Observed Rainfall Variability and Changes over Odisha State

Pulak Guhathakurta, Deepa Kulkarni, Shirish Khedikar, Preetha Menon, Ashwini Kumar Prasad, S T Sable and S C Advani
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/20(2020)/44

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INDIA METEOROLOGICAL DEPARTMENT
PUNE - 411005
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<td><strong>Abstract</strong></td>
<td>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.</td>
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1. Introduction

The state of Odisha lies in the northeastern part of the Indian Peninsula, roughly between latitudes 22°36'N and 17°49'N and longitudes 81°36' E and 87°18'E. The state has an area of 1,55,707 sq.km and consists of 30 districts. The state is bounded by the districts Ranchi, Singbhum (of Bihar) and Medinipur (of West Bengal), on the north; by the districts Raigarh, Raipur, Bastar (of Madhya Pradesh) on the west; by the districts Khammam, East Godavari, Vishakhapatnam, and Srikakulam (of Andhra Pradesh) on the south and by the Bay of Bengal, on the east. The climate of the state is characterized by hot summer and cold winter in the interior and climate of the coastal region near the Bay of Bengal is moist and equable.

The state may be broadly divided into 4 geographical regions, viz. the northern plateau, central river basins, eastern hills and coastal plains. The northern plateau region includes mainly Mayurbhanj, Keonjhar and Sundargarh districts. This is an undulating upland frequently intersected by hill ranges and sloping from north to south. The average elevation in central section of the plateau is 900 meters (m) above sea level. The central river basins lie between the northern plateau and eastern hills and include Balangir, Sonepur, Sambalpur, Deogarh, Bargarh, Jharsuguda, Dhenkanal and Angul districts, and a part of Cuttack district.

The eastern hills which constitute the last portion of the eastern Ghats, lie to the south and southwest of central river basins stretching for about 250 km in northeast- southwest direction through the districts of Koraput, Rayagada, Nawarangpur, Malkangiri, Kalahandi, Nuapada, Gajapati and a part of Ganjam district. The eastern hills are elevated and are generally 900 m above sea level. The coastal plains comprise mostly of Balasore, Bhadrak, Kendrapara, Jagatsinghpur, Jajpur, Puri, Khurda, Nayagarh and a portion of Ganjam and Cuttack districts.

Many studies are available on the observed trends and variability of rainfall and also extreme rainfall events over India, 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 et al., 2011; Guhathakurta & Rajeevan, 2008, Mohapatra and Mohanty, 2005 etc). Also limited studies available for the state. 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).
3. To identify the spatial pattern of intensities of various rainfall events and dry days and also trends if any in the intensity of various rainfall events and also number of dry days.

The analysis has been done in two parts. For identification of the spatial pattern, mean rainfall and 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 for annual. Fig. 1 gives the location of the districts of the state. For identification of mean pattern and also trends of intensities of various rainfall events we used the station daily rainfall data. From the mean and standard deviation, coefficient of variation (CV) is calculated as follows:

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

Fig. 1 Location of the districts of Odisha
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. It can be seen that the state gets highest rainfall (31%) of south west monsoon rainfall in August month while the July month get 30% of the south west monsoon rainfall. June and September receive 18% and 21% of south west monsoon rainfall respectively. Also 80% of annual rainfall receives during the southwest monsoon season only. The variability of monsoon and annual rainfall is also very less (15% and 14% respectively).

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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. Annual rainfall shows decreasing trend. But there is no trend for seasonal rainfall. During the last 30 years highest rainfall of June, July, August and September received in the year 2008, 2009, 2006 and 2007 respectively (344.1mm, 587.2mm, 626.3mm and 400.1mm respectively). Highest annual rainfall of 1905.2 mm received in the year 1990 and highest southwest monsoon rainfall of 1528.1 mm received in the year 1994.
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 trends
4. District rainfall mean, variability and trend

4.1 Mean and coefficient of variation

Table 2 gives the rainfall statistics for the districts of Odisha for the four monsoon months, southwest monsoon season and annual while Fig.4-5 show the spatial pattern of these statistics. It can be seen that the districts viz. Balasore, Mayurbhanj receive highest rainfall during June, districts viz. Sambalpur, Kalahandi and Malkangiri receive highest rainfall during July, while districts viz. Sambalpur, Kalahandi, Nowrangapur and Malkangiri receive during August and SW monsoon season. Balasore district receive highest rainfall in the month September as well as in a whole year. Rainfall receives over these districts are around 250-300 mm in June, 400-500 mm in July and August, 300-350 mm in September, 1300-1400 mm during the SW monsoon and annual 1600-1800 mm. Lowest rainfall receives during the SW monsoon season over Ganjam district (890.6 mm) while Nawapara district receives lowest annual rainfall (1140.6 mm).

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<td>1186.6</td>
<td>20.8</td>
<td>1365.6</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Table 2. Rainfall statistics for the districts of Odisha for the four monsoon months, southwest monsoon season and annual
Fig. 4 Mean rainfall pattern over districts of Odisha
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. It can be seen that rainfall has shown significant decreasing trend during June in the Dhenkanal district and during August in Dhenkanal, Jajpur and Nayagarh district, while no district has shown any significant increasing trend in these months. For the July month no district has shown any significant increasing/decreasing trend. September rainfall has shown significant increasing trend in Boudh and Malkangiri districts. During the whole southwest monsoon season only one district viz. Koraputha has shown significant increasing trend. Annual rainfall shows significant decreasing trend in Dhenkanal district.
5. 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 Odisha 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 10 to 11 days especially in some parts of Mayurbhanj, Balasore, Keonjhar, Kandhamal, Koraput and Nowrangapur districts. While minimum number of rainy days lies in the range of 7 to 8 days especially in some parts of Kendrapada, Jagatsingpur, Puri, Ganjam, Gajapati, Bargarh, Bolangir, Nawapara, Nowrangapur Kalahandi, Koraput and Malkangiri, districts. Whereas in remaining districts, the number of rainy days lies in the range of 8 to 10 days.
Figure 8 shows that in the month of July the maximum number of rainy days lies in the range of 15 to 16 days especially in some parts of Mayurbhanj, Sundargarh, Jharsuguda, Sambalpur, Deogarh, Sonapur, Kalahandi, Kandhamal, Koraput, Nowrangapur and Malkangiri districts. While minimum number of rainy days lies in the range of 12 to 13 days especially in some parts of Jagatsingpur, Puri, Ganjam, Gajapati, Koraput and Malkangiri districts. Whereas in remaining districts, the number of rainy days lies between the range of 13 to 15 days.

Figure 9 shows that in the month of August the maximum number of rainy days lies in the range of 15 to 17 days especially in some parts of Mayurbhanj, Sundargarh, Jharsuguda, Sambalpur, Deogarh, Kalahandi, Kandhamal, Koraput, Nowrangapur and Malkangiri districts. While minimum number of rainy days lies in the range of 12 to 13 days especially in some parts of Ganjam, Gajapati, Koraput and Malkangiri districts. Whereas in remaining districts, the number of rainy days lies in the range of 13 to 15 days.

Figure 10 shows that in the month of September the maximum number of rainy days lies in the range of 11 to 12 days especially in some parts of Mayurbhanj, Keonjhar, Balasore, Cuttack, Khurda, Kandhamal, Gajapati, Koraput, Nowrangapur and Malkangiri districts. While minimum number of rainy days lies in the range of 9 to 10 days especially in some parts of Ganjam, Malkangiri, Bargarh, Bolangir, Sonepur, Nawapara, Kalamandi and Nowrangapur and districts. Whereas in remaining districts, the number of rainy days lies in the range of 10 to 11 days.

Figure 11 shows that during June to September the maximum number of rainy days lies in the range of 50 to 52 days especially in some parts of Mayurbhanj, Balasore, Keonjhar, Sundargarh, Deogarh, Kandhamal, Kalamand, Nowrangapur, Koraput and Malkangiri districts. While minimum number of rainy days lies in the range of 41 to 43 days especially in some parts of Ganjam, Gajapati, Koraput, Nowrangapur, Nawapara, and Malkangiri districts. Whereas in remaining districts, the number of rainy days lies in the range of 43 to 50 days.

Figure 12 shows that during the entire year the maximum number of rainy days lies in the range of 66 to 70 days especially in some parts of Mayurbhanj, Balasore, Keonjhar,
Kandhamal, Gajapati, Koraput and Nowrangapur districts. While minimum number of rainy days lies in the range of 52 to 56 days especially in some parts of Sundargarh, Bargarh, Sonepur, Boudh, Bolangir, Nawapara, Kalahandi, Nowrangapur, Malkangiri and Ganjam districts. Whereas in remaining districts, the number of rainy days lies in the range of 56 to 66 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
5.2 Average frequency of Heavy rainfall days

The average frequency of Heavy rainfall days is calculated for Odisha 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 0.7 to 1 days especially in some parts of Mayurbhanj, Balasore, Keonjhar, Jajpur, Angul, Sambalpur, Bargarh, Kalahandi, Nowrangapur and Koraput districts. While minimum number of Heavy rainfall days lies in the range of 0.3 to 0.42 days especially in some parts of Jagatsingpur, Puri, Khurda, Nayagarh, Kandhamal, Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.42 to 0.73 days.

Figure 14 shows that in the month of July the maximum number of heavy rainfall days lies in the range of 1.25 to 2 days especially in some parts of Angul, Sambalpur, Bargarh, Sonepur, Bolangir, Kalahandi and Nowrangapur districts. While minimum number of heavy rainfall days lies in the range of 0.5 to 0.72 days especially in some parts of Mayurbhanj, Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.72 to 1.25 days.

Figure 15 shows that in the month of August the maximum number of heavy rainfall days lies in the range of 1.23 to 2 days especially in some parts of Kendrapada, Jagatsingpur, Puri, Angul, Sambalpur, Bargarh, Sonepur, Bolangir, Kandhamal, Kalahandi,
and Nowrangapur districts. While minimum number of heavy rainfall days lies in the range of 0.5 to .71 days especially in some parts of Mayurbhanj, Keonjhar, Angul, Dhenkanal, Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.71 to 1.23 days.

Figure 16 shows that during September the maximum number of heavy rainfall days lies in the range of 0.79 to 1 days especially in some parts of Balasore, Kendrapada, Jajpur, Sambalpur, Kandhamal, Kalahandi, and Nowrangapur districts. While minimum number of heavy rainfall days lies in the range of 0.3 to 0.49 days especially in some parts of Sundargarh, Angul, Nayagarh, Khurda, Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.49 to 0.79 days.

Figure 17 shows that during June to September the maximum number of heavy rainfall days lies in the range of 4 to 5 days especially in some parts of Kendrapada, Jajpur, Angul, Sambalpur, Bargarh, Sonepur, Bolangir, Kandhamal, Kalahandi, Koraput and Nowrangapur districts. While minimum number of heavy rainfall days lies in the range of 1 to 2 days especially in some parts of Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of heavy rainfall days lies in the range of 2 to 4 days.

Figure 18 shows that during the entire year the maximum number of heavy rainfall days lies in the range of 4 to 5 days especially in some parts of Balasore, Bhadrak, Kendrapada, Jajpur, Cuttack, Khurda, Puri, Sambalpur, Kandhamal, Kalahandi, and Nowrangapur districts. While minimum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of Sundargarh, Bolangir, Bargarh, Nawapara, Keonjhar, Angul, Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts. Whereas in remaining districts, the number of heavy rainfall days lies in the range of 3 to 4 days.
Fig. 13 Average frequency of heavy rainfall days: June

Fig. 14 Average frequency of rainy days: July

Fig. 15 Average frequency of rainy days: August

Fig. 16 Average frequency of rainy days: September

Fig. 17 Average frequency of rainy days: JJAS

Fig. 18 Average frequency of rainy days: Annual
5.3 Average frequency of Dry days

The average frequency of dry days is calculated for Odisha for June, July, August, September, June to September and Annual. Figure 19 shows that in the month of June the maximum number of dry days lies in the range of 20 to 21 days especially in some parts of Kendrapada, Jagatsingpur, Cuttack, Khurda, Nayagarh, Puri, Ganjam, Bargarh, Bolangir, Nawapara, Nowrangapur, Kalahandi and Malkangiri districts. While minimum number of dry days lies in the range of 17 to 18 days especially in some parts of Mayurbhanj, Keonjhar, Sundargarh, Sambalpur, Deogarh, Angul and Gajapati districts. Whereas in remaining districts, the number of dry days lies in the range of 18 to 20 days.

Figure 20 shows that in the month of July the maximum number of dry days lies in the range of 15 to 17 days especially in some parts of Kendrapada, Jagatsingpur, Cuttack, Khurda, Nayagarh, Puri, Ganjam, Gajapati, Koraput and Malkangiri districts. While minimum number of dry days lies in the range of 11 to 12 days especially in some parts of Mayurbhanj, Keonjhar, Sundargarh, Jharsuguda, Sambalpur, Deogarh, Angul, Nowrangapur, Kalahandi, Kandhamal and Koraput districts. Whereas in remaining districts, the number of dry days lies in the range of 12 to 15 days.

Figure 21 shows that in the month of August the maximum number of dry days lies in the range of 15 to 16 days especially in some parts of Kendrapada, Jagatsingpur, Puri, Ganjam, Gajapati, Koraput and Malkangiri districts. While minimum number of dry days lies in the range of 11 to 12 days especially in some parts of Mayurbhanj, Keonjhar, Sundargarh, Sambalpur, Deogarh, Angul, Nowrangapur, Kalahandi, Kandhamal, Koraput and Malkangiri districts. Whereas in remaining districts, the number of dry days lies in the range of 12 to 15 days.

Figure 22 shows that in the month of September the maximum number of dry days lies in the range of 18 to 19 days especially in some parts of Bargarh, Sonepur, Bolangir, Nawapara, Kalahandi, Nowrangapur and Malkangiri districts. While minimum number of dry days lies in the range of 15 to 16 days especially in some parts of Mayurbhanj, Balasore, Keonjhar, Sundargarh, Deogarh, Sambalpur, Angul, Kandhamal, Gajapati and Koraput districts. Whereas in remaining districts, the number of dry days lies in the range of 15 to 18 days.
Figure 23 shows that during June to September the maximum number of dry days lies in the range of 66 to 70 days especially in some parts of districts Jajpur, Kendrapada, Cuttack, Khurda, Jagatsingpur, Puri, Ganjam, Bargarh, Bolangir, Nawapara, Koraput and Malkangiri. While minimum number of dry days lies in the range of 54 to 57 days especially in some parts of Mayurbhanj, Balasore, Keonjhar, Sundargarh, Deogarh, Sambalpur, Angul, Kandhamal, Gajapati, Rayagada, Nowrangapur and Koraput districts. Whereas in remaining districts, the number of dry days lies in the range of 57 to 66 days.

Figure 24 shows that in the month of during the entire year the maximum number of dry days lies in the range of 273 to 280 days especially in some parts of Jajpur, Kendrapada, Cuttack, Khurda, Nayagarh, Jagatsingpur, Puri, Ganjam, Bargarh, Bolangir, Nawapara and Kalahandi districts. While minimum number of dry days lies in the range of 247 to 254 days especially in some parts of Mayurbhanj, Gajapati, Koraput and Malkangiri districts. Whereas in remaining districts the number of dry days lies in the range of 254 to 273 days.

Fig. 19 Average frequency of dry days: June

Fig. 20 Average frequency of dry days: July
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 Odisha 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 Mayurbhanj, Puri, Ganjam, Gajapati, Nowrangapur and Koraput districts. Whereas there is a significant decrease in Rainy days in stations in Jajpur, Sundargarh, Bargarh, Bolangir and Kalahandi districts. While remaining districts did not show any significant change.
Figure 26 shows that in the month of July there is a significant increase in Rainy days in stations in Balasore, Jajpur, Kendrapada, Cuttack, Puri, Angul, Sundargarh, Jharsuguda and Kandhamal districts. Whereas there is a significant decrease in Rainy days in stations in Koraput district. While remaining districts did not show any significant change.

Figure 27 shows that in the month of August there is a significant increase in Rainy days in stations in Sundargarh and Gajapati districts. Whereas there is a significant decrease in Rainy days in stations in Mayurbhanj, Balasore, Bhadrak, Jajpur, Dhenkanal, Angul, Khurda, Nayagarh, Sundargarh, Sonepur, Bargarh, Bolangir, Nowrangapur, Kalahandi, Kandhamal, Ganjam, Gajapati, Koraput and Malkangiri districts. While remaining districts did not show any significant change.

Figure 28 shows that in the month of September there is a significant increase in Rainy days in stations in Sambalpur, Bargarh, Nawapara, Bolangir, Angul, Nayagarh, Kendrapada, Puri, Ganjam, Gajapati, Rayagada, Kandhamal, Kalahandi, Koraput and Malkangiri districts. Whereas there is no significant decrease or any significant change in Rainy days in any station.

Figure 29 shows that in the month of June to September there is a significant increase in Rainy days in stations in Balasore, Kendrapada, Jajpur, Cuttack, Khurda, Puri, Ganjam, Gajapati, Sundargarh, Jharsuguda, Kandhamal, Kalahandi, Nowrangapur, Koraput and Malkangiri districts. Whereas there is a significant decrease in Rainy days in stations Mayurbhanj, Balasore, Cuttack, Dhenkanal, Sundargarh, Bargarh, Bolangir and Gajapati districts. While remaining districts did not show any significant change.

Figure 30 shows that in the month of during the entire year there is a significant increase in Rainy days in some parts of Mayurbhanj, Balasore, Kendrapada, Jajpur, Khurda, Puri, Gajapati, Sundargarh, Jharsuguda, Bargarh, Kalahandi, Nowrangapur, Koraput and Malkangiri districts. Whereas there is a significant decrease in Rainy days in some parts of Mayurbhanj, Balasore, Jajpur, Cuttack, Dhenkanal, Angul, Sundargarh, Bargarh, Bolangir, Kandhamal, Kalahandi, Ganjam and Gajapati 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

Fig. 29 Trend in frequency of rainy days: JJAS

Fig. 30 Trend in frequency of rainy days: Annual
6.2 Trend in frequency of Heavy rainfall days

The Trend in frequency of Heavy days is calculated for Odisha for June, July, August, September, June to September and Annual. Figure 31 shows that in the month of June there is a significant increase in Heavy rainfall days in Nabarangpur, Kalahandi, Gajapati and Koraput districts. Whereas there is a significant decrease in Heavy rainfall days in Sundargarh, Jharsuguda, Deogarh, Keonjhar, Mayurbhanj, Balasore, Dhenkanal, Angul, Nayagarh, Khordha, Puri, Kalahandi, Kandhamal and Ganjam districts. While remaining districts did not show any significant change.

Figure 32 shows that in the month of July there is a significant increase in Heavy rainfall days in Ganjam district. Whereas there is a significant decrease in Heavy rainfall days in Jharsuguda, Balangir, Kalahandi, Nabarangpur, Rayagada, Angul, Dhenkanal, Cuttack, Nayagarh, Khordha and Jagatsinghpur districts. While remaining districts did not show any significant change.

Figure 33 shows that in the month of August there is a significant increase in Heavy rainfall days in Sundargarh, Deogarh, Balasore, Nayagarh, Ganjam, Gajapati, Koraput and Malkangiri districts. Whereas there is a significant decrease in Heavy rainfall days in Bargarh, Balangir, Kandhamal, Kalahandi, Koraput, Mayurbhanj, Keonjhar, Balasore, Bhadrak, Jajpur, Angul, Cuttack, Nayagarh, Khordha and Puri districts. While remaining districts did not show any significant change.

Figure 34 shows that in the month of September there is a significant increase in Heavy rainfall days in Mayurbhanj, Jharsuguda, Sambalpur, Bargarh, Boudh, Balangir, Kalahandi, Rayagada and Koraput districts. Whereas there is a significant decrease in Heavy rainfall days in Mayurbhanj, Jajpur, Dhenkanal, Puri, Kandhamal and Koraput 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 Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Nabarangpur, Koraput, Malkangiri, Gajapati, Nayagarh, Jagatsinghpur, Balasore and Mayurbhanj districts. Whereas there is a significant decrease in Heavy rainfall days in Jharsuguda, Balangir, Kandhamal, Rayagada, Angul, Dhenkanal, Cuttack, Nayagarh, Puri, Jajpur, Balasore,
Mayurbhanj and Keonjhar districts. While remaining districts did not show any significant change.

Figure 36 shows that during the entire year there is a significant increase in Heavy rainfall days in Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Nabarangpur, Koraput, Malkangiri, Gajapati, Ganjam, Nayagarh, Balasore and Mayurbhanj districts. Whereas there is a significant decrease in Heavy rainfall days in Jharsuguda, Balangir, Kandhamal, Rayagada, Nayagarh, Puri, Khordha, Cuttack, Dhenkanal, Jajpur, Balasore, Mayurbhanj and Keonjhar 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 Odisha 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 Sundargarh, Mayurbhanj, Balasore, Jajpur, Jagatsinghpur, Khordha, Angul, Bargarh, Balangir and Kalahandi districts. Whereas there is a significant decrease in dry days in Nabarangpur, Koraput, Rayagada, Ganjam and Puri 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 Mayurbhanj, Balasore, Balangir, Nabarangpur, Kalahandi, Rayagada, Koraput and Gajapati districts. Whereas there is a significant decrease in dry days in Sundargarh, Jharsuguda, Deogarh, Angul, Kandhamal, Mayurbhanj, Balasore, Jajpur, Kendrapara, Cuttack, Jagatsinghpur, Khordha, Puri and Malkangiri districts. While remaining districts did not show any significant change.

Figure 39 shows that in the month of August there is a significant increase in dry days in Sundargarh, Keonjhar, Mayurbhanj, Balasore, Bhadrak, Jajpur, Kendrapara, Angul, Dhenkanal, Cuttack, Nayagarh, Khordha, Gajapati, Ganjam, Bargarh, Subarnapur (Sonepur), Boudh, Kandhamal, Nuapada, Balangir, Nabarangpur, Rayagada and Koraput districts. Whereas there is a significant decrease in dry days in Sundargarh, Puri and Koraput districts. While remaining districts did not show any significant change.
Figure 40 shows that in the month of September there is a significant increase in dry days in Sundargarh, Angul and Mayurbhanj districts. Whereas there is a significant decrease in dry days in Jharsuguda Deogarh, Angul, Cuttack Jagatsinghpur, Puri, Kandhamal, Ganjam, Bargarh, Nuapada, Subarnapur (Sonepur), Khordha, Kendrapara, Dhenkanal, Cuttack, Nayagarh, Khordha, Gajapati, Ganjam, Bargarh, Subarnapur (Sonepur), Khordha, Balangir, Kalahandi, Koraput. While remaining districts did not show any significant change.

Figure 41 shows that in the month of June to September there is a significant increase in dry days in Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Kandhamal, Nabarangpur, Koraput, Rayagada, Gajapati, Ganjam, Khordha, Nayagarh, Angul, Dhenkanal, Mayurbhanj, Balasore and Bhadrak districts. Whereas there is a significant decrease in dry days in Sundargarh, Jharsuguda, Deogarh, Angul, Kandhamal, Gajapati, Ganjam, Koraput, Rayagada, Puri, Cuttack, Kendrapara, Mayurbhanj and Balasore 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 all districts of Odisha. Whereas there is a significant decrease in dry days in Angul district.
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:

- Odisha gets maximum rainfall in August (31% of SW monsoon rainfall) followed by July (30% of SW monsoon rainfall).
- 80% of annual rainfall receives during southwest monsoon rainfall (June – September).
- Sonepur district receive 91% of annual rainfall in SW monsoon season while Gajapati district receive 65% of annual rainfall in SW monsoon season.
• No significant increasing/decreasing trends in June, July, August, September monthly rainfall.
• Kalahandi district receive maximum rainfall (1380.4mm) during the SW monsoon season while Ganjam district receives lowest rainfall of 890.6mm.
• Maximum rainfall receives during the year over Balasore district (1748.3mm) while Nawapara district receives lowest rainfall of 1140.6mm.
• Significant increasing trend in SW monsoon rainfall has been noticed in Koraput district while no district show significant decreasing trend.
• In annual rainfall Dhenkanal shows significant decreasing trend while no district show significant increasing trend.
• Some parts of Mayurbhanj, Balasore, Keonjhar, Sundargarh, Deogarh, Kandhamal, Kalahandi, Nowrangapur, Koraput and Malkangiri districts receive an average 50 to 52 rainy days (daily rainfall >=2.5mm) out of 122 days of SW monsoon season while some parts of Ganjam, Gajapati, Koraput, Nowrangapur, Nawapara, and Malkangiri districts gets 41 to 43 rainy days.
• For heavy to extremely heavy rainfall (daily rainfall>=6.5mm) some parts of Kendrapada, Jajpur, Angul Sambalpur, Bargarh, Sonepur, Bolangir, Kandhamal, Kalahandi, Koraput and Nowrangapur districts gets 4-5 days during the SW monsoon season and some parts of Ganjam, Gajapati, Rayagada, Koraput and Malkangiri districts get around 2-4 heavy to extremely heavy rainfall days.
• Number of dry days is maximum over some parts of districts Jajpur, Kendrapada, Cuttack, Khurda, Jagatsingpur, Puri, Ganjam, Bargarh, Bolangir, Nawapara, Koraput and Malkangiri (66-70 dry days out of 122 days during the SW monsoon season).
• During the period June to September there is a significant increase in the frequency of Rainy days in stations in Balasore, Kendrapada, Jajpur, Cuttack, Khurda, Puri, Ganjam, Gajapati, Sundargarh, Jharsuguda, Kandhamal, Kalahandi, Nowrangapur, Koraput and Malkangiri districts. Whereas there is a significant decrease in Rainy days in Mayurbhanj, Balasore, Cuttack, Dhenkanal, Sundargarh, Bargarh, Bolangir and Gajapati districts.
• During the entire year there is a significant increase in Rainy days in Mayurbhanj, Balasore, Kendrapada, Jajpur, Khurda, Puri, Gajapati, Sundargarh, Jharsuguda, Bargarh, Kalahandi, Nowrangapur, Koraput and Malkangiri districts. Whereas there is a significant decrease in Rainy days in Mayurbhanj, Balasore, Jajpur, Cuttack, Dhenkanal, Angul, Sundargarh, Bargarh, Bolangir, Kandhamal, Kalahandi, Ganjam and Gajapati districts.
• During the period June to September there is a significant increase in Heavy rainfall days in Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Nabaranapur, Koraput, Malkangiri, Gajapati, Nayagarh, Jagatsinghpur, Balasore and Mayurbhanj districts. Whereas there is a significant decrease in Heavy rainfall days in Jharsuguda, Balangir, Kandhamal, Rayagada, Angul, Dhenkanal, Cuttack, Nayagarh, Puri, Jajpur, Balasore, Mayurbhanj and Keonjhar districts. While remaining districts did not show any significant change.
During the entire year there is a significant increase in Heavy rainfall days in Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Nabarangpur, Koraput, Malkangiri, Gajapati, Ganjam, Nayagarh, Balasore and Mayurbhanj districts. Whereas there is a significant decrease in Heavy rainfall days in Jharsuguda, Balangir, Kandhamal, Rayagada, Nayagarh, Puri, Khordha, Cuttack, Dhenkanal, Jajpur, Balasore, Mayurbhanj and Keonjhar districts.

During June to September there is a significant increase in dry days in Sundargarh, Bargarh, Balangir, Boudh, Kalahandi, Kandhamal, Nabarangpur, Koraput, Rayagada, Gajapati, Ganjam, Khordha, Nayagarh, Angul, Dhenkanal, Mayurbhanj, Balasore and Bhadrak districts. Whereas there is a significant decrease in dry days in Sundargarh, Jharsuguda, Deogarh, Angul, Kandhamal, Gajapati, Ganjam, Koraput, Rayagada, Puri, Cuttack, Kendrapara, Mayurbhanj and Balasore districts.

During the entire year there is a significant increase in dry days in all districts of Odisha. Whereas there is a significant decrease in dry days in Angul district.

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.