Observed Rainfall Variability and Changes over Maharashtra State
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Pulak Guhathakurta, Shirish Khedikar, Preetha Menon, Ashwini Kumar Prasad, S.T. Sable and S C Advani
**Abstract**

India is in the tropical monsoon zone and receives plenty of rainfall as most of the annual rainfall during the monsoon season every year. However, the rainfall is having high temporal and spatial variability and due to the impact of climate changes there are significant changes in the mean rainfall pattern and their variability as well as in the intensity and frequencies of extreme rainfall events. The report brings the result of the analysis based on the recent 30 years of data (1989-2018) on the mean spatial rainfall pattern as well as mean spatial pattern of different rainfall events, trends and variability as well as extreme rainfall events during the monsoon months and annual for the state.

**Key Words**

Rainfall trend, variability, extreme events, dry days
1. Introduction

Maharashtra is located in the north center of peninsular India; Maharashtra State is situated north of 14°N and south of 22°N. It is bounded by Arabian sea on its western side. The state of Gujarat lies north of it, while Madhya Pradesh and Chhattisgarh lie on the northern and eastern sides of Maharashtra respectively. On the southern side, it is bounded by Karnataka and Andhra Pradesh. The Western Ghats (Sahyadri) run north to south separating the coastal districts of Thane, Mumbai City, Mumbai Suburban, Raigad, Ratnagiri and Sindhudurg from the rest of Maharashtra. The average height of the range is about 1 km. West to east the region stretches across 800 kms. 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, while to the east of the Ghats rainfall drops to less than a tenth within a short distance from the Ghats. The state receives rainfall mainly during the southwest monsoon season (June to September). All the important rivers like Godavari, Bhima and Krishna which originate from the water sheds of the Ghats flow east across these drier regions and contribute to their economic benefit. The influence of the smaller and less cohesive east west oriented ranges of Satpura and Ajanta is not so marked.

There are four meteorological subdivisions, viz. Konkan, Madhya Maharashtra, Marathwada and Vidarbha in the state. The state consists of 36 districts as on 1st August 2014, viz. Mumbai City, Mumbai Suburban, Palghar, Raigad, Ratnagiri, Sindhudurg and Thane from Konkan; Ahmednagar, Dhule, Jalgaon, Kolhapur, Nandurbar, Nashik, Pune, Sangli, Satara and Solapur from Madhya Maharashtra; Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani from Marathwada; Akola, Amravati, Bhandara, Buldhana, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha, Washim and Yavatmal from Vidarbha.

Already there are many studies available on the observed trends and variability of rainfall and also extreme rainfall events, but all the studies are based on past 100 years or more data and also the recent years are not included (Guhathakurta et al, 2015; Guhathakurta & Saji, 2013; Guhathakurta et al, 2011; Guhathakurta & Rajeevan, 2008 etc). In the present report all the analysis of observed rainfall patterns, trends and variability have been done based on recent past 30 years (1989-2018) that will help to have idea of the recent changes for climate change adaptation and management by the state authorities.

2. Data and Methodology

Daily Rainfall data from 1989 to 2018 is considered for analysis of trend variability and mean rainfall patterns. From the daily rainfall data monthly rainfall series of each stations are computed and then monthly district rainfall series has been constructed by considering arithmetic average of all the station
rainfall values within the district. The monthly rainfall series of the state has been computed by using area weighted rainfall values of all the districts within the state. The objective of the analysis is to:

1. Identify the spatial pattern of the mean rainfall

2. Understand district wise observed rainfall trend and variability in annual and SW monsoon season (June, July, August and September).

Daily station rainfall data is utilized for identification of the mean spatial patterns and rainfall intensity trends. From mean and standard deviation (SD), the coefficient of variation (CV) is calculated as follows:

\[
\text{Coefficient of variation (CV)} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100
\]

The analysis has been done in two parts. For identification of the spatial pattern mean rainfall, variability and observed trends we have used district rainfall series and results have been brought out for four southwest monsoon months viz. June, July, August, September, for the southwest monsoon season and also for annual. Fig. 1 gives the location of the districts of the state. For identification of mean pattern and trends of intensities of various rainfall events we used the station daily rainfall data.

Fig. 1 Location of the districts of Maharashtra
3. State rainfall mean and variability and trend

Table 1 shows the mean rainfall (mm) and coefficient of variation of the state for the monsoon months, southwest monsoon season and annual during the period 1989-2018. The state gets highest rainfall (33%) of south west monsoon rainfall in July month while the August month get 28% of the south west monsoon rainfall. June and September receive 21% and 18% of south west monsoon rainfall. Also, more than 89% of annual rainfall receives during the southwest monsoon season only. The variability of monsoon or annual rainfall is also very less (14%).

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<tr>
<th></th>
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Table 1 Mean rainfall (mm) and coefficient of variation of the state for the monsoon months, southwest monsoon season and annual

Fig. 2 and 3 show the time series of rainfall in mm for the months of June, July, August, September and southwest monsoon season, annual respectively. The trend lines are also displayed for each of the series. Neither monthly rainfall nor seasonal or annual rainfall show any significant increasing/decreasing trend. In the monthly rainfall July and September rainfall show increasing trend while June and August rainfall show decreasing trend. Both seasonal and annual rainfall show decreasing trend. During the last 30 years highest rainfall of June and July received in the year 2013 (345.7 mm and 507.8 mm respectively) while highest rainfall of 469.0 in August received in the year 1990 and of 293.8 mm in September received in the year 2005. Highest annual rainfall of 1469.2 mm received in the year 1990 and highest southwest monsoon rainfall of 1285.7 mm received in the year 2006.
Fig. 2 Time series of rainfall in mm for the months of June, July, August, September and trends

Fig. 3 Time series of rainfall in mm for the southwest monsoon season and annual and trends
5. District rainfall mean, variability and trend

4.1 Mean and coefficient of variation

Table 2 gives the rainfall statistics for the districts of Maharashtra for the four monsoon months, southwest monsoon season and annual while Fig. 4-5 show the spatial pattern of these statistics. Three coastal districts viz. Sindhudurg, Ratnagiri and Raigad receive highest rainfall over other districts during all the months and season. Rainfall receives over these districts are around 700-900 mm in June, 1100-1200mm in July, 650-800mm in August, 350-450mm in September and during the SW monsoon and annual 3000-3500mm. Lowest rainfall receives during the SW monsoon season over Sangli district (454.2mm) while Ahmednagar district receives lowest annual rainfall (591.2).
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<th>SEPTEMBER</th>
<th>JJAS</th>
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Table 2. Rainfall statistics for the districts of Maharashtra for the four monsoon months, southwest monsoon season and annual
Fig. 4 Mean rainfall pattern over districts of Maharashtra for the monsoon months, southwest monsoon season and annual
Fig. 5 Coefficient of Variation (%) of rainfall over districts of Maharashtra for the monsoon months, southwest monsoon season and annual

4.2 Trend in district rainfall

Fig. 6 shows the trends in district rainfall for (a) June, (b) July (c) August (d) September (e) JJAS and (f) annual. June rainfall has shown significant decreasing trend in the district Jalna and
Parbhani while no district has shown any significant increasing trend. For the July month only, significant trend has been noticed in Palghar district (significant increasing trend). Yavatmal and Chandrapur districts of Vidarbha have shown significant decreasing trend in August rainfall while September rainfall of Sindhudurg district of Konkan region has shown significant increasing trend. During the whole southwest monsoon season only one district viz. Palghar has shown significant increasing trend. For the annual rainfall two districts viz., Aurangabad and Parbhani show significant decreasing trend while only district Palghar showed significant increasing trend.
6. Analysis of Average frequencies for rainfall events of different intensities

5.1 Average frequency of Rainy days

The average frequency of rainy days is calculated for Maharashtra for June, July, August, September, June to September and Annual. Figure 7 shows that in the month of June the maximum number of rainy days lies in the range of 13 to 15 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts. While minimum number of rainy days lies in the range of 6 to 8 days especially in some parts of Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar, Nandurbar, Akola, Amravati, Wardha, Buldana, Washim and Yavatmal districts. Whereas in remaining districts, the number of rainy days lies in the range of 8 to 13 days.

Figure 8 shows that in the month of July the maximum number of rainy days lies in the range of 20 to 22 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai, Palghar and Kolhapur districts. While minimum number of rainy days lies in the range of 7 to 11 days especially in some parts of Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded and Solapur districts. Whereas in remaining districts, the number of rainy days lies in the range of 11 to 20 days.
In the month of August, the maximum number of rainy days lies in the range of 19 to 21 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai, Palghar and Kolhapur districts (Figure 9). While minimum number of rainy days lies in the range of 7 to 11 days especially in some parts of Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Ahmednagar and Solapur districts. Whereas in remaining districts, the number of rainy days lies in the range of 11 to 19 days.

Figure 10 shows that in the month of September the maximum number of rainy days lies in the range of 19 to 21 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts. While minimum number of rainy days lies in the range of 7 to 11 days especially in some parts of Nashik, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Ahmednagar and Solapur districts. Whereas in remaining districts, the number of rainy days lies in the range of 11 to 19 days.

During June to September the maximum number of rainy days lies in the range of 62 to 70 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts (Figure 11). While minimum number of rainy days lies in the range of 28 to 37 days especially in some parts of Dhule, Ahmednagar, Nandurbar, Nashik, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Ahmednagar, Solapur, Akola, Buldana and Washim districts. Whereas in remaining districts, the number of rainy days lies in the range of 37 to 62 days.

Figure 12 shows that during the entire year the maximum number of rainy days lies in the range of 71 to 79 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts. While minimum number of rainy days lies in the range of 37 to 46 days especially in some parts of Sangli, Dhule, Ahmednagar, Nandurbar, Nashik, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Ahmednagar, Solapur, Akola, Buldana, Washim and Yavatmal districts. Whereas in remaining districts, the number of rainy days lies in the range of 46 to 71 days.
Fig. 7 Average frequency of rainy days: June
Fig. 8 Average frequency of rainy days: July

Fig. 9 Average frequency of rainy days: August
Fig. 10 Average frequency of rainy days: September

Fig. 11 Average frequency of rainy days: JJAS
Fig. 12 Average frequency of rainy days: Annual
5.2 Average frequency of Heavy rainfall days

The average frequency of Heavy rainfall days is calculated for Maharashtra for June, July, August, September, June to September and Annual. Figure 13 shows that in the month of June the maximum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts. While minimum number of Heavy rainfall days lies in the range of 0.2 to 0.7 days especially in some parts of Akola, Amravati, Wardha, Buldana, Washim, Yavatmal, Nashik, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar, Nandurbar, Bhandara, Gadchiroli, Chandrapur, Nagpur, Gondiya districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.7 to 2 days.

During the month of July the maximum number of heavy rainfall days lies in the range of 4 to 5 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts (Figure 14). While minimum number of Heavy rainfall days lies in the range of 0.3 to 1.2 days especially in some parts of Akola, Amravati, Wardha, Buldana, Washim, Yavatmal, Nashik, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar, Nandurbar, Bhandara, Gadchiroli and Nagpur districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1.2 to 4 days.

Figure 15 shows that in the month of August the maximum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban and Mumbai districts. While minimum number of Heavy rainfall days lies in the range of 0.2 to 1 days especially in some parts of Akola, Buldana, Washim, Yavatmal, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule and Ahmednagar districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1 to 2 days.

During September, the maximum number of heavy rainfall days lies in the range of 0.9 to 1.2 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban and Mumbai districts (Figure 16). While minimum number of Heavy rainfall days lies in the range of 0.2 to 0.4 days especially in some parts of Akola, Buldana, Washim, Yavatmal, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur and Jalgaon districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.4 to 0.9 days.
In the south west monsoon season the maximum number of heavy rainfall days lies in the range of 9 to 11 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts (Figure 17). While minimum number of Heavy rainfall days lies in the range of 1 to 3 days especially in some parts of Akola, Amravati, Wardha, Buldana, Washim, Yavatmal, Nashik, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar, Nandurbar, Gadchiroli, Chandrapur and Nagpur districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 3 to 9 days.

In annual scale the maximum number of heavy rainfall days lies in the range of 9 to 11 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Kolhapur districts (Figure 18). While minimum number of Heavy rainfall days lies in the range of 1 to 3 days especially in some parts of Akola, Amravati, Wardha, Buldana, Washim, Yavatmal, Nashik, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar, Nandurbar, Gadchiroli, Chandrapur and Nagpur districts. In remaining districts, the number of Heavy rainfall days lies in the range of 3 to 9 days.
5.3 Average frequency of Dry days

The average frequency of dry days is calculated for Maharashtra for June, July, August, September, June to September and Annual and their spatial patterns are shown in Fig. 20-24. In the month of June the maximum number of dry days lies in the range of 20 to 22 days especially in some parts of Akola, Amravati, Buldana, Washim, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar and Nandurbar districts. While minimum number of dry days lies in the range of 12 to 14 days especially in some parts of Sindhudurg, Ratnagiri and Raigarh districts. Whereas in remaining districts, the number of dry days lies in the range of 14 to 20 days.

In the month of July the maximum number of dry days lies in the range of 17 to 20
days especially in some parts of Beed, Osmanabad, Parbhani, Latur, Jalna, Hingoli, Aurangabad, Nanded and Solapur districts. While minimum number of dry days lies in the range of 5 to 8 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Palghar districts. Whereas in remaining districts, the number of dry days lies in the range of 8 to 17 days.

The maximum number of dry days lies in the range of 17 to 20 days especially in some parts of Ahmednagar, Beed, Osmanabad, Parbhani, Latur, Jalna, Nanded and Solapur districts in August. While minimum number of dry days lies in the range of 6 to 9 days especially in some parts of Thane, Mumbai Suburban, Mumbai and Palghar districts. Whereas in remaining districts, the number of dry days lies in the range of 9 to 17 days.

In the month of September, the maximum number of dry days lies in the range of 19 to 21 days especially in some parts of Akola, Amravati, Buldana, Washim, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Aurangabad, Nanded, Solapur, Jalgaon, Dhule, Ahmednagar and Nandurbar districts. While minimum number of dry days lies in the range of 13 to 15 days especially in some parts of Thane, Mumbai Suburban, Mumbai and Palghar districts. Whereas in remaining districts, the number of dry days lies in the range of 15 to 19 days.

Figure 23 shows that during June to September the maximum number of dry days lies in the range of 71 to 79 days especially in some parts of Akola, Buldana, Washim, Satara, Beed, Osmanabad, Parbhani, Latur, Jalna, Aurangabad, Nanded, Solapur, Jalgaon, Dhule and Ahmednagar districts. While minimum number of dry days lies in the range of 37 to 46 days especially in some parts of Sindhudurg, Thane, Ratnagiri, Mumbai Suburban, Mumbai and Palghar districts. Whereas in remaining districts, the number of dry days lies in the range of 46 to 71 days.

During the entire year the maximum number of dry days lies in the range of 290 to 300 days especially in some parts of Akola, Buldana, Washim, Wardha, Jalna and Aurangabad districts. While minimum number of dry days lies in the range of 246 to 257 days especially in some parts of Sindhudurg, Ratnagiri, Kolhapur and Raigarh districts. Whereas in remaining districts, the number of dry days lies in the range of 257 to 290 days.
Fig. 19 Average frequency of dry days: June
Fig. 20 Average frequency of dry days: July
Fig. 21 Average frequency of dry days: August
Fig. 22 Average frequency of dry days: September
Fig. 23 Average frequency of dry days: JJAS
Fig. 24 Average frequency of dry days: Annual
6 Trends in the frequencies of different rainfall events

6.1 Trend in frequency of Rainy days

The trend in frequency of rainy days is calculated for the raingauge stations of Maharashtra having minimum 20 years data during the 30 years period for June, July, August, September, June to September and Annual. Figure 25 shows that in the month of June there is a significant increase in Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Rainy days in stations in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

In the month of July there is a significant increase in Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts (Figure 26). Whereas there is a significant decrease in Rainy days in stations in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 27 depicts that in the month of August there is a significant increase in Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Rainy days in stations in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Significant increase in Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts has been seen in September (Figure 28). There is a significant decrease in Rainy days in stations in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 29 shows that in the month of June to September there is a significant increase in Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Rainy days in stations in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in Rainy days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts (Figure 30). Whereas there is a significant
decrease in Rainy days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Fig. 25 Trend in frequency of rainy days: June

Fig. 26 Trend in frequency of rainy days: July

Fig. 27 Trend in frequency of rainy days: August

Fig. 28 Trend in frequency of rainy days: September
6.2 Trend in frequency of Heavy rainfall days

The Trend in frequency of Heavy days is calculated for the raingauge stations of Maharashtra having minimum 20 years data during the 30 years period for June, July, August, September, June to September and Annual. Figure 25 shows that in the month of June there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Heavy days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

In the month of July there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts (Figure 31). Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 32 shows that in the month of August there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 33 depicts that in the month of September there is a significant increase in
Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. There is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 35 shows that during June to September there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts (Figure 36). Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.
6.3 Trend in frequency of Dry days

The Trend in frequency of dry days is calculated for the raingauge stations of Maharashtra having minimum 20 years data during the 30 years period for June, July, August, September, June to September and Annual. Figure 37 shows that in the month of June there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 38 shows that in the month of July there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a
significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

In Figure 39 we can see that in the month of August there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 40 depicts that in the month of September there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

During the entire season June to September there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts (Figure 41). Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

Figure 42 shows that during the entire year there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.
Fig. 37 Trend in frequency of dry days: June

Fig. 38 Trend in frequency of dry days: July

Fig. 39 Trend in frequency of dry days: August

Fig. 40 Trend in frequency of dry days: September

Fig. 41 Trend in frequency of dry days: JJAS

Fig. 42 Trend in frequency of dry days: Annual
7. Conclusions

In the present study we have investigated the rainfall pattern and its variability and also changes based on recent 30 years data. In the analysis we have considered monsoon months, the monsoon season and annual scale. The spatial scale has been considered from state to district for study of rainfall total and stations are being considered for seeing intensities of rainfall. The analysis brought many significant features of rainfall pattern and can be used for water agricultural managements. Some of the important results can be summarized as:

- Maharashtra gets maximum rainfall in July (33% of SW monsoon rainfall) followed by August (28% of SW monsoon rainfall).
- 89% of annual rainfall receives during southwest monsoon rainfall (June –September).
- Raigad and Ratnagiri districts of Konkan region receive 94-95% of annual rainfall in SW monsoon season while Sangli and Solapur districts receive 73-76% of annual rainfall in SW monsoon season.
- No significant increasing/decreasing trends in June, July, August, September monthly rainfall.
- Maximum rainfall receive during the SW monsoon season over the districts in Konkan region (2361mm -3322mm) while parts of Madhya Maharashtra and Marathwada receive lowest rainfall (454-600mm). Sangli district receives lowest rainfall of 454mm.
- Maximum rainfall receive during the year over the districts in Konkan region (2457mm -3538mm) while parts Ahmednagar receives lowest annual rainfall of 591mm.
- Significant increasing trend in SW monsoon rainfall has been noticed in Palghar district while no district show significant decreasing trend.
- In annual rainfall Palghar shows significant increasing trend while Aurangabad and Parbhani show significant decreasing trend.
- Konkan regions receive on an average 60-70 rainy days (daily rainfall >=2.5mm) out of 122 days of SW monsoon season while Vidarbha region gets 37-45 rainy days and central parts of Maharashtra get even less than 37 rainy days.
- For heavy to extremely heavy rainfall (daily rainfall >=6.5mm) Konkan region gets 8-11 days during the SW monsoon season, western parts of Madhya Maharashtra and extreme NE parts of the state get around 3-5 heavy to extremely heavy rainfall days.
- Number of dry days is maximum over central parts of the state (70-79 dry days out of 122 days during the SW monsoon season while on an average 289-300 dry days in 365 days have been noticed in many parts of northern districts of Maharashtra.
- During the period June to September there is a significant increase in the frequency of Rainy days in stations in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Rainy days in in stations Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts.
- During the entire year there is a significant increase in Rainy days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Rainy
days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts.

During the period June to September there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in Heavy rainfall days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in Heavy rainfall days in Pune, Solapur, Kolhapur, Ahmednagar, aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts.

During June to September there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts.

During the entire year there is a significant increase in dry days in Nandurbar, Jalgaon, Raigarh, Kolhapur and Bhandara districts. Whereas there is a significant decrease in dry days in Pune, Solapur, Kolhapur, Ahmednagar, Aurangabad, Jalna, Beed, Hingoli, Nanded, Yavatmal, Wardha districts.

Acknowledgement:

The authors acknowledge Secretary, MOES, DGM, India Meteorological Department and Head, Climate Research and Services for guidance, suggestions and encouragement to carry out the works. Acknowledge also to Hydrology section and National Data Centre for making availability of the data.

References:

The report brings out observed rainfall variability and trends over the state as an impact of climate change based on recent 30 years of data (1981-2018)

Rainfall pattern of monsoon months, south west monsoon season and annual of the state and it’s districts as well as extreme rainfall event of different intensity of stations are analysed.