. (1989) and Kulkarni (1991) have studied severe rainstorms in Maharashtra State, India. Their studies indicate that severe rainstorms here are mostly confined to the Vidarbha region (see Fig. 1); this is mostly due to the fact that the Vidarbha region lies in the southwest quadrant of the area of tropical disturbances moving through the country during the monsoon season.

A number of water resources projects have been proposed for implementation in the Vidarbha region during the coming Five Year Plan schemes. Considering this, we analysed all the severe rainstorms of the Vidarbha region during the 100 yr period from 1891 to 1990, using the Depth-Area-Duration (DAD) method. The maximum average raindepths obtained for different areas and over different durations will be useful to

the design engineers and hydrologists of this region for estimating probable maximum flood (PMF) values, which are required for the design of dam spillway capacities as well as for verifying and checking the spillway capacities of existing dams and reservoirs and for taking remedial measures where necessary.

2. Rainfall climatology of Vidarbha. Areawise, Vidarbha (about $97\,537 \text{ km}^2$) is the second largest subdivision of Maharashtra State. The rainfall characteristics of this subdivision are governed to a large extent by its location in the central part of the country. The southwest or summer monsoon rainfall sets in over the Vidarbha region by about 10 June and withdraws by about the first week of October. Table 1 gives the mean monthly, seasonal and annual rainfall of the Vidarbha subdivision. The table shows that Vidarbha receives about 107 cm of rainfall annually, and that 88% of this falls during the monsoon months of June to September.

The highest amounts of rainfall recorded over periods of 1 day ('1-day rainfall') at long-term stations were identified from the 100 yr rainfall data. It was observed that the highest 1-day rainfall at the majority of stations ranged between 25 and 40 cm. Table 2 lists the stations which had a maximum 1-day rainfall of 30 cm or more, along with their extreme raindepths (probable maximum precipitation, PMP). The table shows that the stations at Dharni and Ghorajheri recorded the highest 1-day rainfall, 40 and 41 cm.

Knowledge of extreme 1-day rainfall at specific locations is useful in the planning and design of water resources projects for conservation of storm runoff and in designing waterways under bridges and culverts.

Table 1. Mean monthly, monsoonal (Jun–Sep) and annual rainfall, in cm, over the Vidarbha subdivision

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun–Sep	Annual
1.1	1.4	1.3	1.1	1.2	16.4	32.5	25.9	19.0	4.6	1.8	0.8	93.8	107.1

Table 2. Highest 1-day rainfall (>30 cm) over the Vidarbha subdivision (1891 to 1990). PMP: probable maximum precipitation

Rainstorm	Station	District	Highest 1-day rainfall (cm)	Date of occurrence	PMP (cm)
1	Deolgaon raja	Buldhana	30.4	21 Aug 1903	59.0
2	Mehokar	Buldhana	32.5	11 Sep 1892	62.7
3	Karanja	Akola	30.0	27 Sep 1891	60.4
4	Telhara	Akola	39.2	14 Sep 1959	80.2
5	Dharni	Amraoti	41.1	25 Aug 1965	68.6
6	Hinganghat	Wardha	31.2	18 Jul 1913	51.5
7	Nagpur	Nagpur	31.4	12 Jun 1911	57.7
8	Parseoni	Nagpur	31.8	12 Jul 1942	61.0
9	Umrer	Nagpur	33.0	14 Aug 1953	58.3
10	Badalkasa	Bhandara	37.5	31 Aug 1947	76.6
11	Khyrbund	Bhandara	33.5	2 Sep 1961	69.8
12	Pangree	Bhandara	39.5	25 Jul 1937	80.3
13	Sakoli	Bhandara	38.3	26 Jun 1908	69.5
14	Pandharkawara	Yeotmal	33.9	17 Aug 1963	73.8
15	Yeotmal	Yeotmal	33.7	21 Jul 1937	61.5
16	Ahiri	Chandrapur	31.9	14 Aug 1953	68.2
17	Armori	Chandrapur	33.7	5 Sep 1910	69.9
18	Brahmapuri	Chandrapur	32.3	31 Aug 1938	70.3
19	Chimur	Chandrapur	33.5	9 Aug 1927	69.9
20	Gadchiroli	Chandrapur	32.0	2 Aug 1908	61.5
21	Garmusi	Chandrapur	31.2	13 Aug 1949	69.9
22	Ghorajheri	Chandrapur	40.0	19 Jul 1959	72.5

Examination of past synoptic situations has shown that heavy rainfall over the Vidarbha subdivision during the southwest monsoon season is mostly due to: (1) westward or west-northwestward movement of different cyclonic disturbances, i.e. depressions, lows, upper air cyclonic circulations, etc., over the Vidarbha subdivision, and (2) position and strength of the axis of the seasonal monsoon trough, especially when it is south of its normal position.

3. DAD analysis of severe rainstorms over Vidarbha. The Vidarbha subdivision consists for the most part of the river basins of 2 major rivers, viz. the Wardha and Wainganga, along with their tributaries. The drainage areas of these 2 rivers in Vidarbha are ca 46 182 km² and 37 988 km², respectively. These rivers become flooded during the monsoon season, causing extensive loss of life and destruction of

Table 3. Raindepths (cm) of severe rainstorms over Vidarbha for areas up to 50 000 km² and durations of (a) 1 day, (b) 2 days and (c) 3 days

Storm no.	Period	Storm centre (District)	Point	Area (× 100 km ²):							
				1	5	10	50	100	250	300	500
(a) 1-day duration											
1	26 Jun 1908	Sakoli (Bhandara)	38.0	37.7	37.0	36.4	31.9	28.2	20.4	19.0	15.4
2	4 Aug 1912	Armori (Chandrapur)	27.7	27.4	26.9	26.3	23.3	21.0	16.4	—	—
3	17 Jun 1927	Arvi (Wardha)	29.1	28.7	28.2	27.5	22.1	17.8	13.7	12.9	10.5
4	2 Jul 1930	Wani (Yeotmal)	36.0	35.6	33.5	31.5	22.1	18.8	16.0	—	—
5	16 Jun 1936	Umrer (Nagpur)	20.0	19.9	19.7	19.5	17.8	16.7	15.4	15.0	13.5
6	3 Aug 1953	Brahmapuri (Chandrapur)	30.5	29.5	27.7	27.0	20.0	17.9	16.5	16.2	15.2
7	14 Aug 1953	Ahiri (Chandrapur)	32.0	31.5	31.0	30.6	26.8	23.8	17.8	16.2	13.5
8	13 Aug 1986	Rajura (Chandrapur)	31.0	30.5	29.4	28.4	25.5	23.5	20.0	19.6	18.1
Envelope value			38.0	37.7	37.0	36.4	31.9	28.2	20.4	19.6	18.1
(b) 2-day duration											
1	25–26 Jun 1908	Sakoli (Bhandara)	43.0	42.7	42.2	41.2	36.4	31.8	24.3	23.2	20.3
2	3–4 Aug 1912	Armori (Chandrapur)	51.9	51.4	50.8	49.8	44.4	40.4	32.7	30.5	24.0
3	17–18 Jun 1927	Arvi (Wardha)	37.7	37.2	35.8	34.2	26.2	23.2	19.5	18.7	16.1
4	2–3 Jul 1930	Wani (Yeotmal)	71.3	69.7	61.0	56.0	37.1	32.0	26.1	24.9	20.6
5	16–17 Jun 1936	Kunghari (Nagpur)	36.0	35.9	35.6	35.3	33.4	31.2	28.4	27.6	24.6
6	3–4 Aug 1953	Brahmapuri (Chandrapur)	44.9	44.0	41.8	40.0	33.1	29.2	25.2	25.0	23.9
7	13–14 Aug 1953	Ahiri (Chandrapur)	47.2	47.0	46.5	45.8	40.5	36.2	27.9	26.0	21.0
8	13–14 Aug 1986	Rajura (Chandrapur)	61.2	60.7	59.8	58.3	50.9	46.0	37.5	35.2	29.9
Envelope value			71.3	69.7	61.0	58.3	50.9	46.0	37.5	35.2	29.9
(c) 3-day duration											
1	25–27 Jun 1908	Sakoli (Bhandara)	46.3	46.2	46.0	46.0	42.5	38.4	29.0	28.0	23.8
2	3–5 Aug 1912	Brahmapuri (Chandrapur)	57.9	57.9	57.8	57.7	55.0	51.6	42.0	39.0	31.1
3	17–19 Jun 1927	Arvi (Wardha)	38.4	38.1	36.6	35.1	28.4	25.8	22.9	22.2	20.2
4	1–3 Jul 1930	Wani (Yeotmal)	77.4	75.3	71.2	65.5	46.5	39.2	33.5	32.0	28.2
5	15–17 Jun 1936	Kunghari (Nagpur)	39.4	39.2	39.0	38.9	35.9	32.2	29.8	29.1	28.0
6	3–5 Aug 1953	Brahmapuri (Chandrapur)	44.9	44.1	42.5	41.7	39.0	36.2	33.1	32.3	29.6
7	13–15 Aug 1953	Ahiri (Chandrapur)	49.2	49.0	48.8	48.2	44.9	40.9	33.3	31.8	27.1
8	12–14 Aug 1986	Rajura (Chandrapur)	66.2	65.5	64.4	62.8	54.8	49.0	40.9	39.8	37.2
Envelope value			77.4	75.3	71.2	65.5	55.0	51.6	42.0	39.8	37.2

property and agricultural lands. In order to estimate probable maximum flood (PMF), it is essential to determine maximum average raindepths yielded by different rainstorms over the region.

Daily rainfall data from 100 to 150 long-term rainfall stations, uniformly distributed in and around the Vidarbha region, were used to analyse severe rainstorms for the period 1891 to 1990. Examination of this data showed that during this 100 yr period, 8 extremely severe rainstorms affected this subdivision. These are listed in Table 3.

Fig. 1 shows where the heavy rain centres of some of these rainstorms were located. It should be noted that, even when heavy rain centres are located in this region, their isohyetal patterns may extend over the neighbouring regions (see Figs. 2 to 4). All these rainstorms were analysed using the standard DAD technique (WMO 1969, 1986). In this technique, a rainstorm is taken as a unit of study and a 3-dimensional relationship is determined between (1) average raindepth, (2) storm area and (3) a given duration of time. Using this technique, average raindepths were obtained for 1-, 2-, and 3-day periods during rainstorms for areas up to 50 000 km². However, it should be noted

that all these rainstorms had an areal extent of more than 100 000 km².

The DAD data for 1-, 2- and 3-day periods are given in Table 3. The data show that out of 8 severe rainstorms which affected this region, 4 rainstorms occurred in the month of August, 3 in June and 1 in July. The highest rainfall recorded over a 1-day period occurred in June 1908 (i.e. 38 cm) and for 2- and 3-day periods the maximum values were recorded during the July 1930 rainstorm, with point rainfall values of 71 and 77 cm respectively. It was also observed that the August 1986 rainstorm contributed the highest raindepths for areas >25 000 km² over 1- and 3-day periods and for areas >1000 km² over 2-day periods. The rainstorms producing envelope raindepths over 1-, 2- and 3-day periods were as follows:

over 1-day periods:	≤25 000 km ²	Jun 1908
	≤50 000 km ²	Aug 1986
over 2-day periods:	≤500 km ²	Jul 1930
	≤50 000 km ²	Aug 1986
over 3-day periods:	≤1000 km ²	Jul 1930
	≤25 000 km ²	Aug 1912
	≤50 000 km ²	Aug 1986

Fig. 1. Maharashtra, India, showing 3-day rainstorm centres over the plain area and coastal region of the state

Figs. 2, 3 & 4 give the 3-day isohyetal patterns of severe rainstorms of June 1908, July 1930 and August 1986, respectively. The DAD raindepths thus obtained for 1-, 2- and 3-day periods (see Table 3) can be utilized to obtain design storm estimates for water resources projects in the Wardha and Wainganga river basins of the Vidarbha subdivision.

4. Relationship between central and areal rainfall. Often, design engineers have to provide preliminary estimates of maximum rainfall at short notice for the design of hydraulic structures. The conventional methods of rainstorm analysis, referred to in Section 3, over and near the basin under study are time-consuming and require detailed analysis of past rainfall data before any final estimates can be given. In view of this, the relationship between central rainfall and its areal extent for the most severe rainstorms over the north Indian plains has been studied by Raman & Chhabra (1966) and Dhar & Bhattacharya (1977). Using their technique, an attempt was made here to establish a relationship between central rainfall and the average maximum raindepths of different areas obtained during severe rainstorms in Vidarbha.

The DAD raindepths of severe rainstorms given in Table 3 for 1-, 2- and 3-day durations were expressed

as percentages of the point rainfall values for each standard area. The mean percentage raindepths thus obtained for all the severe rainstorms were used for further analysis.

4.1. Log-linear relationship: It was observed that the percentage ratios obtained for all the severe rainstorms of Vidarbha differed among the different durations (1, 2 and 3 days). An attempt was therefore made to verify whether the linear equation given below was valid for these percentage ratios:

$$Y = 100 - kA^n \quad (1)$$

where Y is the percentage ratio of the average maximum rainfall over an area A to the central rainfall of the storm and k and n are constants. k and n were evaluated by the least squares method and are as follows:

Duration	k	n
1 day	0.0926	0.6153
2 days	0.0738	0.6325
3 days	0.0333	0.6964

The goodness-of-fit of Eq. (1) for all 3 durations using the Chi-square test showed that the equation was statistically significant at the 99.5% level. Using this relationship, scatter diagrams (Fig. 5) were prepared to

Fig. 2. The 3-day isohyetal pattern of the 25–27 June 1908 rainstorm over Maharashtra and neighbouring areas

Fig. 3. The 3-day isohyetal pattern of the 1-3 July 1930 rainstorm over Maharashtra and neighbouring areas

Fig. 4. The 3-day isohyetal pattern of the 12-14 August 1986 rainstorm over Maharashtra and neighbouring areas

show the nature of the relationship between observed and estimated percentage values for 1- to 3-day durations. Fig. 5 shows that there is a one-to-one correspondence between the observed and estimated percentage values for areas $\leq 25\,000\text{ km}^2$, while for larger areas (i.e. lower percentage ratios) the correspondence is not as close. Therefore, for larger areas, this equation does not give correct estimates of the average maximum rain-depths.

4.2. Exponential relationship: In order to obtain a general equation which was valid for both large and small areas, another type of equation was used by Horton (1924). According to him, the relationship between percentage values of rainfall and rainstorm areas could be expressed in the following exponential form:

$$Y = 100e^{-kA^n} \quad (2)$$

Fig. 5. Relationship between observed and estimated rainfall values using the log-linear equation

Fig. 6. Relationship between observed and estimated rainfall values using the exponential equation

The symbols in Eq. (2) have the same meaning as in Eq. (1). k and n were evaluated by the least squares method and are as follows:

Duration	k	n
1 day	0.000635	0.673306
2 days	0.000533	0.688303
3 days	0.000254	0.742529

The goodness-of-fit of Eq. (2) for all 3 durations using the Chi-square test showed that these equations were statistically significant at the 99.9% level. Scatter diagrams were prepared (see Fig. 6) to compare the values estimated using Eq. (2) with observed values

for 1-, 2- and 3-day durations of rainstorms in Vidarbha. It can be seen in Fig. 6 that practically all the points lie on a straight line, forming a 45° angle, and even points for larger areas (i.e. lower percentage values) have a better one-to-one correspondence as compared to those in Fig. 5.

Thus we conclude that the relationship between the areal-to-point percentage values and area of rainstorms for 1- to 3-day durations is exponential, as far as storms in Vidarbha are concerned, and that Eq. (2) gives better estimates of areal rainfall than Eq. (1).

5. Summary and conclusion. The following broad conclusions can be drawn from this study:

(1) The mean annual rainfall of the Vidarbha subdivision is ca 107 cm. The highest 1-day rainfall (41.1 cm) was recorded at Dharni.

(2) Examination of 100 yr daily rainfall data from 1891 to 1990 revealed that the Vidarbha subdivision experienced 8 extremely severe rainstorms. These rainstorms were analysed using the DAD technique, and maximum average raindepths of these rainstorms from point to 50 000 km² were recorded in this study for 1- to 3-day durations.

This analysis showed that the rainstorms yielding the greatest raindepth for 1-day duration were in June 1908 and August 1986; for 2-day duration, in July 1930 and August 1986; and for 3-day duration, in July 1930, August 1912 and August 1986. The raindepths obtained from these rainstorms can be utilized for PMP study, preparation of PMP generalized charts and/or the preparation of design storm estimates for the Vidarbha region.

(3) The average maximum raindepths obtained over different areas from the severe rainstorms of Maharashtra, expressed as a percentage of central rainfall for different durations, can be estimated fairly accurately using an exponential equation of the form $Y = 100e^{-kA^n}$. This study has shown that this equation gives better estimates of areal raindepths, for small as well as large areas, over 1- to 3-day durations of rainstorms in Vidarbha.

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