551.577.37 (547.1 MAH)

VARIABILITY OF EXTREME HEAVY RAINFALL IN MAHARASHTRA

1. Maharashtra state has specific topographical features and rainfall characteristics. It is bounded by the Arabian Sea on its western side. The Western Ghats (Sahyadri) runs north to south separating the coastal districts of Thane, Mumbai city, Mumbai suburban, Raigarh, Ratnagiri and Sindhudurg from rest of Maharashtra. As the ridge runs across at right angles to the monsoon stream, it forms an important climatic divide. The western slopes and the coastal districts get very heavy monsoon rains more than 2000 to 3000 mm while to the east of the ghats rainfall drops to less than a tenth within a short distance from the ghats. Because of this topography and also track of monsoon depressions crossing the state from east to west, state has specific rainfall characteristics. It has large spatial variability of monsoon rainfall. It would be worth to examine the extreme rainfall characteristics against climatology of the state in view of the recent record break extreme rainfall on 26-27 July 2005 at Santacruz.

Extreme rainfall studies in different regions of the country have been made by many scientists. Stephenson and Rupa kumar (1999) studied impact of extreme daily rainfall events on ensemble forecast of the Indian monsoon. Heavy rainfall studies over Bombay and Kerala state have been made by Prasad and Agarwal (1996) and Saseendran *et al.* (1995), respectively. Desai *et al*. (1996) studied very heavy rainfall over northwestern parts of India for Punjab, Himachal Pradesh and Haryana. Case studies of very heavy rainfall over Kolkata have been made by Banerjee *et al.* (1967) and Dhar and

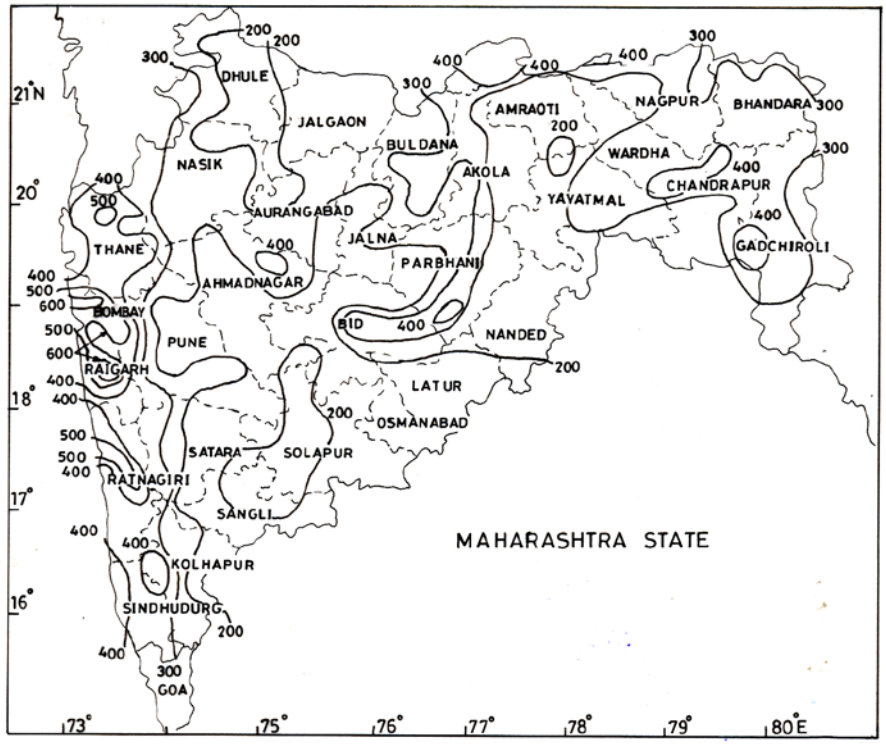

Fig. 1. Extreme rainfall (mm) in 24 hr over Maharashtra

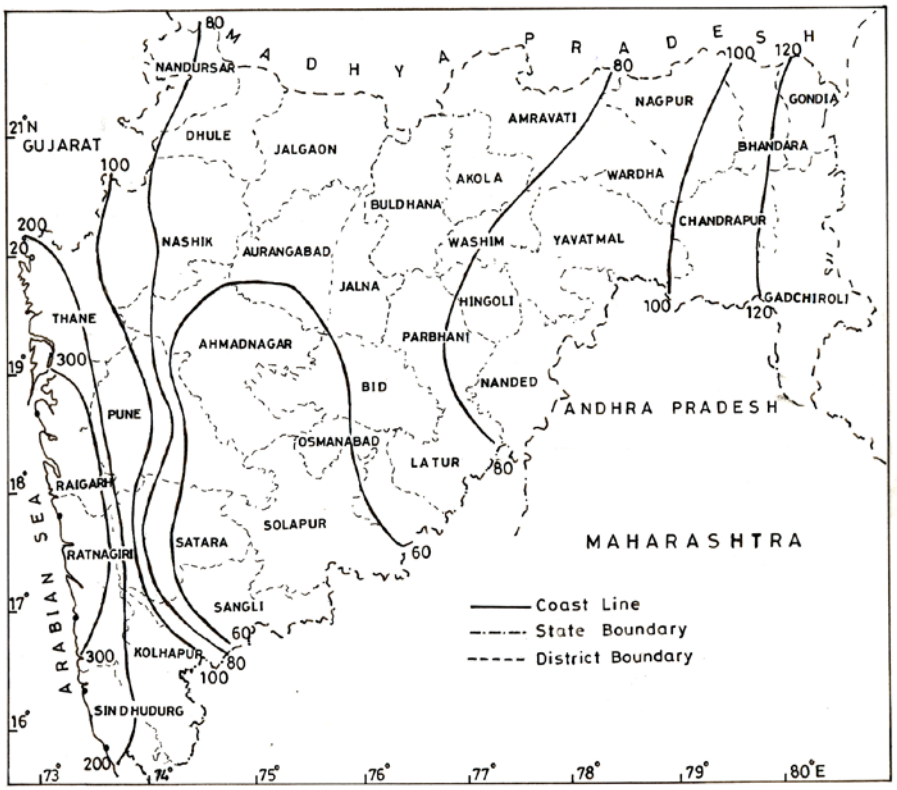

Fig. 2. Seasonal normal rainfall (cm) – June to September

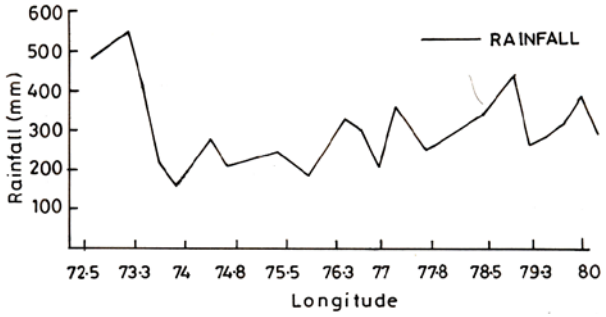

Fig. 3. Extreme rainfall at 20° Latitude

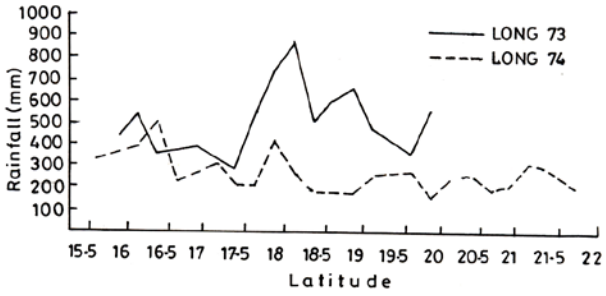

Fig. 4. Extreme rainfall along 73° E & 74° E Longitude

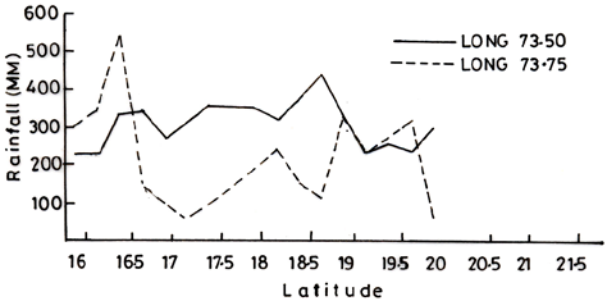

Fig. 5. Rainfall during southwest monsoon season along Longitudes 73.5° E & 73.75° E

Ramchandran (1970). Study of Depressions, Cyclonic storms in the Bay of Bengal with very heavy rainfall have been made by Thapliyal *et al*. (2000) and Ganesan *et al.* (2000). Alam *et al.* (2003) has studied frequency of Bay of Bengal cyclonic storms and depressions crossing different coastal zones. It revealed that most of the monsoon depressions cross the Kolkata-Vishakhapatnam coast of India. Also, the frequency distribution of Bay of Bengal storms has 2 peaks - one in May and another in November, which is useful for seeing extreme rainfall events.

There are few studies on droughts, dry and wet week probabilities, case studies of heavy rainfall etc., over Maharashtra. Gore and Thapliyal studied occurrence of dry and wet weeks over Maharashtra (2000), Gore and Sinha Ray studied variability in drought incidence over Maharashtra (2002). However, no much studies have been done on extreme rainfall events over entire state of Maharashtra.

In this paper variability of extreme rainfall over Maharashtra has been examined by considering the climatology and topography of Maharashtra and is useful in identifying region of higher amount of extreme rainfall. Latitudinal and longitudinal variation of extreme rainfall and normal rainfall has also been examined. Study of temporal variability has been made for identifying possible period of extreme rainfall event for various districts in the state.

2. Daily rainfall data from 1875-2000 has been utilized for computation of extreme heavy rainfall in 24 hours for about 342 stations of 35 districts in Maharashtra. Daily rainfall data for the period 1951-2000 for 342 stations of 35 districts have been considered for computation of rainfall normals. By considering data from 1875-2000 extreme heavy rainfall values during 24 hours have been extracted for the stations in Maharashtra. Spatial variability of extreme rainfall and that of normal rainfall in southwest monsoon season have been examined with the help of isopleths analysis (Fig. 1 and Fig. 2). Latitudinal and longitudinal variation of extreme rainfall and normal rainfall has been studied with the help of diagrams (Fig. 3, Fig. 4 and Fig. 5). Extreme rainfall variability over different stations has been studied with frequency distribution of extreme rainfall amount for 35 districts which is depicted in Table 1. Rainfall variability (coefficient of variation) is also studied during southwest monsoon season (Fig. 6) Temporal variability of extreme rainfall for 35 districts was examined in different standard weeks during June to September and is shown in Table 2.

3. In some coastal regions and adjoining areas extreme heavy rainfall in 24 hrs more than 400 mm is noticed. In some parts of Mumbai and Raigarh districts extreme heavy rainfall more than 500 mm is noticed. A small portion in Mumbai and adjoining parts of Raigarh near Matheran shows extreme rainfall more than 600 mm. The recent record break of extreme rainfall of 944.2 mm on 26-27th July 2005 at Santacruz is noticed in the above mentioned area. Extreme rainfall of 742 mm occurred at

TABLE 1

Frequency table for extreme rainfall (mm) for Maharashtra State

S. No.	District	101-200 (mm)	201-300 (mm)	301-400 (mm)	401-500 (mm)	501-600 (mm)	601-700 (mm)	701-800 (mm)	801-900 (mm)	901-1000 (mm)
1.	Ahmadnagar	8	4	1	1	-	-	-	-	-
2.	Akola	-	4	3	-	-	-	-	-	-
3.	Amravati	1	10	-	4	-	-	-	-	-
4.	Aurangabad	3	6	-	-	-	-	-	-	-
5.	Beed	6	2	1	-	-	-	-	-	-
6.	Bhandara	-	1	6	-	-	1	-	-	-
7.	Buldhana	5	7	2	-	-	-	-	-	-
8.	Chandrapur	-	4	6	1	-	-	-	-	-
9.	Dhule	2	4	-	-	-	-	-	-	-
10.	Gadchiroli	-	3	4	1	-	-	-	-	-
11.	Gondia	-	1	3	-	-	-	-	-	-
12.	Hingoli	1	-	1	-	-	-	-	-	-
13.	Jalgaon	1	12	-	-	-	-	-	-	-
14.	Jalna	4	1	-	-	-	-	-	-	-
15.	Kolhapur	7	6	2	1	-	-	-	-	-
16.	Latur	4	-	-	-	-	-	-	-	-
17.	Mumbai City	-	-	-	1	1	-	-	-	1
18.	Mumbai Suburban	-	-	2	-	-	1	-	-	-
19.	Nagpur	1	5	5	-	-	-	-	-	-
20.	Nanded	3	5	1	-	-	-	-	-	-
21.	Nandurbar	3	3	2	-	-	-	-	-	-
22.	Nashik	10	8	1	3	-	-	-	-	-
23.	Osmanabad	4	1	-	-	-	-	-	-	-
24.	Parbhani	3	1	-	1	-	-	-	-	-
25.	Pune	10	6	1	1	2	-	-	-	-
26.	Raigarh	-	-	6	6	-	3	2	-	-
27.	Ratnagiri	-	1	5	3	2	-	-	-	-
28.	Sangli	7	2	-	-	-	-	-	-	-
29.	Satara	9	3	3	1	-	-	-	-	-
30.	Sindhudurg	-	-	6	2	1	-	-	-	-
31.	Solapur	7	5	-	-	-	-	-	-	-
32.	Thane	-	2	5	6	1	-	-	-	-
33.	Wardha	-	5	2	-	-	-	-	-	-
34.	Washim	-	4	1	-	-	-	-	-	-
35.	Yavatmal	3	6	2	-	-	-	-	-	-
	Total	102	122	71	32	7	5	2	-	1

TABLE 2

Temporal variation of extreme rainfall (mm) during June – September

S. No.	District	28 – 3 May Jun	4-10 Jun	11-17 Jun	18-24 Jun	25 - 1 Jun- Jul	2-8 July	9-15 July	16-22 July	23-29 July	30 - 05 July Aug	6-12 Aug	13-19 Aug	20-26 Aug	27 - 2 Aug-Sep	3-9 Sep	10-16 Sep	17-23 Sep	24-30 Sep
1.	Ahmadnagar	1	1	-	-	-	1	-	1	-	-	-	-	-	2	1	3	1	-
2.	Akola	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-	3	-	-
3.	Amravati	-	-	-	-	-	1	1	1	1	1	-	1	2	3	1	3	-	-
4.	Aurangabad	-	1	-	-	-	-	-	1	-	-	-	-	-	2	1	1	-	2
5.	Beed	-	-	-	1	-	-	-	-	2	-	-	1	1	2	-	-	1	1
6.	Bhandara	-	-	-	-	1	1	1	-	1	1	1	-	-	2	-	-	-	-
7.	Buldhana	-	-	1	-	1	-	1	1	-	-	1	1	1	-	2	3	-	1
8.	Chandrapur	-	-	-	-	1	1	1	2	-	-	1	2	1	2	-	-	-	-
9.	Dhule	-	1	-	-	-	-	-	1	1	1	-	2	-	-	-	-	-	-
10.	Gadchiroli	-	-	-	-	1	-	-	3	-	1	1	1	-	-	1	-	-	-
11.	Gondia	-	-	-	1	-	-	-	-	1	-	-	-	-	2	-	-	-	-
12.	Hingoli	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-
13.	Jalgaon	-	-	2	-	1	-	-	-	-	2	1	6	1	-	-	-	-	-
14.	Jalna	-	1	-	-	-	-	-	1	-	1	-	-	-	1	-	-	-	-
15.	Kolhapur	-	-	-	-	3	-	1	1	4	1	-	-	-	-	1	-	1	1
16.	Latur	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1
17.	Mumbai City	-	-	-	-	-	2	-	-	1	-	-	-	-	-	-	-	-	-
18.	Mumbai Suburban	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-
19.	Nagpur	1	-	1	-	-	-	5	1	-	-	1	1	-	-	1	-	-	-
20.	Nanded	-	-	-	-	2	-	-	-	-	-	2	-	1	-	-	-	1	1
21.	Nandurbar	-	1	-	-	-	-	-	-	-	2	2	1	1	-	1	-	-	-
22.	Nashik	-	1	1	1	1	3	1	1	3	2	-	1	-	1	-	3	1	-
23.	Osmanabad	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	1	-
24.	Parbhani	-	1	-	-	1	-	-	-	-	1	-	1	1	-	-	-	-	-
25.	Pune	-	1	-	1	2	-	-	2	3	-	-	1	2	-	1	-	1	2
26.	Raigarh	-	2	-	1	1	2	2	3	3	-	-	-	-	-	1	-	2	-
27.	Ratnagiri	1	3	-	2	3	-	-	1	1	-	-	-	-	-	-	-	-	-
28.	Sangli	-	-	-	1	-	-	-	-	1	-	-	1	-	-	-	2	1	-
29.	Satara	-	5	-	3	-	1	-	1	-	1	-	-	-	-	-	-	-	-
30.	Sindhudurg	-	-	2	3	2	-	-	-	1	1	-	-	-	-	-	-	-	-
31.	Solapur	-	-	1	1	-	-	-	-	-	-	1	-	1	-	4	-	3	-
32.	Thane	-	-	-	1	1	2	1	3	2	1	-	-	-	2	-	1	1	-
33.	Wardha	-	-	-	1	1	1	2	1	-	1	-	-	-	-	-	-	-	-
34.	Washim	-	1	-	-	2	-	1	-	-	-	-	-	-	-	-	1	-	-
35.	Yavatmal	-	-	1	-	2	-	-	4	-	-	-	1	-	-	1	1	-	1
	Total	3	19	9	17	28	17	16	32	25	17	12	23	12	20	17	21	14	10

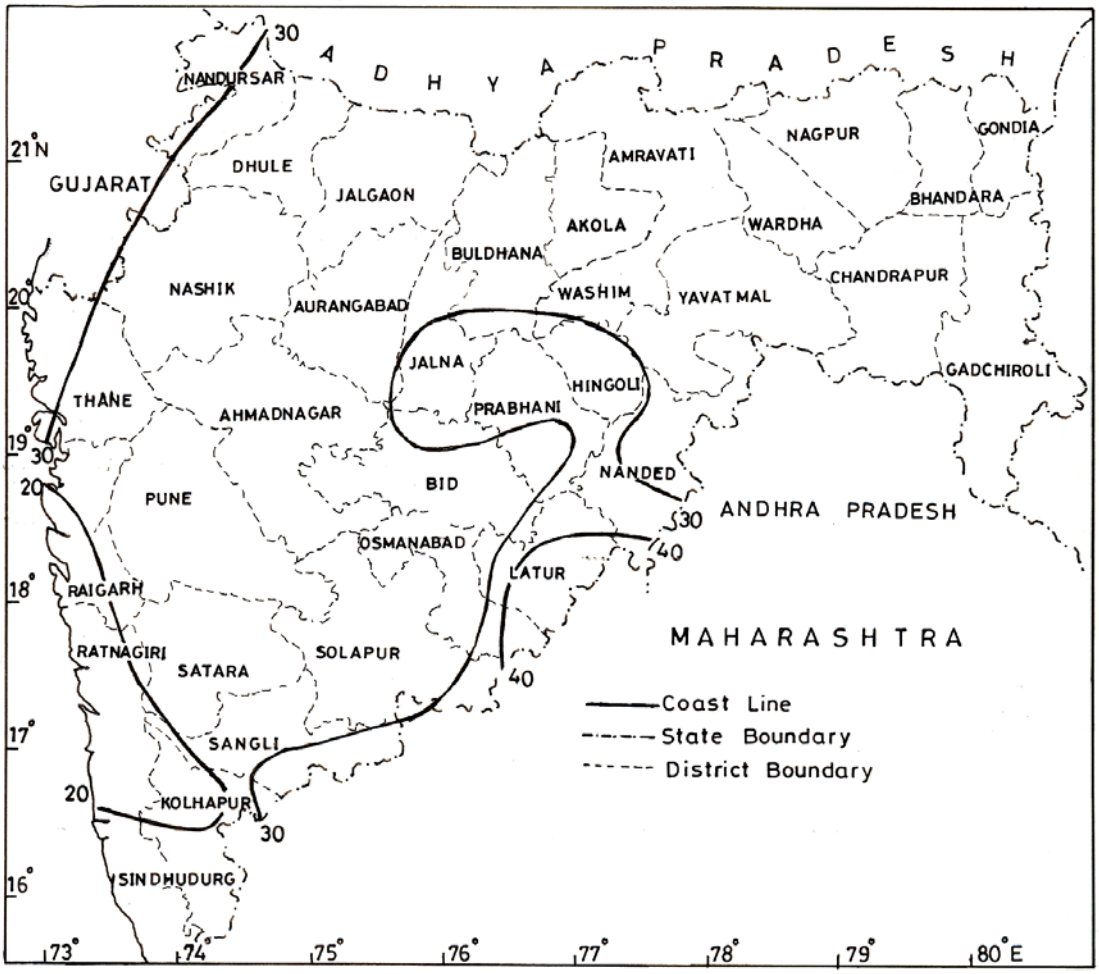

Fig. 6. Coefficient of rainfall variation – Southwest monsoon (June to September)

Sriwardhan on 26th June 1968 in Raigarh district. Another region in coastal parts is the region of Dapoli and Chiplun from Ratnagiri district shows extreme rainfall more than 500 mm. Extreme rainfall amount decreases further eastward. Beyond 74° E, extreme rainfall less than 300 mm is noticed in major parts, except some small regions in central parts and northeastern parts of the state. Central parts of the districts Buldhana, central and western parts of Akola, central parts of Washim, Hingoli and Parbhani have extreme rainfall of more than 300 mm. Near Parbhani extreme rainfall of about 400 mm is noticed. Beyond this central region of the state extreme rainfall further decreases in the district Amravati, western parts of Wardha, Yavatmal, Nanded etc. In central and southeastern parts of the state *viz*., major parts of Ahmadnagar, central and eastern-southeastern parts of Pune, eastern parts of Satara, eastern parts of Kolhapur, western and southern parts of Sangli, southeastern parts of Solapur, Osmanabad district have extreme rainfall less than 200 mm. Also, in central and eastern parts of Nandurbar, major parts of Dhule and adjoining small parts of Nashik, Aurangabad and Jalgaon have extreme rainfall less than 200 mm. In other parts of these districts, it is in the range of 200-300 mm. However, in northern parts of Sangli, extreme southeastern parts of Pune and western parts of Solapur extreme rainfall in the range 200-300 mm is noticed.

In northeastern parts of the state *viz*., central and southern parts of Nagpur, major parts of Bhandara and Gondia districts, central and eastern parts of Yavatmal, northern and eastern parts of Chandrapur, major parts of Gadchiroli extreme rainfall more than 300 mm is noticed. In few localized parts of Chandrapur, Gadchiroli, northern

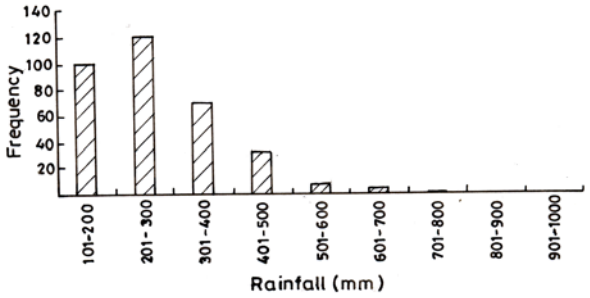

Fig. 7. Frequency distribution for amount of extreme rainfall

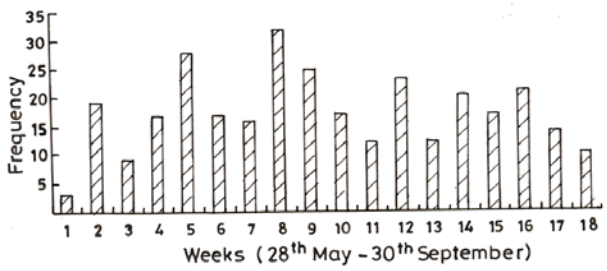

Fig. 8. Frequencies for extreme rainfall in different weeks during southwest monsoon season (28 May – 30 September)

parts of Amravati extreme rainfall of 400 mm is also noticed. Fig. 7 shows frequency distribution for amount of extreme rainfall.

In coastal parts and adjoining hilly areas, normal rainfall during monsoon season is about 2000-3000 mm. From coast to near foothills of Western Ghats rainfall increases to more than 3000 mm. In some localized areas *viz*., Matheran, Bhir, Lonawala, Mahabaleshwar rainfall more than 4000 mm is noticed, whereas in hilly areas like Mahabaleshwar in Satara district and Ganganbawda in Kolhapur district higher amount of rainfall at about 5500 mm is noticed. The amount of rainfall decreases towards east of Western Ghats where it is very much low in the central parts of the state and is of the order of 330 to 500 mm. It increases further eastwards about 1000 – 1500 mm in the northeastern parts of the state.

During the southwest monsoon season Coefficient of Variation (C.V.) is more than 30 % in the southeastern and extreme northwestern parts of the state. In extreme western parts it is less than 20 % and in other parts of the state, it ranges between 20 and 30 %.

Table 1 shows the districtwise frequency for heaviest rainfall (mm) for Maharashtra state. Most of frequency distribution is in the intervals 101-200 mm and 201 - 300 mm. The extreme rainfall more than 600 mm is noticed in Bhandara, Mumbai suburban, Mumbai and Raigarh districts.

Table 2 shows the temporal variation of extreme rainfall (mm) in Maharashtra. It is equally distributed in all the weeks of the southwest monsoon season. Fig. 8 shows histogram showing frequencies for extreme rainfall in different weeks during southwest monsoon season. It shows that extreme rainfall for different stations over the state may occur in any week during the southwest monsoon season. However, from the frequency table occurrence of the frequency of extreme rainfall for various districts and possible period may be identified. It would be worth in identifying these frequencies for districts Raigarh, Ratnagiri which are under tropical monsoon climate. Such type of districtwise frequency table is most useful in identifying possible period of extreme rainfall event for various districts in the state.

The areal coverage of Maharashtra state is large at a latitude 20° N. As such, it would be interesting to see longitudinal variation of extreme rainfall along a fix latitude 20° N. Fig. 3 shows longitudinal variation of extreme rainfall at 20° N. It shows that extreme rainfall is highest along longitude 73.5° E and suddenly drops down upto 74° E. It slowly increases later and oscillates in the range 200 to 300 mm upto 77.25° E. After 78.5° E, it is mostly around 300 mm.

It is noticed that at longitude 73° E, there is a large variation of extreme rainfall. This longitude runs along the coastal stations. Within the latitudes, 18° N to 19° N, extreme rainfall events of rainfall more than 600 mm have been occurred. The heaviest extreme rainfall was occurred recently on 26-27th July 2005 at Santacruz was 944.2 mm and that of 742 mm occurred at Sriwardhan on 26th June 1968 in Raigarh district. Beyond these latitudes extreme rainfall about 300-500 mm is noticed. At longitude 74° E the variation of extreme rainfall is not much and most of the events occurred within a limit of 200-300 mm.

During southwest monsoon season at longitude 73.75° E, it is seen in Fig. 5 that near latitude 16.5° N, a peak in rainfall more than 5000 mm is noticed at the station Gaganbawda in Kolhapur. It is a hilly station. Latitudinal variation at other latitudes along 73.75° E varies from 100 to 300 mm approximately. Variation of normal rainfall during southwest monsoon at longitude 73.5° E varies mostly in between 200-400 mm.

The study shows the important features as below :

(*i*) Spatial rainfall variability for extreme rainfall and normal rainfall in southwest monsoon season is large in western parts of the state.

(*ii*) The range of the extreme rainfall in Maharashtra state varies from 100 to 944 mm.

(*iii*) The range of the normal rainfall is from 330 mm in lowest rainfall region of central parts to 5470 mm in western parts of the state.

(*iv*) There is large variation of extreme rainfall along longitude 73° E.

(*v*) In grid 73° - 73.75° E and within latitudes 18° N to 19° N extreme rainfall events of more than 600 mm have been noticed.

(*vi*) The districts prone to very heavy extreme rainfall events are Raigarh and Mumbai.

(*vii*) The heaviest extreme rainfall of 944.2 mm was occurred at Santacruz in Mumbai district on 26-27th July 2005. The second heaviest extreme rainfall of 742 mm was occurred at Sriwardhan in Raigarh district on 26th June 1968.

(*viii*) The frequency distribution of extreme rainfall is mostly in the intervals 101-200 mm and 201-300 mm.

(*xi*) The temporal distribution of extreme rainfall events in different weeks of southwest monsoon is mostly equally distributed. It is highest in 16th - 22nd July.

(*x*) Examination of temporal distribution of extreme heavy rainfall shows that extreme rainfall in Maharashtra state may occur in any week of southwest monsoon in various parts.

(*xi*) Information on the probable period for extreme rainfall event for districts may be identified from tabular form and is useful for planning purpose.

4. The authors are thankful to Shri A. B. Dhule and Mrs. P. P. Bhagwat for assistance and Mrs. P. R. Iyer for typesetting.

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(*24 March 2006, Modified 22 December 2006*)