Observed Rainfall Variability and Changes over Bihar State
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Pulak Guhathakurta, Sudeepkumar B L, Preetha Menon, Ashwini Kumar Prasad, Neha Sangwan 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.
1. Introduction

The state Bihar is in the eastern part of India.

It covers an area of 94,163 square kms bounded by 24°20'N to 27°31’N latitude and 83°20’E to 88°18’E longitude. It is an entirely land-locked state, having an average elevation of about 150 meters above mean sea level. The state shares its boundary with Nepal to the north, the states of West Bengal to the east, Jharkhand to the south and Uttar Pradesh to the west.

Topographically, Bihar state can be divided into three regions.
1. The Sub-Himalayan foot hills
2. The Indo Gangetic Plain
3. The Southern Plateau region

The Sub-Himalayan foot hills region lies in the northern part of the state. There are some small hills like Someshwar and the Dun hills, in the extreme north of West Champaran district. These hills are offshoots of the Himalayan system. South of it lies the Tarai region, a belt of marshy and sparsely populated region.

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 (Warwade et al, 2018; Guhathakurta et al, 2015; Guhathakurta et al, 2011; Guhathakurta & Rajeevan, 2008 etc) in the study. 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 Bihar
3. State rainfall mean, 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 (33% of south west monsoon rainfall) in July month while the August month gets 28% of the south west monsoon rainfall. June and September receive 17% and 21% of south west monsoon rainfall, respectively. More than 85% of annual rainfall receives during the southwest monsoon season only. The variability of monsoon and annual rainfall are also less, 19% and 18% for monsoon and annual, respectively.

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<tr>
<th></th>
<th>June</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. The southwest monsoon season rainfall shows a significant decreasing trend, but neither monthly rainfall nor annual rainfall show any significant increasing/decreasing trend. Although, a decreasing trend is observed in all the southwest monsoon months as well as both the seasonal and annual mean. During the last 30 years, the highest rainfall of June, July, August and September received in the year 2008 (291.8 mm), 2007 (548.9 mm), 1998 (377.1 mm) and 2016 (357.9 mm), respectively and the lowest rainfall of June, July, August and September received in the year 2009 (69.4 mm), 2013 (158.7 mm), 2016 (150.9 mm) and 1992 (86 mm), respectively. Highest southwest monsoon rainfall of 1349.3 mm and annual rainfall of 1516.8 mm received in the year 2007 and the lowest southwest monsoon rainfall of 539.5 mm and annual rainfall of 632.5 mm received in 2010.
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
4. District rainfall mean, variability and trend

4.1 Mean and coefficient of variation

Table 2 gives the rainfall statistics for the districts of Bihar for the four monsoon months, southwest monsoon season and annual. Fig.4-5 show the spatial pattern of these statistics. Three districts in the northeast viz. Kishanganj, Arariya and Purnia and one in the northwest viz. West Champaran receive highest rainfall over other districts during all the southwest monsoon months and the season. Rainfall received over these districts are around 150-350 mm in June, 350-600 mm in July, 300-450 mm in August, 200-400 mm in September, 1100-1700 mm during the southwest monsoon and 1300-2100 mm in annual. In general, districts over the southwest of Bihar received less rainfall during the southwest monsoon season (698-897 mm) as well as annual (780-1029 mm). The highest mean southwest monsoon rainfall (1694.1 mm) and annual rainfall (2023.2 mm) is observed over Kishanganj district and the lowest mean southwest monsoon rainfall (697.9 mm) and annual rainfall (780.1 mm) is observed over Arwal district.

The districts exhibiting maximum and minimum variability of mean rainfall are Buxar (92.4%) and Kishanganj (38.6 %) for June, Vaishali (70.9 %) and Katihar (35%) for July, Sheohar(64.9%) and Banka (26.5%) for August and Vaishali (74.6%) and Aurangabad (47.5%) for September. Vaishali (52.2%) and Bhagalpur (21.4%) show the maximum and minimum variability of rainfall during the southwest monsoon, respectively. While, Sheohar (55.3%) and Gopalganj (19.6%) show the maximum and minimum variability of annual rainfall, respectively.

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<th>JULY MEAN</th>
<th>JULY CV</th>
<th>AUGUST MEAN</th>
<th>AUGUST CV</th>
<th>SEPTEMBER MEAN</th>
<th>SEPTEMBER CV</th>
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</table>
Table 2. Rainfall statistics for the districts of Bihar for the four monsoon months, southwest monsoon season and annual
Fig. 4 Mean rainfall pattern over districts of Bihar for (a) June, (b) July (c) August, (d) September, (e) southwest monsoon season and (f) annual
Fig. 5 Coefficient of Variation (%) over districts of Bihar for (a) June, (b) July (c) August, (d) September, (e) southwest monsoon season and (f) annual
4.2 Trend in district rainfall

Fig. 6 shows the trends in district rainfall over Bihar. August rainfall has significant decreasing trend in the Bhojpur district and September rainfall has significant decreasing trend in the districts of Bhojpur, Purnia, Katihar and Nawada. June and July rainfall do not have any significant trend. Although, in June Arwal, Jahanabad, Lakhisarai, Sheikhpura, Madhepura and Banka districts have increasing trend whereas all other districts have a decreasing trend. But these trends are not significant. In July West Champaran, Darbhanga, Bhabua, Aurangabad, Sheikhpura, Lakhisarai, Munger and Banka districts have an increasing trend (not significant) whereas all other districts have decreasing trend (not significant). In August Kishanganj, Araria, Darbhanga, Samastipur, West Champaran, Arwal, Lakhisarai, Nawada districts have increasing trend whereas all other districts except Bhojpur, there is a decreasing trend. These trends are also not significant. The district rainfall in September has increasing trend in Arwal and Jahanabad and decreasing trend in all other districts (except Bhojpur, Purnia, Katihar and Nawada) which are not significant. In the southwest monsoon season, nine districts namely Katihar, Purnia, Madhepura, Saharsa, Khagaria, Begusarai, Bhojpur, Siwan and Gopalganj has a significant decreasing trend. While, Lakhisarai and West Champaran show an increasing trend and all other districts show a decreasing trend during the season, which are not significant. The annual rainfall shows a significant decrease in Katihar, Purnia, Siwan, Gopalganj, Bhojpur and Sitamarhi districts. It shows an increasing trend in Lakhisarai and West Champaran and decreasing trend in all other districts, but the trends are not significant.
Fig. 6 Trends in district rainfall for (a) June, (b) July (c) August (d) September (e) southwest monsoon and (f) annual
5. Analysis of Average frequencies for rainfall events of different intensities

5.1 Average frequency of Rainy days

The average frequency of rainy days in Bihar is calculated for June, July, August, September, southwest monsoon season and Annual and is depicted in Figure 7. In June, maximum number of rainy days lies in the range of 10-11 days in Kishanganj and in some parts of Sapaul, Arariya, Purnia, Katihar and Bhagalpur located in the northeast of Bihar, and the frequency of rainy days decreases towards the southwest districts. Minimum number of rainy days lies in the range of 5-6 days in most parts of Gopalganj, Siwan, Saran, Patna, Nalanda, Gaya, Jahanabad, Arwal, Bhojpur, Aurangabad, Rohtas, Buxar and Kaimur. The remaining parts of the state has number of rainy days in the range 6-10 days.

In July, the maximum number of rainy days lies in the range of 14-16 days in Kishanganj, Arariya and Purnia and in some parts of West Champaran and Bhagalpur. Minimum number of rainy days in July is observed in the range of 10-12 days in most parts of Sitamarhi, Madhubani, Sheohar, Gopalganj, Siwan, Bhojpur, Buxar and Kaimur. The rest parts of the state it is in the range of 12-14 days. In general, the frequency of rainy days decreases from east to west in July except in the north parts of Bihar where the number of rainy days increases towards both east and west. In August, maximum number of rainy days lies in the range of 13-14 days in Kishanganj and in some parts of Arariya, Purnia, Bhagalpur, Banga, Jamui, Kaimur, Gaya and West Champaran. Minimum number of rainy days in August is in the range of 10-11 days in most parts of Muzaffarpur, Sheohar, Sitamarhi and Madhubani, while the remaining parts of the state has number of rainy days in the rangeof 11-13 days.

In September, maximum number of rainy days is in the range of 10-11 days in Kishanganj and in some parts of Arariya, Purnia, Katihar, Bhagalpur, Banka, Jamui, Madhepura and Gagaria. The extreme northwest parts of West Champaran also has the maximum number of rainy days. Minimum number of rainy days lies in the range of 7-8 days in most parts of West Champaran, East Champaran, Sheohar, Muzaffarpur and Sitamarhi. The remaining parts of the state has number of rainy days in the range of 8-10 days.

During southwest monsoon, the frequency of rainy days is more in the eastern districts and it decreases towards the western districts. The maximum number of rainy days lies in the range of 44-48 days in Kishanganj and some parts of Arariya, Purnia, Katihar, Bhagalpur and West Champaran. Minimum number of rainy days lies in the range of 30-34 days in most parts of Madhubani, Sitamarhi, Sheohar, Muzaffarpur, Kaimur, Buxar, Bhojpur, Arwal, Saran and Siwan. Remaining parts of the state has number of rainy days in the range 34-44 days.

In the annual scale the maximum frequency of rainy days lies in the range of 55-61 days in Kishanganj and some parts of Arariya, Purnia, Katihar, Bhagalpur and West Champaran, minimum frequency lies in the range of 36-41 days in most parts of Madhubani, Sheohar, Muzaffarpur, Kaimur,
Buxar, Bhojpur, Arwal, Saran and Siwan, and the remaining parts of the state has the frequency of 41-55 days.

Fig. 7 Average frequency of rainy days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) Annual
5.2 **Average frequency of Heavy rainfall days**

The average frequency of Heavy rainfall days in Bihar is calculated for June, July, August, September, June to September and Annual (Figure 8). In June, the maximum frequency of heavy rainfall days lies in the range 0.7-1 day in Kishanganj, in some parts of Araria, Purnia and in isolated places of Katihar, Bhagalpur, West Champaran and Sitamarhi, while the minimum frequency of heavy rainfall days lies in the range 0.2-0.4 days in most parts of Siwan, Buxar, Kaimur, Jahanabad, Nalanda, Sheikhpura, Nawada and Jamui. The remaining frequency lies in the range of 0.4-0.7 days. In July the maximum frequency lies in the range of 1.6-2 days in most parts of Kishanganj, in some parts of Araria and in isolated parts of Purnia, Bhagalpur, West Champaran and Sitamarhi, while the minimum frequency lies in the range of 0.6-0.9 days in most parts of Siwan, Saran, Patna, Nalanda, Sheikhpura, Nawada, Gaya, Jahanabad, Arwal, Bhojpur, Aurangabad Buxar, Rohtas and Kaimur. The remaining parts of the state has a frequency in the range of 0.9-1.6 days. In the month of August, the maximum frequency of heavy rainfall days lies in the range 1.18-2 days in Kishanganj, and in isolated parts of Purnia, Bhagalpur, West Champaran and Sitamarhi, whereas minimum frequency lies in the range of 0.5-0.7 days in most parts of Arwal, Jahanabad, Gaya, Nalanda, Nawada and Sheikhpura. The remaining parts of the state has a frequency in the range of 0.7-1.18 days. In September, the maximum frequency lies in the range of 1-2 days in Kishanganj, in some parts of Araria and Purnia, Katihar and in isolated parts of Bhagalpur, Jamui and West Champaran, while the minimum frequency lies in the range of 0.3-0.5 days in most parts of Saran, Siwan, Vaishali, Patna, Nalanda, Nawada, Arwal, Aurangabad, Rohtas and Buxar. The remaining parts of the state has a frequency range of 0.5-1 days. In general, the frequency of heavy rainfall days decreases from the foot hills of Himalayas (north) to plateau regions(south) in Bihar.

During southwest monsoon, the maximum frequency of heavy rainfall days is in the range of 4.3-5 days in Kishanganj and in some parts of Purnina, Bhagalpur and West Champaran, while the minimum frequency is in the range of 1-2.4 days in Siwan, Saran, Vaishali, Patna, Nalanda, Nawada, Sheikhpura, Gaya, Jahanabad, Arwal, Bhojpur, Buxar, Rohtas and Kaimur districts. The remaining parts of the state has frequency in the range of 2.4-4.3 days. The spatial distribution of annual frequency of heavy rainfall is like that of southwest monsoon with maximum frequency in the range of 4.8-6 days and minimum in the range of 1-2.6 days.
Fig. 8 Average frequency of heavy rainfall days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) Annual
5.3 Average frequency of Dry days

The average frequency of dry days of Bihar is calculated for June, July, August, September, southwest monsoon season and Annual as indicated in Figure 9. A maximum of 22-24 dry days in June is observed in the districts of Gopalganj, Siwan, Saran, Vaishali, Patna, Nalanda, Nawada, Gaya, Aurangabad, Rohtas, Kaimur, Buxar, Bhojpur, Arwal and Jahanabad. Minimum number of dry days of the month is in the range of 17-19 days and is observed in the districts of Kishanganj, Arariya and Purnia. The remaining parts of the state has 19-22 dry days. In July, the maximum number of dry days are less and in the range of 17-19 days mainly in Gopalganj, Siwan, Saran, Sheohar, Madhubani, Bhojpur and Buxar districts. The minimum number of dry days are also less, in the range of 12-14 days and mainly distributed in the districts of Kishanganj, Arariya, Purnia, Katihar and Bhagalpur. The remaining parts of the state has number of dry days in the range of 14-17 days. In the month of August, the maximum number of dry days are in the range of 18-20 days and mainly in the districts of Sitamarhi, Madhubani, Sheohar, East Champaran, Gopalganj, Siwan, Saran, Muzzafarpur and Vaishali. While, the minimum number of dry days are in the range of 14-16 days in the districts of Kishanganj, Arariya, Purniya, Supaul, Katihar and Bhagalpur. The rest of the districts in the state has dry days in the range of 16-18 days. In September, the maximum dry days are in the range of 20-22 days and mainly seen in the districts of Sitamarhi, Madhubani, Sheohar, East Champaran, West Champaran, Gopalganj, Siwan, Saran, Muzzafarpur, Buxar, Bhojpur, Patna, Kaimur, Rohtas, Aurangabad and Vaishali. While, minimum number of dry days are in the range of 17-18 days in the districts of Kishanganj, Arariya, Purniya, Supaul, Katihar and Bhagalpur. The remaining parts of the state has number of dry days in between 18-20 days. In general, the number of dry days increases from east to west in Bihar.

The maximum number of dry days during the southwest monsoon season is in the range of 72-76 days mainly in the districts of Gopalganj, Siwan, Saran, West Champaran, East Champaran, Muzaffarpur, Sheopar, Madhubani, Sitamarhi, Buxar, Bhojpur, Patna, Jahanabad, Nalanda, Kaimur, Rohtas, Aurangabad and Gaya. While, minimum number of dry days are in the range of 57-61 days in the districts of Kishanganj, Arariya, Purniya, Supaul, Katihar and Bhagalpur. The remaining parts of the states has number of dry days in the range 61-72 days. During the entire year, the maximum number of dry days is in the range of 280-289 days mainly in the districts of Gopalganj, Sivan, Saran, Bhojpur, Patna, Arwal, Jahanabad, Nawada and Aurangabad. While, minimum number of dry days is in the range of 247-255 days and mainly in the districts of Kishanganj, Arariya, Purniya, Supaul and Katihar. The remaining part of the state has number of dry days in the range of 255-280 days. In general, the number of dry days decreases from west to east which is more prominent in central and southern parts of Bihar.
Fig. 9 Average frequency of dry days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) 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 rain gauge stations of Bihar having minimum 20 years data during the 30 years period for June, July, August, September, southwest monsoon and Annual and depicted in Figure 10. In June, there is a significant decrease in the number of rainy days in stations in Siwan, Madhubani, Saharsa, Begusarai, Nalanda, Lakhisarai, Sheikhpura, Jamui, Nawada, Gaya, Aurangabad, Rohtas, Purnia, Katihar, and Bhagalpur while there is a significant increase in the number of rainy days in stations in the districts of Madhubani and Jamui. Remaining districts do not show any significant trend. In the month of July, there is a significant decrease in the number of rainy days in stations in Sitamarhi, Madhubani, Drabhanga, Patna, Begusarai, Rohtas, Jamui, Purnia, Katihar, and Bhagalpur while there is a significant increase in the number of rainy days in stations in the districts of Madhubani and Jamui. Remaining districts do not show any significant trend. In August, a significant decrease in the number of rainy days in stations in the districts of West Champaran, Madhubani, Supaul, Saharsa, Ghagaria, Munger, Bhagalpur, Lakhisarai, Jamui, Nawada, Gaya, Aurangabad, Rohtas, Buxar, Patna, Begusarai, Samastipur, Vaishali, Muzaffarpur, Saran, and Gopalganj and a significant increase in the number of rainy days in stations in the districts of Patna, Nalanda, and Katihar. Remaining districts do not show any significant trend. In September, a significant decrease in the number of rainy days in the stations of Gopalganj, Siwan, Saran, Muzaffarpur, Vaishali, Samastipur, Begusarai, Ghagaria, Bhagalpur, Lakhisarai, Munger, Banka, Jamui, Nawada, Gaya, Aurangabad, Rohtas, Bhabua, Bhojpur, Jahanabad, Madhubani, Supaul, Arariya, Purnia, and Katihar and there is a significant increase in the number of rainy days in stations in Madhubani and Drabhanga districts for September.

In the southwest monsoon season, there is a significant decreasing trend for the number of rainy days in stations in Banka, Begusarai, Bhabua, Bhagalpur, Buxar, West Champaran, Darbhanga, Gaya, Jamui, Katihar, Khagaria, Kishanganj, Lakhisarai, Madhubani, Munger, Muzaffarpur, Nawadah, Patna, Purnea, Rohtas, Samastipur, Saran, Sitamarhi, Siwan, Supaul, Vaishali, and Arwal districts and a significant increase in the stations in East Champaran, Madhubani, Muzaffarpur, Supaul, Arariya, Katihar, and Gaya. While remaining districts do not have a significant trend. In the entire year, a significant decreasing trend in the number of rainy days is seen over stations in all the districts except East Champaran, Gopalganj, Saharsa, Madhepura, Bhojpur, Arwal, and Jahanabad and a significant increasing trend is observed in stations in the districts of East Champaran, Madhubani, Muzaffarpur, Supaul, Arariya, Katihar, Gaya, Patna, and Bhabua. In general, many stations show a significant decreasing trend in the number of rainy days.
during the monsoon months as well as in the Annual.

Fig. 10 Trend in frequency of rainy days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) Annual
6.2 Trend in frequency of Heavy rainfall days

The Trend in frequency of Heavy rainfall days is calculated for the rain gauge stations of Bihar having minimum 20 years data during the 30 years period for June, July, August, September, southwest monsoon season and Annual and depicted in Figure 11. In June, there is a significant decrease in heavy rainfall days in Siwan, East Champaran, Madhubani, Supaul, Arariya, Kishanganj, Samastipur, Munger, Bhabua and Aurangabad districts and a significant increase in heavy rainfall days in West Champaran, Muzaffarpur, Bhabua, Rohtas, Aurangabad, Jahanabad, Nawada, Sheikhpura and Jamui. Remaining districts do not have a significant trend. In July, there is a significant decrease in the number of heavy rainfall days in Sitamarhi, Madhubani, Supaul, Arariya, Muzaffarpur, Madhepura, Katihar, Bhagalpur, Jamui, Nawada, Gaya, Buxar, Bhojpur, Patna, Nalanda, Vaishali, Saran, Samastipur, Begusarai, Khagaria and Lakhisarai districts and a significant increase in the number of heavy rainfall days in Bhabua, Aurangabad, Gaya, Jamui, Sheikhpura, East Champaran and Muzaffarpur districts. The remaining districts have no trend in the number of heavy rainfall days. In the month of August, a significant decrease is observed in Madhubani, Katihar, Bhagalpur, Jamui, Gaya, Aurangabad, Rohtas, Bhabua, Buxar, Bhojpur, Patna, Arwal, Siwan and Muzaffarpur districts and a significant increase is observed in West Champaran, Arariya, Drabanga, Jamui and Nawada districts. Remaining districts do not show any trend. In September, a significant decrease in Arariya, Purnia, Katihar, Banka, Nawada, Gaya, Rohtas, Bhabua, Buxar, Bhojpur, Nalanda, Patna, Samastipur, Vaishali, Gopalganj, Siwan and West Champaran districts and a significant increase is seen in Siwan, Patna and Banka districts is seen. Remaining districts do not show any trend.

In the southwest monsoon, there is a significant decrease in the number of heavy rainfall days in Sitamarhi, Madhubani, Supaul, Arariya, Kishanganj, Purnia, Madhepura, Katihar, Banka, Jamui, Gaya, Aurangabad, Rohtas, Buxar, Bhojpur, Patna, Nalanda, Begusarai, Khagaria, Gopalganj, Siwan, Saran and Vaishali districts and a significant increase in the number of heavy rainfall days is seen in East Champaran, Gopalganj, Gaya, Sheikhpura, Jamui, Khagaria and Bhagalpur districts. The remaining districts do not show any significant trend. In the annual scale, significant decrease is seen in Sitamarhi, Madhubani, Supaul, Arariya, Kishanganj, Purnia, Katihar, Madhepura, Jamui, Gaya, Aurangabad, Rohtas, Buxar, Bhojpur, Patna, Nalanda, Begusarai, Khagaria, Gopalganj, Siwan, Saran and Vaishali districts and a significant increase is seen in West Champaran, East Champaran, Gopalganj, Madhubani, Gaya, Jamui, Sheikhpura, Bhagalpur, Banka and Ghagaria districts. Remaining districts do not show any trend. In general, it is noted that a significant decrease is seen in most of the districts of Bihar in the southwest monsoon season, thus leading to the significant decrease of the same in the annual scale as well.
Fig. 11 Trend in frequency of heavy rainfall days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) Annual
6.3 Trend in frequency of Dry days

The Trend in frequency of dry days is calculated for the rain gauge stations of Bihar having minimum 20 years data during the 30 years period for Bihar for June, July, August, September, June to September and Annual and is given in Figure 12. It shows that there is a significant increase in the number of dry days in West Champaran, East Champaran, Madhubani, Kishanganj, Purnia, Bhagalpur, Banka, Jamui, Nawada, Gaya, Nalanda, Patna, Begusara and Munger districts and there is a significant decrease in the number of dry days in Purnia, Madhubani and Muzaffarpur districts. Remaining districts do not show any significant trend. In July, an increasing trend is observed in Gopalganj, Sitamarhi, Madhubani, Muzaffarpur, Drabhanga, Supaul, Kishanganj, Vaishali, Bhojpur, Patna, Begusarai, Lakhisarai, Jamui and Bhagalpur districts and a significant decreasing trend is observed in East Champaran, Siwan, Madhepura, Bhabua, Gaya and Sheikhpura districts. Remaining districts do not have any significant trend. In the month of August, a significant increase in the number of dry days is seen in all districts except East Champaran, Sheohar, Madhepura, Katihar, Gaya, Bhabua, Jahanabad, Nalanda, Sheikhpura and Saran districts and a significant decrease in the number of dry days is seen in Drabhanga, Patna, Sheikhpura, Bhabua, Aurangabad, Nawada and Katihar districts. Remaining districts do not have any significant trend. In September, there is a significant increasing trend in the number of dry days in all districts except Sheohar, Saharsa, Madhepura, Lakhisarai, Sheikhpura, Jahanabad and Rohtas and there is a significant decreasing trend in East Champaran, Madhubani, Drabahnga and Banka districts.

In the southwest monsoon season, a significant increase in the number of dry days in all the districts of Bihar except Sheohar, Saharsa, Madhepura, Lakhisarai, Sheikhpura, Jahanabad, Arwal, Buxar, Bhojpur and Bhabua districts and a significant decrease in the number of dry days in Siwan, Purnia and Nawada districts is seen. In the annual scale, a significant increase in the number of dry days in East Champaran, West Champaran, Madhubani, Supaul, Arariya, Katihar, Bhagalpur, Banka, Jamui, Nawada, Gaya Bhabua, Rohtas, Buxar, Patna, Jahanabad, Siwan, Muzaffarpur, Begusarai, Khagaria, Lakhisaraidistricts and a significant decrease in the number of dry days in Siwan, Nalanda, Begusarai, Jamui, Katihar and Bhagalpur districts are seen. Remaining districts do not have any significant trend. In general, a significant increase in the number of dry days is seen over may districts of Bihar during the entire study period.
Fig. 12 Trend in frequency of dry days for (a) June, (b) July, (c) August, (d) September, (e) southwest monsoon season and (f) 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 southwest monsoon season and annual scale. The spatial scale has been considered from state to district for the study of mean rainfall, and stations are considered for the study of 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:

- Bihar gets more than 85% of its annual rainfall in the southwest monsoon season.
- The highest rainfall (33% of south west monsoon rainfall) is received in July month followed by August (28% of the south west monsoon rainfall).
- The southwest monsoon season rainfall shows a significant decreasing trend, whereas monthly rainfall and annual rainfall do not show any significant increasing/decreasing trend.
- The highest mean southwest monsoon rainfall (1694.1 mm) is observed over Kishanganj district and the lowest mean southwest monsoon rainfall (697.9 mm) is observed over Arwal district.
- Three districts in the northeast viz. Kishanganj, Arariya and Purnia and one in the northwest viz. West Champaran receive higher rainfall over other districts during the southwest monsoon season.
- Districts over the southwest of Bihar received less rainfall during the southwest monsoon season (698-897 mm).
- There is a significant decrease in the southwest monsoon rainfall in Katihar, Purnia, Madhepura, Saharsa, Khagaria, Begusarai, Bhojpur, Siwan and Gopalganj districts.
- The annual rainfall has a significant decreasing trend in Katihar, Purnia, Siwan, Gopalganj, Bhojpur and Sitamarhi districts.
- In the southwest monsoon season, maximum number of rainy days (~ 44-48 days) is observed in Kishanganj and some parts of Arariya, Purnia, Katihar, Bhagalpur and West Champaran and minimum number of rainy days (~ 30-34 days) is observed in most parts of Madhubani, Sitamarhi, Sheohar, Muzaffarpur, Kaimur, Buxar, Bhojpur, Arwal, Saran and Siwan districts.
- The annual average frequency of rainy days is maximum (~ 55-61 days) in Kishanganj and some parts of Arariya, Purnia, Katihar, Bhagalpur and West Champaran and minimum (~ 36-41 days) in most parts of Madhubani, Sheohar, Muzaffarpur, Kaimur, Buxar, Bhojpur, Arwal, Saran and Siwan districts.
- In the southwest monsoon, the maximum frequency of heavy rainfall days (~ 4.3-5 days) is in Kishanganj and in some parts of Purnina, Bhagalpur and West Champaran, while the minimum
frequency (~1-2.4 days) is in Siwan, Saran, Vaishali, Patna, Nalanda, Nawada, Sheikhpura, Gaya, Jahanabad, Arwal, Bhojpur, Buxar, Rohtas and Kaimur districts.

The maximum number of dry days during the southwest monsoon season is (~72-76 days) is observed mainly in the districts of Gopalganj, Siwan, Saran, West Champaran, East Champaran, Muzaffarpur, Sheopar, Madhubani, Sitamarhi, Buxar, Bhojpur, Patna, Jahanabad, Nalanda, Kaimur, Rohtas, Aurangabad and Gaya, and minimum number of dry days (~57-61 days) are observed in the districts of Kishanganj, Arariya, Purniya, Supaul, Katihar and Bhagalpur.

In annual scale, the maximum number of dry days (~280-289 days) is observed mainly in the districts of Gopalganj, Siwan, Saran, Bhojpur, Patna, Arwal, Jahanabad, Nawada and Aurangabad and minimum number of dry days (~247-255 days) is observed mainly in the districts of Kishanganj, Arariya, Purniya, Supaul and Katihar districts.

A significant decreasing trend for the number of rainy days in southwest monsoon in Banka, Begusarai, Bhabua, Bhagalpur, Buxar, West Champaran, Darbhanga, Gaya, Jamui, Katihar, Khagaria, Kishanganj, Lakhisarai, Madhubani, Munger, Muzaffarpur, Nawadah, Patna, Purnea, Rohtas, Samastipur, Saran, Sitamarhi, Siwan, Supaul, Vaishali and Arwal districts is observed.

A significant increasing trend for the number of rainy days in southwest monsoon in East Champaran, Madhubani, Muzaffarpur, Supaul, Arariya, Katihar and Gaya districts are seen.

In annual scale, a significant decreasing trend in the number of rainy days is seen in all the districts of Bihar except East Champaran, Gopalganj, Saharsa, Madhepura, Bhojpur, Arwal and Jahanabad and a significant increasing trend is observed in the districts of East Champaran, Madhubani, Muzaffarpur, Supaul, Arariya, Katihar, Gaya, Patna and Bhabua.

In the southwest monsoon, there is a significant decrease in the number of heavy rainfall days in Sitamarhi, Madhubani, Supaul, Arariya, Kishanganj, Purnia, Madhepura, Katihar, Banka, Jamui, Gaya, Aurangabad, Rohtas, Buxar, Bhojpur, Patna, Nalanda, Begusarai, Khagaria, Gopalganj, Siwan, Saran and Vaishali districts and a significant increase in the number of heavy rainfall days is seen in East Champaran, Gopalganj, Gaya, Sheikhpura, Jamui, Khagaria and Bhagalpur districts.

In the annual scale, significant decrease in the number of heavy rainfall days in Sitamarhi, Madhubani, Supaul, Arariya, Kishanganj, Purnia, Katihar, Madhepura, Jamui, Gaya, Aurangabad, Rohtas, Buxar, Bhojpur, Patna, Nalanda, Begusarai, Khagaria, Gopalganj, Siwan, Saran and Vaishali districts and a significant increase in the number of heavy rainfall days in West Champaran, East Champaran, Gopalganj, Madhubani, Gaya, Jamui, Sheikhpura, Bhagalpur, Banka and Gagaria districts.
In the southwest monsoon season, a significant increase in the number of dry days in all the districts of Bihar except Sheohar, Saharsa, Madhepura, Lakhisarai, Sheikhpura, Jahanabad, Arwal, Buxar, Bhojpur and Bhabua districts and a significant decrease in the number of dry days in Siwan, Purnia and Nawada districts is observed.

In the annual scale, there is a significant increase in the number of dry days in East Champaran, West Champaran, Madhubani, Supaul, Arariya, Katihar, Bhagalpur, Banka, Jamui, Nawada, Gaya Bhabua, Rohtas, Buxar, Patna, Jahanabad, Siwan, Muzaffarpur, Begusarai, Khagaria, Lakhisarai districts and a significant decrease in the number of dry days in Siwan, Nalanda, Begusarai, Jamui, Katihar and Bhagalpur 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 its districts as well as extreme rainfall event of different intensity of stations are analysed.