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A study of maximum point and areal rainfall in the Bhima basin upto Ujjani dam site*

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ABSTRACT. In this study both point and areal rainfall analyses have been attempted for the Bhima basin upto Ujjani dam site. Point rainfall magnitudes for the stations within the basin have been worked out for 2 and 100-year return periods and a nomogram has been prepared by which rainfall magnitudes for the intermediate return periods of 5, 10, 25 and 50 years can be determined. Design rainfall for the basin has been calculated for 100, 500 and 1000-year return periods on the basis of 75 years' rain storm analyses of the basin. Maximum rainfall experienced over this basin during the last 75-year period has also been compared with the maximum rainfall experienced in the neighbouring basins of Godavari and Krishna for different durations. Mean annual rainfall of the basin was found to be of the order of 37 inches of which 92 per cent is contributed during the monsoon months of June to October. It was also observed that in this region maximum 1, 2 and 3-day basin rainfall are about 12, 18 and 23 per cent respectively of the mean annual basin rainfall.

1. Introduction

River *Bhima* rises on the lee side of the Western Ghats at an altitude of about 3100 ft near the temple of Bhima Shanker, 25 miles north of Khandala. It joins the *Krishna* river about 1 miles north of Raichur. Its total length upto its confluence with the *Krishna* is about 535 miles. About 85 miles from its source, the *Mula-Mutha* river joins it from the right and 18 miles downstream from this point, the *Ghod* river joins it from the left (Fig. 1).

A masonary-cum-earth dam about 137-ft high is proposed to be constructed across the river at Ujjani (Fig. 1). The total catchment area upto Ujjani dam site is about 5700 sq. miles.

2. Mean annual rainfall of the basin

At present there are 16 raingauge stations within the basin upto Ujjani (Fig. 1). The daily rainfall data of about 14 raingauges are available continuously since 1891 in the printed rainfall tables of Maharashtra State. Within the basin there are two meteorological observatories located at Poona and Jeur. The latter is located close to Ujjani while the former is situated in the south-western sector of the basin. A recording raingauge has been functioning at the Poona Observatory since April 1929.

The existing raingauge network over the Ghat area of the basin is quite inadequate for a satisfactory analysis of the basin rainfall. However, for arriving at tentative conclusions, isohyetal analysis of the basin rainfall was carried out on the basis of existing network, keeping in view the broad conclusions drawn by Sarker (1967) regarding orographic rainfall over the Western Ghats.

Mean monthly and annual isohyetal maps of the basin were prepared using 1950 normals of rainfall of the 60 raingauges in and around the basin. Table 1 gives the mean monthly and mean annual rainfall of the basin upto Ujjani dam site and Fig. 2 shows the mean annual rainfall over the basin. It is seen from Table 1 that mean annual rainfall of the basin is about 37 inches and monsoon (June to October) rainfall is about 92 per cent of the mean annual total. From an examination of the mean annual rainfall map (Fig. 2) of the basin it has been observed that only 15 per cent of the total basin area (*i.e.*, Ghat area) receives annual rainfall above 50 inches. The major portion of the basin area (*i.e.*, about 63 per cent) receives rainfall of the order of 20 to 50 inches annually. The area of the basin receiving less than 20 inches is, however, small and of the order of about 22 per cent of the total area.

3. Variability of rainfall

Coefficients of variability of the annual and monsoon rainfall are calculated in respect of 40 stations in and near the basin using rainfall data

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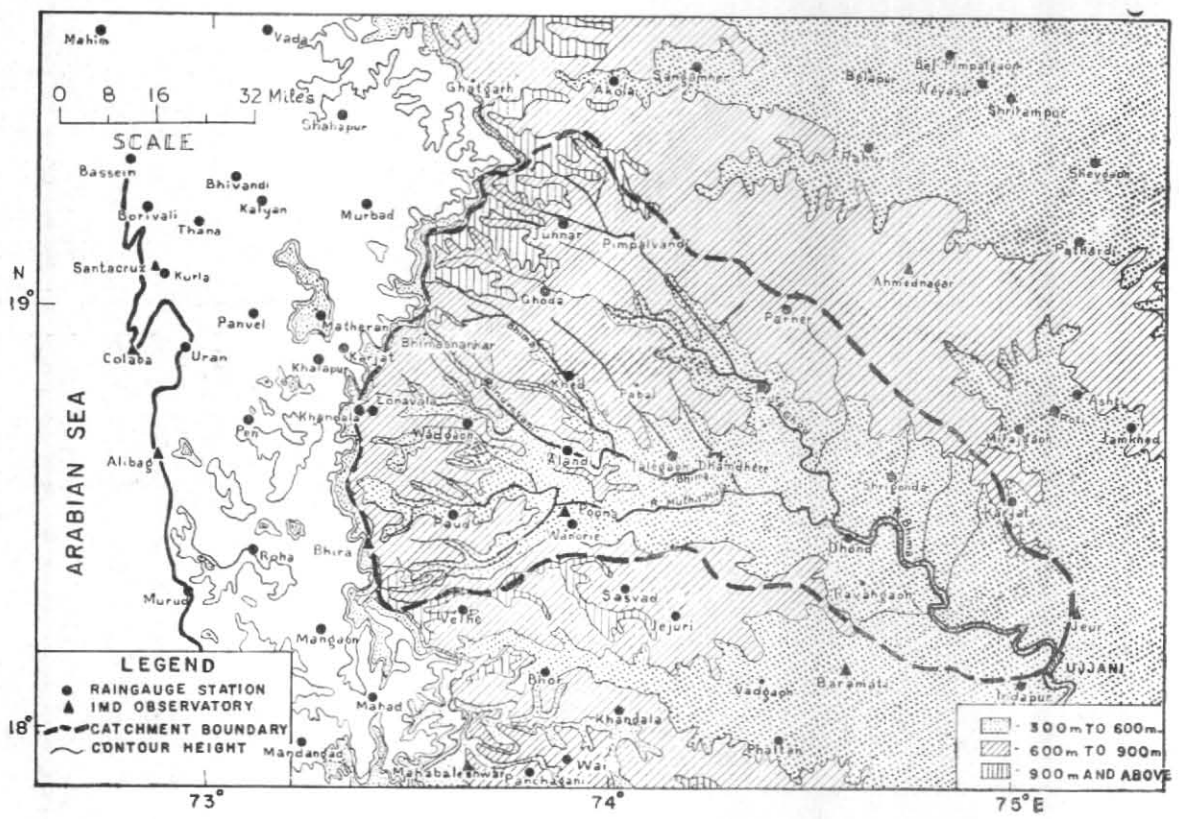

Fig. 1. Bhima basin upto Ujjani dam site

of the period 1901 to 1950. Since 92 per cent of the annual rainfall occurs during the monsoon months, it was found that there is not much difference between the annual and the monsoon coefficients of variability at individual stations. Fig. 3 shows the isolines of coefficient of variability for the monsoon period. The variability is least and of the order of 20 to 25 per cent along the Ghat area of the basin and is maximum (*i.e.*, 35 to 40 per cent) in the eastern portion of the basin.

4. Maximum one-day point rainfall

Maximum one-day point rainfall for different return periods from 2 to 100 years and probable maximum precipitation (PMP) at individual stations have been studied using the 60 to 70-year daily data of about 50 stations in and around the basin. Gumbel's procedure as adopted by Chow (1953) has been used in working out the maximum point rainfall for the return periods of 2, 5, 10, 25, 50 and 100 years. Using the U.S. Weather Bureau (1961) procedure, a nomogram has been prepared (Fig. 4) which gives the magnitudes of rainfall for the intermediate return periods if 2 and 100-year values are known. Table 2 gives the magnitudes of 2 and 100-year rainfall for 14 stations in the basin for which period (60 to 70 years) data are available. For obtaining rainfall magnitudes for intermediate return periods of 5, 10, 25 and 50 years the nomogram may be used in the following manner.

The values of 2 and 100-year rainfall are plotted on the corresponding intercepts of the nomogram. These are joined by a straight edge and the points of intersection of the straight edge with the different vertical intercepts give the magnitudes of one-day rainfall for corresponding return periods. In Fig. 4 a straight edge joining 2 and 100-year rainfall magnitudes (obtained from Table 2) for Poona has been shown by way of illustration and rainfall magnitudes for return periods of 5, 10, 25 and 50 years as picked up from this diagram are 3·6*, 4·0*, 4·6 and 5·1 inches respectively. It has, however, been observed that rainfall values thus obtained for different return periods for any station in the basin are within

*These values refer to partial duration series. The one-day values obtained for Poona in this study were compared with the similar values obtained by Mazumdar (1966) for Poona. It was seen that the values for higher return periods tally fairly well. Mazumdar, however, used one-day Poona data for the 50-year period (1903 to 1952) while in this study 70-year data has been used.

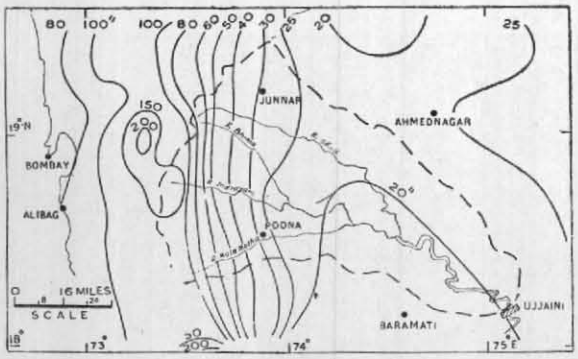

Fig. 2. Normal annual isohyets 1901 to 1905 (inches) for Bhima basin upto Ujjani dam site

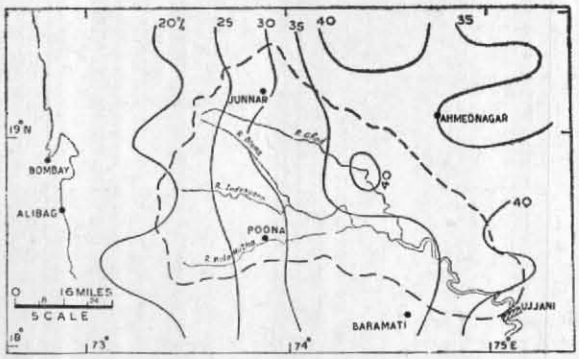

Fig. 3. Coefficient of variability of monsoon (Jun-Oct) rainfall for Bhima catchment upto Ujjani dam site

± 1 per cent of the actual value calculated by Chow's (*loc. cit.*) method.

5. Probable maximum precipitation

Probable maximum precipitation (PMP) for one-day duration at individual stations in the basin has been worked out by the Hershfield technique (1965). According to this method PMP for any station can be worked out by the following frequency equation —

$$X_{PMP} = \overline{X} + K_m \sigma \qquad (1)$$

where X_{PMP} is the PMP rainfall for a station, $\overline{X}$ and σ are the mean and standard deviation of extreme annual rainfall series and K_m is the envelope frequency factor. In equation (1) using K_m value of Hershfield based upon the world record rainfall data, PMP values were determined for 14 stations within the basin and are given in Table 2. It has, however, been noticed that these values, on an average, are 3·27 times the highest observed one-day rainfall at individual stations. Lockwood (1969) feels that the Hershfield's value of $K_m = 15$ is too high for use in many tropical areas. Mazumdar and Rangarajan (1966) while studying the PMP values for east UP stations have suggested that instead of using the world envelope value, we should use the regional envelope value for K_m in Eq. (1). The regional envelope value for stations in and around the Bhima basin was found to be of the order of 6 and the PMP values calculated on this basis are shown in Table 2. The return period of these values for each station was found to be greater than 1000 years.

6. Analysis of heavy rain storms over the basin

All the major rain storms that the basin experienced during the 75-year period (1891 to 1965) were examined by the scrutiny of daily rainfall data of stations in and near the basin. For each year of this period, one heaviest rain spell of 3-day duration was selected for isohyetal analysis and weighted rainfall for each day of the rain spell was worked out. In this way, 75 rain spells (each of 3-day duration) were analysed by depth-duration method. The weighted maximum rain depths obtained over the basin (upto Ujjani) for 1, 2 and 3-day durations were plotted and an envelope curve was drawn through the highest values (Fig. 5). The maximum rain depths picked up from the envelope curve for different durations are given in Table 3.

It is sometimes said that the envelope curve method is subjective and yields varying results with the increase or decrease of the sample size. To check this point, maximum rain depths for different durations were worked out based upon

TABLE 1

Mean monthly and annual rainfall over the Bhima basin upto Ujjani dam site

Month	Rainfall (inch)	% of annual
Jan	0·14	0·4
Feb	0·06	0·2
Mar	0·09	0·2
Apr	0·33	0·9
May	0·83	2·2
Jun	6·38	17·3
Jul	10·60	28·5
Aug	7·14	19·3
Sep	6·96	18·8
Oct	3·02	8·2
Nov	1·26	3·4
Dec	0·20	0·5
Annual	37·01	—
Jun to Sep	31·08	83·9
Jun to Oct	34·10	92·1

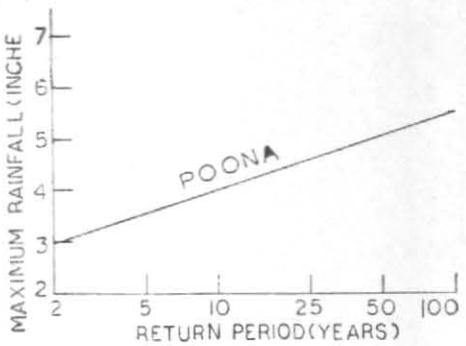

Fig. 4. Return period (partial duration series) interpolation diagram

TABLE 2

Magnitudes of maximum one-day rainfall for stations within the Bhima Basin (upto Ujjani)

Rainfall stations	Period of record	Observed highest 1-day rainfall (inch)	2-year 1-day rainfall* (inch)	100-year 1-day rainfall (inch)	PMP value, using $K_m = 15$ (inch)	PMP value using regional envelope value for K_m (inch)
Alandi	1891-1960	4·73	2·92	5·58	16·50	7·83
Dhond	1892-1960	6·15	2·88	6·31	20·00	9·13
Ghoda	1891-1960	6·95	2·96	7·03	22·94	10·29
Junnar	1891-1960	8·26	3·24	8·49	29·19	12·79
Karjat (Ahm.)	1891-1960	6·33	3·26	6·67	20·28	9·45
Khed	1891-1960	4·98	2·86	5·93	18·26	8·46
Lonawala	1891-1960	19·41	10·42	20·07	59·41	28·14
Parner (Ahm.)	1891-1960	5·91	2·83	6·20	19·44	8·89
Paud	1891-1960	8·41	4·45	8·76	26·11	12·29
Poona	1891-1960	5·36	2·98	5·53	15·98	7·66
Shrigonda	1891-1960	7·40	3·11	7·20	23·29	10·49
Sirur	1899-1960	7·15	2·92	6·63	21·45	9·69
Telegaon-Dhamdhera	1891-1960	5·38	2·90	6·27	19·62	9·00
Vadagaon	1891-1960	7·60	3·88	7·82	23·71	11·08

*These values refer to partial duration series

3σ confidence limit of the storm sample and are also indicated in Table 3 by way of comparison. It is seen that for each duration the maximum rain depths obtained by the two methods are almost identical.

Analysis of heavy rain spells over the basin has shown that the maximum 1-day rain depth was caused by the rain spell of 6 to 8 September 1895 and the maximum 2 and 3-day depths were caused by the rain spell of 2 to 4 August 1956. It has been noticed while going through the past flood records of this basin that the highest recorded flood was caused by the August 1956 rain storm when the river rose by about 15 ft above its danger level of 1661·68 ft at Dhond (CW & PC 1965).

TABLE 3

Comparison of maximum rain depths (experienced over the basin) obtained by different methods

Duration (Days)	Maximum rain depths (inch)	
	Envelope curve method	Statistical method
1	4·5	4·4
2	6·7	6·9
3	8·3	8·4

TABLE 4

Maximum rain depth likely to be expected over Bhima basin (upto Ujjani) in different durations and return periods

Duration (Days)	Rain depths (inch)		
	100-yr	500-yr	1000-yr
1	4·8	5·8	6·3
2	7·4	9·1	9·9
3	9·1	11·1	12·0

TABLE 5

Maximum 1 and 2-day rainfall as per cent of maximum 3-day rainfall

	Bhima upto Ujjani	Godavari upto Gangapur	Krishna upto Sangali
Area (sq. miles)	5740	6000	3800
3-day max. rainfall (inch)	8·3	7·9	10·5
1-day max. rainfall as per cent of 3-day rainfall	54	52	56
2-day max. rainfall as per cent of 3-day rainfall	79	81	80

7. Frequency analysis of rain storm data

The weighted annual maximum rain depths over the basin for durations of 1, 2 and 3 days for the 75-year period (1891 to 1965) were subjected to frequency analysis using the Chow's (*loc. cit.*) technique. Fig. 6 gives the computed lines of maximum rainfall for different durations. For each computed line the formal theoretical relationships are given below —

$$\text{1-day} : Y_1 = 0{\cdot}89\,K + 1{\cdot}98$$
$$\text{2-day} : Y_2 = 1{\cdot}36\,K + 3{\cdot}14$$
$$\text{3-day} : Y_3 = 1{\cdot}63\,K + 3{\cdot}91$$

where $K = -(1{\cdot}1 + 1{\cdot}795 \log_{10} \log_{10} T/T - 1)$; Y is the extreme rainfall in inches for different durations and T is the return period in years. From the computed frequency lines (Fig. 6) maximum rain depths for different durations of 1, 2 and 3 days and return periods of 100, 500 and 1000 years were picked up and the same are given in Table 4.

From Fig. 6 the return periods for the envelope rain depths given in Table 3 have been picked up and are given below —

Duration	*Return period (Yrs)*
1-day	65
2-day	50
3-day	55

It is noticed from the above that the maximum rain depths experienced over the basin during the last 75-year period have been of the magnitude whose return periods are just over 50 years or so.

8. Comparison of maximum basin rainfall depths with those of the neighbouring basins

In the upper reaches, Bhima basin is flanked by the basins of *Godavari* to the north and *Krishna* in the south. All these three basins (in their upper reaches) are located in the meteorologically homogeneous sub-division of Madhya Maharashtra.

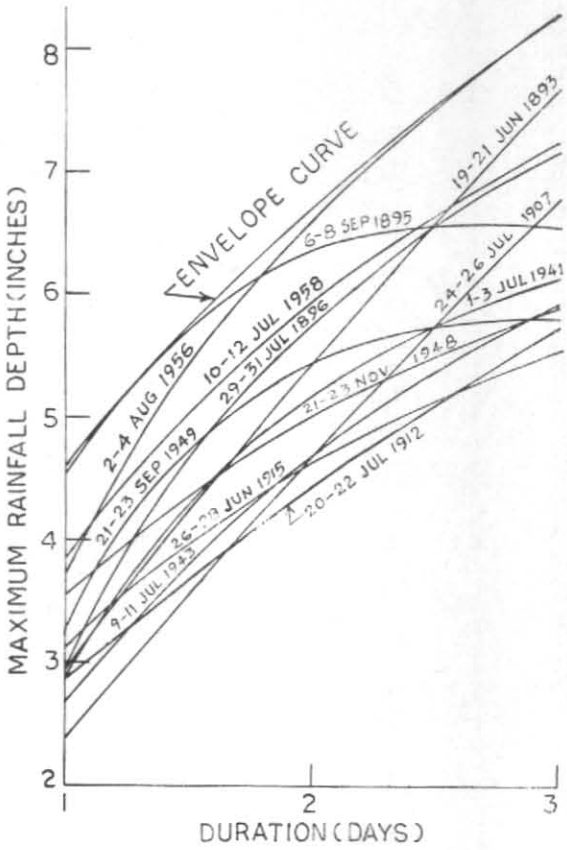

Fig. 5. Depth-duration curves for the twelve heaviest rain spells over Bhima basin upto Ujjani dam site

TABLE 6

Maximum basin rainfall as per cent of mean annual rainfall

	Krishna-Godavari upper reaches		
	Bhima upto Ujjani	Godavari upto Gangapur	Krishna upto Sangali
Mean annual rainfall (MAR) (inch)	37·0	29·7	53·6
1-day max. rainfall as per cent of MAR	12	13	11
2-day max. rainfall as per cent of MAR	18	21	16
3-day max. rainfall as per cent of MAR	22	27	20

Table 5 shows the maximum rain depths experienced by these basins in a 3-day duration during the 75-year period from 1891 to 1965. For the sake of comparison, maximum 1 and 2-day rainfall depths of each of the basins have been expressed as percentages of their respective maximum 3-day rainfall. It is seen from the table that the ratios of 1 and 2-day rainfall to the 3-day rainfall of the respective basins are practically of the same order. Thus this study has shown that in this region 1-day basin rainfall on an average is about 54 per cent and 2-day rainfall is about 80 per cent of the 3-day basin rainfall.

Maximum 1, 2 and 3-day rainfall of each of these basins have also been expressed as percentages of the mean annual rainfall of the respective basins and these percentages have been shown in Table 6. It is seen that on an average maximum 1-day rainfall is about 12 per cent, 2-day about 18 per cent and 3-day about 23 per cent of the mean annual rainfall of the respective basins. Such percentages are quite useful and handy when tentative estimates are required for preliminary investigations and when detailed studies cannot be undertaken for lack of time. This type of statistics was also collected for a few important basins in the country for which maximum basin rainfall studies are available (Dhar *et al.* 1962, 1965, 1966 and 1968)

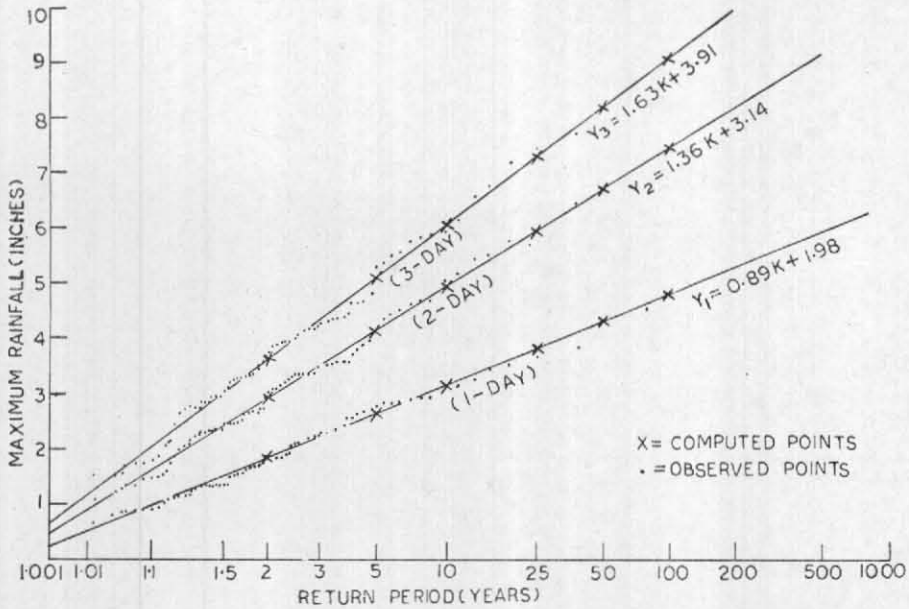

Fig. 6. Gumbel lines for 1, 2 & 3-day maximum rainfall over Bhima basin upto Ujjani

and it has been observed that high percentages are generally obtained in the case of such basins which are located directly in the path of rain storms. The 3-day maximum rainfall for the Baitarni basin in Orissa was found to be about 30 per cent of the mean annual rainfall while in the case of Yamuna basin (upto Tajewala) it was found to be only 13 per cent. The 3-day percentage were found to vary from 17 to 37 per cent in the case of some Australian basins by Karoly and Alexander (1960).

9. Summary

From the foregoing the following conclusions may broadly be drawn —

(*i*) Mean annual rainfall of the Bhima basin (upto Ujjani dam site) is about 37 inches and 92 per cent of this is received during June to October.

(*ii*) Coefficient of variability of the monsoon rainfall is 20 to 25 per cent along the Ghat area of the basin. It was found to increase from 35 to 40 per cent in the eastern portion of the basin.

(*iii*) Probable maximum one-day precipitation (PMP) has been worked out for individual stations within the basin by Hershfield method and the PMP values obtained are given in Table 2. Maximum one-day rainfall magnitudes for return periods of 2 and 100 years have also been worked out by Chow's technique for different stations within the basin. A nomogram has been prepared for determining the maximum point rainfall values of intermediate return periods of 5, 10, 25 and 50 years.

(*iv*) Design storm for the basin has been determined for the return periods of 100, 500 and 1000 years. It has also been seen that envelope depths of rainfall have a return period of just over 50 years.

(*v*) Comparison of maximum rain depths experienced in the three neighbouring basins, *viz.*, (*a*) Godavari upto Gangapur (*b*) Bhima upto Ujjani and (*c*) Krishna upto Sangali, during the last 75 years has shown that on an average 1 and 2-day maximum rain depths are about 54 and 80 per cent respectively of the 3-day maximum rainfall. Also 1, 2 and 3-day maximum rain depths are about 12, 18 and 23 per cent respectively of the mean annual basin rainfall. Similar statistics for some of the important river basins in the country has also been studied and it is noticed that the highest ratios are generally found in the case of those basins which lie directly in the path of monsoon depressions and storms.

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