Observed Rainfall Variability and Changes over Punjab State
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Pulak Guhathakurta, Pednekar R A, Shirish Khedikar, Preetha Menon, Ashwini Kumar Prasad and Neha Sangwan
### 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

The state of Punjab lies roughly between 29°30'N and 32°30'N latitudes, 73°30' E and 77°00'E longitudes. It is bounded by Pakistan on its west: Sirsa. Hissar and Kurukshtetra districts of Haryana and Ganganagar district of Rajasthan on its south; Ambala district of Haryana and Solan, Bilaspur, Una, Kangra districts of Himachal Pradesh on the east and Kathua district of Jammu and Kashmir on its north. The area of the state which is mostly plain is roughly 50,300 square kilometers.

Punjab, literally means "Land of five rivers", but now there are only three rivers, namely the Ravi, the Beas and the Sutlej. The state comprises of two doabs or tracks, lying between the three rivers. They are, the Bist-Jullundur also called the Saharwal-Doab, lying between the Beas and the Sutlej; and the Bari, between the old bed of the Beas and the Ravi.

The whole state is a vast alluvial plain, except in the northeast region which falls under Himalayan (Siwaliks) sub montane-region. All the three rivers of the state rise in the Himalayas and after a long course of several hundred kilometers amidst snow-clad ranges, emerge on to the plains. In the course of its travel each stream cuts a wide valley, which lies well below level of the plains. Within this valley, the river meanders in narrow, ill-defined and ever shifting route. In winter, the stream is comparatively small, but as the mountain snow melts at the approach of the hot season, the waters rise and overflow the surrounding country, often submerging several kilometers on either side. At the close of the rainy season, the waters recede, of fertile loam.

There are many studies 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 etc). Also, there are limited studies on district rainfall trends and variability of the state Punjab. 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 station are computed and then monthly district rainfall series has been constructed by considering arithmetic average of all the station rainfall values within the district. Fig.1 gives the location of the districts of the state. 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:

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

Fig. 1: Location of the districts of Punjab

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 (28%) of south west monsoon rainfall in July month while the August month get 26
% of the south west monsoon rainfall. June and September receive 11% and 15% of south west monsoon rainfall. Also, more than 79% of annual rainfall received during the southwest monsoon season only. The variability of monsoon rainfall is 29% and annual rainfall is 25%.

<table>
<thead>
<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, southwest monsoon season and annual respectively. The trend lines are also displayed for each of the series. In the monthly rainfall, June and September rainfall show increasing trend while July and August rainfall show decreasing trend. Similarly, both seasonal and annual rainfall show decreasing trends. During the last 30 years highest rainfall of June and July received in the year 2008 and 1993 (159.4 mm and 360.4 mm respectively) while highest rainfall of 383.5 in August received in the year 1995 and 202.1 mm in September received in the year 2018. Highest annual rainfall of 896.7 mm as well as highest southwest monsoon rainfall of 757.8 mm received in the same year 1995.

Fig. 2: Time series of rainfall in mm for the months of June, July, August, September 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 Punjab for June, July, August, September, southwest monsoon season and annual while Fig.4 -5 show the spatial pattern of these statistics. Shahid Bhagat Singh Nagar and Rupnagar district received highest rainfall over other districts during all the months and season. Rainfall received over these districts are around 81-102 mm in June, 246-308mm in July, 238-298mm in August and 114-142 mm in September while during the SW monsoon 676-846 mm and annual 872-1090mm. Lowest rainfall received during the SW monsoon season over Taran Taran district (209.4mm) while Ferozepur district received lowest annual rainfall (234.4).
Table 2.: Rainfall statistics for the districts of Punjab for the four monsoon months, southwest monsoon season and annual.

<table>
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<tr>
<th>DISTRICT</th>
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<th>JULY CV</th>
<th>AUGUST MEAN</th>
<th>AUGUST CV</th>
<th>SEPTEMBER MEAN</th>
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Table 2.: Rainfall statistics for the districts of Punjab for the four monsoon months, southwest monsoon season and annual.
Fig. 4: Mean rainfall pattern over districts of Punjab
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 June rainfall has shown significant increasing trend in the districts Taran Taran and Barnala while no district has shown any significant decreasing trend. For the July month significant decreasing trend has been noticed in Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur and Fazilka districts and Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, Mansa. Fatehgarh Sahib and Patiala districtshave shown significant decreasing trend in August rainfall.September rainfall of SAS Nagar district has shown significant increasing trend. During the whole southwest monsoon season Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, Patiala and Fatehgarh Sahib Nagar districts have shown significant decreasing trend.
For the annual rainfall Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, Patiala and Mansa districts show significant decreasing trend while only SAS Nagar district showed significant increasing trend.

Fig.6: Trends in district rainfall for (a) June, (b) July (c) August (d) September (e) JJAS and (f) annual rainfall.
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 the rain gauge stations of Punjab for June, July, August, September months and for the cumulative period 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 5 to 6 days especially in some parts of Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Rupnagar, Patiala and SAS Nagar districts. While minimum number of rainy days lies in the range of 2 to 3 days especially in some parts of Taran Taran, Jalandhar, Firozepur, Faridkot, Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Fatehgarh Sahib, Mansa, Sangrur, Patiala districts. Whereas in remaining districts, the number of rainy days lies in the range of 3 to 5 days.

Figure 8 shows that in the month of July the maximum number of rainy days lies in the range of 10 to 12 days especially in some parts of Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Rupnagar and Patiala district. While minimum number of rainy days lies in the range of 4 to 6 days especially in some parts of Taran Taran, Firozepur, Faridkot Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Ludhiana, Barnala, Mansa, Sangrur and Patiala district. Whereas in remaining districts, the number of rainy days lies in the range of 6 to 10 days.

Figure 9 shows that in the month of August the maximum number of rainy days lies in the range of 10 to 11 days especially in some parts of Pathankot, Gurdaspur, SAS Nagar, Hoshiarpur, Rupnagar and Patiala districts. While minimum number of rainy days lies in the range of 3 to 5 days especially in some parts of Taran Taran, Firozepur, Faridkot Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Ludhiana, Barnala, Mansa, Sangrur and Patiala district. Whereas in remaining districts the number of rainy days lies in the range of 5 to 10 days.

Figure 10 shows that in the month of September the maximum number of rainy days lies in the range of 5 to 6 days especially in some parts of Pathankot, Gurdaspur, SAS Nagar, Hoshiarpur, Rupnagar and Patiala districts. While minimum number of rainy days lies in the range of 2 to 3 days especially in some parts of Taran Taran, Jalandhar, Firozepur, Faridkot Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Barnala, Mansa, Sangrur and Patiala district. Whereas in remaining districts the number of rainy days lies in the range of 3 to 5 days.

Figure 11 shows that during June to September the maximum number of rainy days lies in the range of 27 to 31 days especially in some parts of Pathankot, Gurdaspur, SAS Nagar, Hoshiarpur, RupNagar and Patiala districts. While minimum number of rainy days lies in the range of 11 to 15 days.
especially in some parts of Taran Taran, Firozepur, Faridkot, Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Barnala, Mansa, Sangrur and Patiala districts. Whereas in remaining districts, the number of rainy days lies in the range of 15 to 27 days.

Figure 12 shows that during the entire year the maximum number of rainy days lies in the range of 39 to 45 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Amritsar, Rupnagar and Patiala districts. While minimum number of rainy days lies in the range of 16 to 22 days especially in some parts of Taran Taran, Firozepur, Faridkot, Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Barnala, Mansa, Sangrur and Patiala districts. Whereas in remaining districts, the number of rainy days lies in the range of 22 to 39 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 the raingauge stations of Punjab for June, July, August, September months and for the cumulative period 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 0.24 to 1 days especially in some parts of Pathankot, Kapurthala, Hoshiarpur, Shahid Bhagat Singh Nagar, Rupnagar, Fatehgarh Sahib, SAS Nagar and Patiala district. While minimum number of Heavy rainfall days lies in the range of 0.01 to 0.08 days especially in some parts of Amritsar, Taran Taran, Ferozepur, Faridkot, Jalandhar, Ludhiana, SRL Muktsar Sahib, Bhatinda, Mansa, Barnala, Sangrur, Fatehgarh Sahib, SAS Nagar district. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.08 to 0.24 days.

Figure 14 shows that in the month of July the maximum number of heavy rainfall days lies in the range of 0.81 to 1 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Rupnagar, Patiala, SBS Nagar and SAS Nagar districts. While minimum number of Heavy rainfall days lies in the range of 0.1 to 0.37 days especially in some parts of Amritsar, Taran Taran, Ferozepur, Faridkot, Moga, Jalandhar, Ludhiana, Fazilka, Bhatinda, Mansa, Sangrur, Patiala, Fatehgarh Sahib and SAS Nagar districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.37 to 0.81 days.

Figure 15 shows that in the month of August the maximum number of heavy rainfall days lies in the range of 0.95 to 2 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Rupnagar and Patiala districts. While minimum number of Heavy rainfall days lies in the range of 0.2 to 0.39 days.
especially in some parts of Taran Taran, Ferozepur, Faridkot, Moga, Bhatinda, Barnala, Sangrur, Mansa, Patiala, Fazilka, SRL Muktsar Sahib and Ludhiana districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.39 to 0.95 days.

Figure 16 shows that during September the maximum number of heavy rainfall days lies in the range of 0.40 to 1 days especially in some parts of Pathankot, Sahid Bhagat Singh Nagar, Fatehgarh Sahib, SAS Nagar and Patiala districts. While minimum number of Heavy rainfall days lies in the range of 0.1 to 0.19 days especially in some parts of Pathankot, Gurdaspur, Amritsar, Ferozepur, Faridkot, Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Mansa, Sangrur, Barnala and Ludhiana districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.19 to 0.40 days.

Figure 17 shows that during June to September the maximum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, SBS Nagar, Barnala Rupnagar, SAS Nagar and Patiala districts. While minimum number of Heavy rainfall days lies in the range of 0.5 to 0.95 days especially in some parts of Amritsar, Taran Taran, Ferozepur, Faridkot, Moga, Ludhiana, Barnala, Sangrur, Bhatinda, Mansa, Fazilka and Patiala districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.95 to 2.05 days.

Figure 18 shows that during the entire year the maximum number of heavy rainfall days lies in the range of 2.27 to 3 days especially in some parts of Pathankot, Gurdaspur Hoshiarpur SBS Nagar Rupnagar SAS Nagar and Patiala districts. While minimum number of Heavy rainfall days lies in the range of 0.6 to 1.04 days especially in some parts of Amritsar, Taran Taran, Ferozepur, Faridkot, Moga, Ludhiana, Sangrur, Barnala, Bhatinda, Mansa, Patiala and Fazilka districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1.04 to 2.27 days.

Fig. 13 Average frequency of heavy rainfall days: June
Fig. 14 Average frequency of rainy days: July
5.3 Average frequency of Dry days

The average frequency of dry days is calculated for the rain gauge stations of Punjab for June, July, August, September months and for the cumulative period 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 31 to 33 days especially in some parts of Amritsar, Taran Taran and Pathankot districts. While minimum number of dry days lies in the range of 22 to 25 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Kapurthala, Jalandhar, Sahid Bhagat Singh Nagar, Rupnagar, Ludhiana, FatehgarhSahib, SAS Nagar, Patiala, Fazilka, Moga, Bhatinda and Taran Taran districts. Whereas in remaining districts, the number of dry days lies in the range of 25 to 31 days.
Figure 20 shows that in the month of July the maximum number of dry days lies in the range of 28 to 29 days especially in some parts of Amritsar, Taran Taran and Pathankot districts. While minimum number of dry days lies in the range of 18 to 21 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Kapurthala, Jalandhar, Sahid Bhagat Singh Nagar, Rupnagar, Ludhiana, Fatehgarh Sahib, SAS Nagar, and Patiala districts. Whereas in remaining districts, the number of dry days lies in the range of 21 to 28 days.

Figure 21 shows that in the month of August the maximum number of dry days lies in the range of 28 to 29 days especially in some parts of Amritsar and Taran Taran districts. While minimum number of dry days lies in the range of 18 to 21 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Shahid Bhagat Singh Nagar, Ludhiana, Fatehgarh Sahib, SAS Nagar, Patiala and Rupnagar districts. Whereas in remaining districts, the number of dry days lies in the range of 21 to 28 days.

Figure 22 shows that in the month of September the maximum number of dry days lies in the range of 31 to 33 days especially in some parts of Gurdaspur, Pathankot, Amritsar and Taran Taran districts. While minimum number of dry days lies in the range of 22 to 25 days especially in some parts of Pathankot Gurdaspur Hoshiarpur, Jalandhar, Kapurthala, Shahid Bhagat Singh Nagar, Rupnagar Fatehgarh Sahib, SAS Nagar, Patiala, Ferozepur, Bhatinda Moga, Ludhiana, Taran Taran Kapurthala, Jalandhar, Sangrur, Faridkot and Muktsar Sahib districts. Whereas in remaining districts, the number of dry days lies in the range of 25 to 31 days.

Figure 23 shows that during June to September the maximum number of dry days lies in the range of 31 to 33 days especially in some parts of Pathankot, Amritsar, Taran Taran districts. While minimum number of dry days lies in the range of 22 to 25 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Shahid Bhagat Singh Nagar, Ludhiana, Rupnagar, Fatehgarh Sahib, Patiala, SAS Nagar, Ferozepur, Bhatinda and Mansa districts. Whereas in remaining districts, the number of dry days lies in the range of 25 to 31 days.

Figure 24 shows that in the month of during the entire year the maximum number of dry days lies in the range of 348 to 352 days especially in some parts of Pathankot Amritsar and Taran Taran districts. While minimum number of dry days lies in the range of 259 to 281 days especially in some parts of Pathankot, Gurdaspur Hoshiarpur, Jalandhar, Kapurthala, Shahid Bhagat Singh Nagar, Rupnagar, Fatehgarh Sahib, SAS Nagar, Patiala, Taran Taran, Ferozepur, Moga, Bhatinda, Sangrur and Mansa districts. Whereas in remaining districts, the number of dry days lies in the range of 281 to 348 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
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 Punjab 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 Taran Taran, Kapurthala, Ludhiana, Barnala and Sangrur, districts. Whereas there is a significant decrease in Rainy days in stations in Amritsar, SAS Nagar and Patiala 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 Ferozepur district. Whereas there is a significant decrease in Rainy days in stations in Gurdaspur, Amritsar, Hoshiarpur, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Rupnagar, Moga, Fatehgarh Sahib, SAS Nagar, Patiala, Sangrur, Bhatinda, Faridkot, Fazilka and Moga districts. 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 Kapurthala and Bhatinda districts. Whereas there is a significant decrease in Rainy days in stations in Gurdaspur, Amritsar, Hoshiarpur, Shahid Bhagat Singh Nagar, Rupnagar, Ferozepur, Fatehgarh Sahib, Patiala, Sangrur, Barnala and Bhatinda districts. While remaining districts did not show any significant change.

Figure 28 shows that in the month of September there is a significant decrease in Rainy days in stations in Pathankot, Hoshiarpur, Amritsar, Jalandhar, Ferozepur, Fatehgarh Sahib, Sangrur and Patiala 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 Ferozepur, Kapurthala and Bhatinda. Whereas there is a significant decrease in Rainy days in Pathankot, Gurdaspur, Hoshiarpur, Amritsar, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Ludhiana, Ferozepur, Bhatinda, Mansa, Barnala, Patiala, Fatehgarh Sahib, SAS Nagar, Rupnagar and Sangrur 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 Ferozepur, Kapurthala and Bhatinda districts. Whereas there is a significant decrease in Rainy days in Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Rupnagar, Ferozepur, Bhatinda, Barnala, Patiala, Fatehgarh Sahib, SAS Nagar, Rupnagar and Sangrur 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 Punjab 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 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 Patiala district. Whereas there is a significant decrease in Heavy rainfall days in Hoshiarpur, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, SRL Muktsar Sahib, Rupnagar, Sangrur, Mansa, Patiala and Bhatinda 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 Kapurthala districts. Whereas there is a significant decrease in Heavy rainfall days in Taran Taran, Jalandhar, Hoshiarpur, Shahid Bhagat Singh Nagar, Ferozepur, Fatehpur, Patiala, Sangrur, Barnala, Fazilka, Mansa and Bhatinda. 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 Pathankot, Faridkot, districts. Whereas there is a significant decrease in Heavy rainfall days in Shahid Bhagat Singh Nagar, Ferozepur, Fatehpur, Barnala and Bhatinda 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 Kapurthala, Faridkot and Sangrur districts. Whereas there is a significant decrease in Heavy rainfall days in Amritsar, Rupnagar, Shahid Bhagat Singh Nagar, Ludhiana, SAS Nagar, Fatehpur, Patiala, Sangrur, Barnala, Mansa, Bhatinda, Ferozepur and Fazilka, 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 Kapurthala and Faridkot districts. Whereas there is a significant decrease in Heavy rainfall days in Amritsar, Hoshiarpur, Rupnagar, Shahid Bhagat Singh Nagar, Ludhiana, SAS Nagar, Fatehpur, Sangrur, Patiala, Rupnagar, SRL Muktsar Sahib, Barnala, Mansa, Bhatinda and Fazilka districts. While remaining districts did not show any significant change.
Fig. 31: Trend in frequency of heavy rainfall days: June

Fig. 32: Trend in frequency of heavy rainfall days: July

Fig. 33: Trend in frequency of heavy rainfall days: August

Fig. 34: Trend in frequency of heavy rainfall days: September

Fig. 35: Trend in frequency of heavy rainfall days: JJAS

Fig. 36: Trend in frequency of heavy rainfall days: Annual
6.3 Trend in frequency of Dry days

The Trend in frequency of dry days is calculated for Punjab 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, Ludhiana, SAS Nagar, Shahid Bhagat Singh Nagar, Fatehpur, Sangrur, Bhatinda and Patiala districts. Whereas there is a significant decrease in dry days in Pathankot, Amritsar, Hoshiarpur, Rupnagar, Jalandhar, Ferozepur, Faridkot and Kapurthala, 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 Pathankot, Ferozepur, Moga, Sangrur and Patiala districts. Whereas there is a significant decrease in dry days in Pathankot, Ludhiana, SRL Muktsar Sahib and Bhatinda 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 Hoshiarpur, Kapurthala, Ferozepur, Ludhiana, Barnala, Sangrur and Patiala districts. Whereas there is a significant decrease in dry days in Amritsar, Taran Taran and Kapurthala 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 Pathankot, Amritsar, Fatehpur, Sangrur and Patiala districts. Whereas there is a significant decrease in dry days in Amritsar, Shahid Bhagat Singh Nagar, Ludhiana, SRL Muktsar Sahib, Bhatinda, Moga and Sangrur districts. 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 Kapurthala districts. Whereas there is a significant decrease in dry days in Pathankot, Gurdaspur, Amritsar, Kapurthala, Jalandhar, Ludhiana, SAS Nagar, Patiala, Sangrur, Mansa, SRL Muktsar Sahib, Fazilka and Ferozepur districts. While remaining districts did not show any significant change.

Figure 42 shows that in the month of during the entire year there is a significant increase in dry days in Shahid Bhagat Singh Nagar and Kapurthala districts. Whereas there is a significant decrease in dry days in Pathankot, Amritsar, Taran Taran, Hoshiarpur, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Rupnagar, Sangrur and SAS Nagar 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:

- Punjab gets maximum rainfall in July (28% of SW monsoon rainfall) followed by August (26% of SW monsoon rainfall).
- 79% of annual rainfall received during southwest monsoon rainfall (June –September).
- Rupnagar and Fatehgarh Sahib receive maximum (82%) of annual rainfall in SW monsoon season while Taran Taran district receive lowest (73-76%) of annual rainfall in SW monsoon season.
- No significant increasing trends in the districts of State but decreasing trends in Hoshiarpur, Jalandhar, Ferozepur, Shahid Bhagat Singh Nagar (Nawanshahr), Fatehgarh sahib, Fazilka and Patiala districts in SW monsoon season. In annual rainfall SAS Nagar shows significant increasing trend while Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar (Nawanshahr), Ferozepur, Fazalka, Mansa and Patiala shows significant decreasing trend.
- Maximum rainfall receive during the SW monsoon season over the districts in Gurdaspur and Rupnagar (676mm -846mm) while Taran Taran, Ferozepur, Moga, Muktsar, Bhatinda, Barnala and Sangrur district receive lowest rainfall (169-338 mm) during the SW monsoon season.
- Pathankot, Gurdaspur, SAS Nagar, Hoshiarpur, RupNagar and Patiala receive on an average 27 to 31 rainy days (daily rainfall >=2.5mm) out of 122 days of SW monsoon season while TaranTaran, Firozepur, Faridkot, Moga, Fazilka, SRL Muktsar Sahib, Bhatinda, Barnala, Mansa, Sangrur and Patiala gets 11to 15 days rainy days Whereas in remaining districts, the number of rainy days lies in the range of 15 to 27 days.
- For heavy to extremely heavy rainfall (daily rainfall >=6.5mm) Pathankot, Gurdaspur, Hoshiarpur, SBS Nagar, Barnala, Rupnagar, SAS Nagar and Patiala gets 2 to 3 days during the SW monsoon season and Amritsar, Taran Taran, Ferozepur, Faridkot, Moga, Ludhiana, Barnala, Sangrur, Bhatinda, Mansa, Fazilka and Patiala gets Heavy rainfall.
days ranging from 0.5 to 0.95 days. Whereas in remaining districts, the number of rainy days lies in the range of 0.95 to 2.05 days.

Number of dry days is maximum over Pathankot, Amritsar and Taran Taran districts in the range 31-33 dry days out of 122 days during the SW monsoon season while minimum number of dry days lies in the range of 22 to 25 days especially in some parts of Pathankot, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Sahid Bhagat Singh Nagar, Ludhiana, Rupnagar, Fatehgarh Sahib, Patiala, SAS Nagar, Ferozepur, Taran Taran, Bhatinda and Mansa districts. Whereas in remaining districts, the number of dry days lies in the range of 25 to 31 days.

During the period June to September there is significant decrease in Rainy days in Ferozepur, Kapurthala and Bhatinda districts. Whereas there is a significant decrease in Rainy days in Pathankot, Gurdaspur, Hoshiarpur, Amritsar, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Ludhiana, Ferozepur, Bhatinda, Mansa, Barnala, Patiala, Fatehgarh Sahib, SAS Nagar, Rupnagar and Sangrur districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in Rainy days in Ferozepur, Kapurthala and Bhatinda districts. Whereas there is a significant decrease in Rainy days in Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Ludhiana, Ferozepur, Bhatinda, Barnala, Patiala, Fatehgarh Sahib, SAS Nagar, Rupnagar and Sangrur districts. While remaining districts did not show any significant change.

During the period June to September there is a significant increase in heavy rainfall days in Kapurthala, Faridkot and Sangrur districts. Whereas there is a significant decrease in Heavy rainfall days in Amritsar, Rupnagar, Shahid Bhagat Singh Nagar, Ludhiana, SAS Nagar, Fatehpur, Patiala, Sangrur, Barnala, Mansa, Bhatinda, Ferozepur and Fazilka districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in Heavy rainfall days in Kapurthala and Faridkot districts. Whereas there is a significant decrease in Heavy rainfall days in Amritsar, Hoshiarpur, Rupnagar, Shahid Bhagat Singh Nagar, Ludhiana, SAS Nagar, Fatehpur, Sangrur, Patiala Rupnagar, SRL Muktsar Sahib, Barnala, Mansa, Bhatinda and Fazilka districts. While remaining districts did not show any significant change.
During June to September there is a significant increase in dry days in Kapurthala districts. Whereas there is a significant decrease in dry days in Pathankot, Gurdaspur, Amritsar, Kapurthala, Jalandhar, Ludhiana, SAS Nagar, Patiala, Sangrur, Mansa, SRL Muktsar Sahib, Fazilka and Ferozepur districts. While remaining districts did not show any significant change.

During the entire year there is a significant increase in dry days in Shahid Bhagat Singh Nagar and Kapurthala districts. Whereas there is a significant decrease in dry days in Pathankot, Amritsar, TaranTaran, Hoshiarpur, Kapurthala, Jalandhar, Shahid Bhagat Singh Nagar, Rupnagar, Sangrur and SAS Nagar districts. While remaining districts did not show any significant change.
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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.