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Annual and Seasonal Rainfall Trends over Different Districts of Punjab

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Abstract : Seasonal and annual trends of changes in rainfall have been studied using monthly data series of 102 years (1901-2002) for 17 different districts of Punjab, India. Sen's non-parametric estimator of slope was used to estimate the magnitude of trend whose statistical significance was assessed by Mann-Kendall test. All the districts have shown increasing trend in annual rainfall. This increasing trend was found statistically significant for all districts except Hoshiarpur, Nawanshahr and Rupnagar. Similarly, all districts indicated increasing trend in monsoon, pre-monsoon and post-monsoon season. Increasing trend in monsoon rainfall was found significant for all districts except Gurdaspur, Hoshiarpur, Nawanshahr and Rupnagar. The winter rainfall was found to be decreasing (statistically non-significant) for all the districts.

INTRODUCTION

Study of rainfall trend is important for a country like India whose food security and economy is significantly dependent on timely availability of rainfall. About 80% of the rainfall in India occurs during four monsoon months (June-September) with large spatial and temporal variations over the country. Such heavy concentration of rainfall results in scarcity of water in many parts of the country during non-monsoon period. The consumption of water by different sectors shows that agriculture consumes nearly 85.3% of water, domestic sector 6.6%, industry sector 1.2%, energy sector 0.3% and other sectors 6.4% (GOI, 2000). The agriculture output is primarily governed by timely availability of water. Therefore, for India, where agriculture has significant influence on economy, availability of adequate water for irrigation under changed climatic scenarios is very important. In future, population growth along with higher demand of water for irrigation and industries will put more pressure on water.

Punjab contributes nearly 70% of wheat and 55% of rice to the central pool of food grains and hence is commonly referred to as the bread basket of the country. Productivity of wheat and rice which is highly dependent on climatic changes, will need to be maintained at a higher level to meet the future food demands of increasing population in India. Various studies have indicated implications of climate change for India and concluded that cereal production is estimated to decrease and nutrition security of the population-rich but land-hungry regions of India would be hampered. Climatic changes (temperature, radiation and rainfall) and carbon dioxide levels can affect the yields of rice and wheat through their direct effect as well as indirect effects. The IPCC Fourth Assessment Report (2007) indicates that climate change will have significant impact on crop production and water management systems in coming decades. In addition, there is the potential for earlier negative surprises linked to increased frequency of extreme events.

Changes in rainfall patterns and increased temperature could have a direct impact on water resources. The patterns of floods, droughts, storms and cyclonic activity could change, leading to major implications with regard to the drinking water supplies, hydropower generation, irrigation activities, and threats to life and property. It is understood that changes in precipitation levels will be accompanied by increased evaporation rates as temperatures rise. The combination of these changes will have profound effects on soil moisture levels in river catchments, which will effect agriculture production.

Increased frequency and severity of extreme weather conditions will increase the vulnerability of the farming sector. Water stress situations or drought as a result of hotter, drier summers will have a serious impact on soils, and the impact on both crop quality and variability will lead to a higher need for water in agriculture. Equally, waterlogged soils on which excess water needs to be frequently drained may not only lead to crop losses, but can impact severely upon crop quality and variability.

STUDY AREA AND DATA USED

Punjab (Fig. 1) with a geographical area of 50,362 sq. km. occupies 1.57% of the country's total geographical area and is a part of the Indo-Gangetic plains formed due to alluvial deposits by rivers and tributaries. Punjab extends from the latitudes 29.30° North to 32.32° North and longitudes 73.55° East to 76.50° East. It is bounded on the west by Pakistan, on the north by Jammu and Kashmir, on the northeast by Himachal Pradesh and on the south by Haryana and Rajasthan. Land in the state is mainly shared by activities like, agriculture (84%) and forests (6.07%), besides built up areas, water bodies, wastelands, etc. Administratively, state was divided into 12 districts (Amritsar, Gurdaspur, Faridkot, Ferozepur, Kapurthala, Jalandhar, Ludhiana, Hoshiarpur, Ropar, Bathinda, Patiala & Sangrur) which were increased to 14 in 1992 (including Mansa & Fatehgarh Sahib), to 17 in

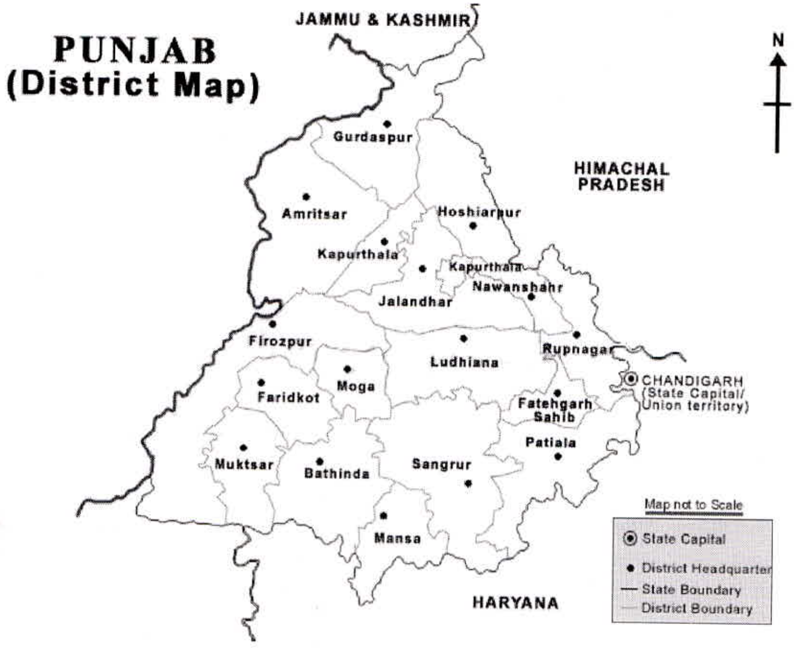

Fig. 1: Study area showing location of 17 districts

1996 (including Moga, Nawanshehar & Mukatsar) and to 20 in 2006 (including Barnala, Mohali & Tarantaran).

Three perennial rivers, namely the Sutlej, Beas and Ravi, flow through the state. In addition, Ghaggar which is almost a seasonal river, flows through the south western part of Punjab. Together these rivers have a water potential of about 14.54 Million Acre Feet (MAF) or 1.79 million hectare metre (mham). The state also has a network of canals (14500 km) and drains (800 km). Out of these, six major canals are the Upper Bari Doab Canal; Bist Doab Canal; Sirhind Canal; Bikaner Canals; Bhakra Main Canal; and Ferozepur Canal. The total surface and ground water resources in the state are estimated to be about 3.13 mham. Due to the presence of a large number of rivers, most of the Punjab is a fertile plain. The southeast region of the state is semi-arid and gradually presents a desert landscape. A belt of undulating hills extends along the northeastern part of the state at the foot of the Himalayas. With the ushering of green revolution and increase in paddy cultivation, ground water resources in the state are being used for irrigation to a large extent. The ground water is also a major source of drinking water. The total replenishable ground water resource in the state is 1.87 mham/yr out of which 0.18 mham is used for domestic & industrial uses. The net draft for irrigation is 1.61 mham/yr. The use of ground water in excess of recharge is leading to a fall in water table.

The climate of Punjab is typically subtropical with hot summers (temperatures reaching up to 47°C) and cold winters (temperatures reaching sub zero in certain areas). The average annual rainfall ranges from 58 cms in plains to 96 cms in sub montane regions and decreases from North to South.

District-wise monthly rainfall data of Punjab available at http://www.indiawaterportal.org/ has been used in this study. This database is the publicly available Climate Research Unit (CRU) TS2.1 dataset, out of the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich, UK. This published dataset consists of interpolated (on a 0.5 degree latitude-longitude grid) global monthly rainfall, temperature, humidity and cloud cover data, from 1901 to 2002 (Mitchell and Jones, 2005). The CRU TS 2.1 is a set of monthly climate grids which are constructed for nine climate variables and interpolated onto a 0.5° grid and provide best estimates of month-by month variations. The raw station data are derived from seven different sources and are corrected for in-homogeneities using a modified version of the Global Historical Climatology Network (GHCN) method. For the purpose of converting the CRU dataset from its original format, the opensource GIS software GRASS (Geographic Resources Analytical Support System) was used on a Ubuntu Linux operating system. The original datasets were converted into GRASS raster formats. GRASS GIS modules along with Linux scripting were used to extract the monthly average rainfall; maximum, minimum and average temperatures; and vapour pressure (humidity), from 1901 to 2002, for the Indian subcontinent.

The district-wise meteorological data was obtained by simple linear averaging from the gridded data of the CRU dataset. Where there were data gaps in the CRU grids and the data gap was less than 25% of the district area, we have done a simple approximation to get the data for each district. Where the data gap was more than 25%, we have not shown any data for that district.

This paper has analyzed the rainfall data of 17 districts for the period 1901-2002. For seasonal analysis of rainfall, a year has been divided into four seasons namely, pre-monsoon (April-June), monsoon (July-September), post-monsoon (October-November) and winter season (December-March), depending upon climatic conditions prevailing over the region.

METHODOLOGY

The magnitude of the trend in the seasonal and annual series was determined using the Sen's estimator (Sen, 1968) and statistical significance of the trend in the time series was analysed using Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975).

Magnitude of trend

The magnitude of trend in a time series was determined using a non-parametric method known as Sen's estimator (Sen, 1968). This method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Partal and Kahya, 2006; Kumar *et al.*, 2010). In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{for i} = 1,2,\ldots\ldots,\text{N} \qquad (1)$$

where x_j and x_k are data values at time j and k (j>k) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \qquad (2)$$

A positive value of â indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Significance of trend

To ascertain the presence of statistically significant trend in hydrologic climatic variables such as temperature, precipitation and streamflow with reference to climate change, nonparametric Mann-Kendall (MK) test has been employed by a number of researchers (Burn *et al.*, 2004; Singh et al., 2008a, b; Kumar and Jain, 2010). The MK method searches for a trend in a time series without specifying whether the trend is linear or non-linear. In the present study, the MK test was also applied. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. Following Bayazit and Onoz (2007), no pre-whitening of the data series was carried out as the sample size is large (n e" 50) and slope of trend was high (> 0.01).

The statistics (S) is defined as (Salas, 1993)

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sgn}(x_j - x_i) \qquad (3)$$

where N is number of data points. Assuming (x_j-x_i) = è, the value of *sgn(è)* is computed as follows:

$$\text{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \qquad (4)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using a normal distribution (Helsel and Hirsch, 1992) with the mean and the variance as follows:

$$E[S] = 0 \qquad (5)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)}{18} \qquad (6)$$

where n is the number of tied (zero difference between compared values) groups, and t_k is the number of data points in the *k*th tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch *et al.*, 1993):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad (7)$$

If the computed value of %Z%> $z_{á/2}$, the null hypothesis (H_o) is rejected at á level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

RESULTS AND DISCUSSION

Temporal and spatial distribution of rainfall
The rainfall characteristics of different districts of Punjab are reported in Table 1. Mean seasonal, mean annual and coefficient of variation of the annual rainfall are also given in Table 1. Gurdaspur district received the maximum mean annual rainfall followed by Rupnagar and Hoshiarpur, whereas Mukatsar district received the minimum mean annual rainfall. Three districts namely Gurdaspur, Hoshiarpur, Rupnagar received mean rainfall above 600mm, four districts (Nawanshahr, Patiala, Fatehgarh Sahib and Jalandhar) between 500mm-600mm, four districts (Amritsar, Kuparthala, Ludhiana, and Sangrur) between 400mm-500mm and remaining six districts (Bhatinda, Faridkot, Firozpur, Mansa, Moga, and Mukatsar) received mean rainfall between 300mm-400mm (Fig. 2). The contribution of monsoon rainfall varies from 78% (Amritsar) to 83% (Fatehgarh Sahib and Patiala). The coefficient of variation (CV) of the annual rainfall varies from 24% (Patiala and Rupnagar to 32% (Amritsar).

The temporal variability of rainfall for selected districts is shown in Fig. 3. The linear trend lines indicate increasing rainfall over all the districts.

Table 1. Seasonal distribution of average rainfall in different districts in Punjab

S No	District	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
		Mean (mm)	CV*	Mean (mm)	% of Annual	Mean (mm)	% of Annual	Mean (mm)	% of Annual	Mean (mm)	% of Annual
1	Amritsar	469.9	0.32	49.9	10.6	364.1	77.5	9.2	2.0	46.8	10.0
2	Bhatinda	334.1	0.29	31.6	9.5	269.8	80.8	5.3	1.6	27.3	8.2
3	Faridkot	336.4	0.31	33.7	10.0	268.7	79.9	5.2	1.6	28.7	8.5
4	Fatehgarh Sahib	516.8	0.25	36.8	7.1	429.4	83.1	9.5	1.8	41.0	7.9
5	Firozpur	319.9	0.31	33.6	10.5	251.6	78.7	5.4	1.7	29.4	9.2
6	Gurdaspur	639.9	0.29	63.6	9.9	497.8	77.8	12.3	1.9	66.3	10.4
7	Hoshiarpur	634.5	0.27	54.0	8.5	509.9	80.4	11.4	1.8	59.3	9.3
8	Jalandhar	513.0	0.29	43.7	8.5	416.6	81.2	9.4	1.8	43.3	8.4
9	Kapurthala	493.9	0.30	44.1	8.9	397.3	80.5	8.8	1.8	43.6	8.8
10	Ludhiana	474.2	0.27	37.0	7.8	390.4	82.3	8.3	1.7	38.5	8.1
11	Mansa	353.3	0.29	30.0	8.5	290.8	82.3	6.1	1.7	26.4	7.5
12	Moga	384.1	0.31	35.4	9.2	308.9	80.4	7.0	1.8	32.8	8.6
13	Mukatsar	302.5	0.31	31.3	10.3	240.4	79.4	4.7	1.5	26.3	8.7
14	Nawanshahr	595.4	0.26	44.2	7.4	488.7	82.1	10.9	1.8	51.6	8.7
15	Patiala	525.8	0.24	37.3	7.1	437.0	83.1	10.2	1.9	41.4	7.9
16	Rupnagar	637.0	0.24	44.3	6.9	526.8	82.7	11.8	1.9	54.1	8.5
17	Sangrur	405.3	0.28	33.7	8.3	332.8	82.1	7.1	1.7	31.7	7.8

**CV: Coefficient of variation*

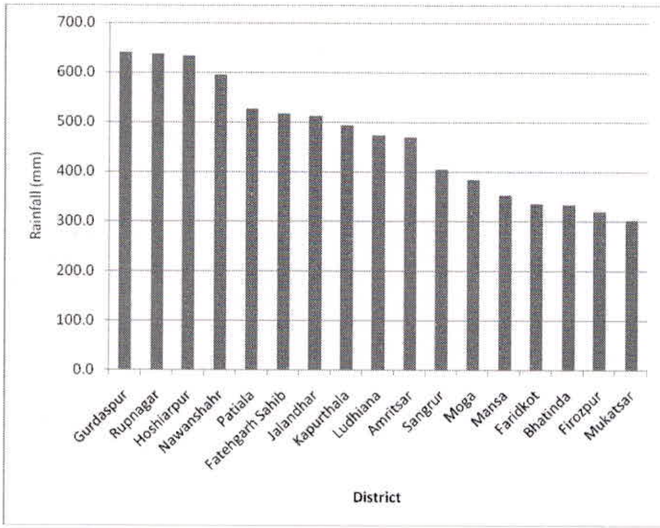

Fig. 2 : Mean annual rainfall for different districts of Punjab

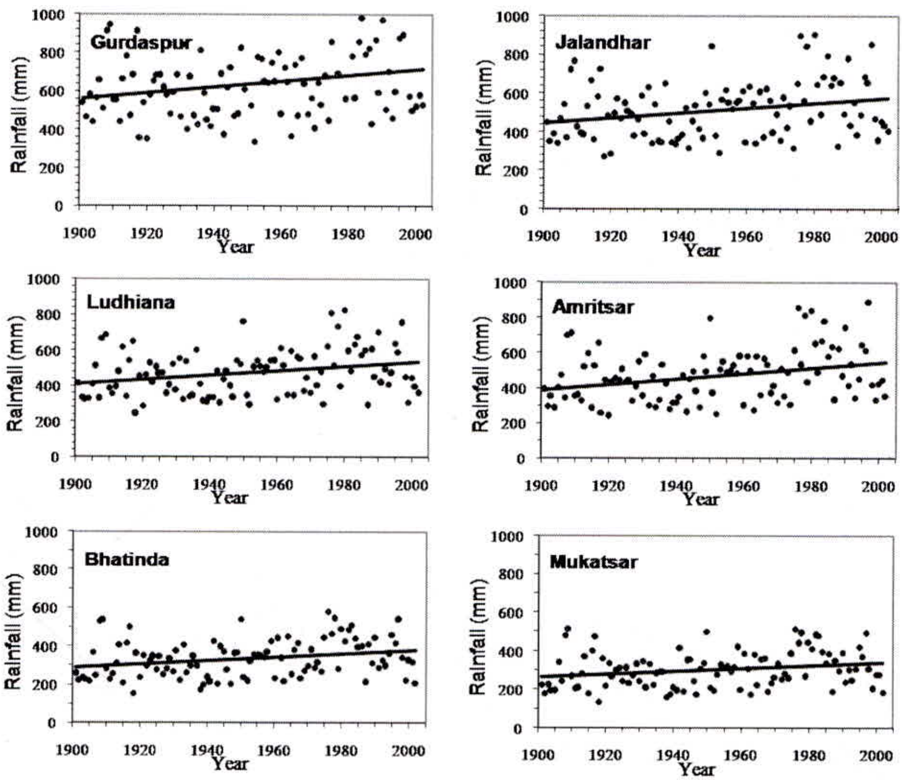

Fig. 3: Temporal variation of annual rainfall for some districts of Punjab. Thick lack line is the linear trend line in rainfall.

Rainfall trends

The magnitude of the trend in annual and seasonal rainfall as determined using the Sen's estimator is given in Table 2. Trends of rainfall variations show that annual and seasonal rainfall (except winter season) increased over all districts but the magnitude of trend varies from one district to another. The increase in annual rainfall over different districts varied between 1.458 mm/year (for Amritsar district) to 0.824 mm/year (for Mukatsar district). Further, the increase was, in general, higher for the districts in north-west and smaller for the districts in south-east. Since the districts such as Gurdaspur and Hoshiarpur are among the highest rainfall districts of Punjab and Mansa and Bhatinda experience the lowest rainfall, it implies that the rainfall variability in the State is likely to increase in the future. At the same time, increase in rainfall for Bhatinda, Mansa, and Moga is a good sign because currently these districts receive quite low annual rainfall.

Seasonal analysis of rainfall trends shows that pre-monsoon, monsoon and post-monsoon rainfall increased over all the districts whereas winter rainfall decreased over all the districts. In the monsoon season, the maximum increase is of the order of 1.223 mm/year for Amritsar and minimum increase is for Mukatsar district (0.657 mm/year). All the districts have shown the same direction of trend for annual and monsoon rainfall, perhaps because the monsoon season has the major contribution of annual rainfall. The decreasing trend in winter season rainfall is found to vary from -0.005 mm/year (Mansa) to -0.083 mm/year (Rupnagar).

Trends and magnitude of changes in annual rainfall in terms of percentage of mean per 100 years for all the districts are reported in Table 2. The maximum increase in annual rainfall is of the order of 36.2% of mean per 100 years for Moga and minimum increase is of the order of 13.5% of mean per 100 years for Rupnagar district. The

Table 2: Sen's estimator of slope for rainfall*

S.N.	District	Annual		Pre-Monsoon		Monsoon		Post-Monsoon		Winter	
		mm/yr	% of mean/ 100 yr	mm/yr	% of mean/ 100 yr	mm/yr	% of mean/ 100 yr	mm/yr	% of mean/ 100 yr	mm/yr	% of mean/ 100 yr
1	Amritsar	**1.458**	**31.0**	**0.165**	**33.1**	**1.223**	**33.6**	**0.041**	**44.3**	-0.054	-11.5
2	Bhatinda	**1.026**	**30.7**	0.101	31.9	**0.839**	**31.1**	**0.026**	**48.9**	-0.009	-3.3
3	Faridkot	**1.066**	**31.7**	0.102	30.2	**0.907**	**33.8**	**0.023**	**43.9**	-0.009	-3.1
4	Fatehgarh Sahib	**1.145**	**22.2**	**0.128**	**34.8**	**0.914**	**21.3**	0.033	34.7	-0.051	-12.4
5	Firozpur	**0.923**	**28.9**	0.096	28.6	**0.784**	**31.2**	**0.024**	**44.7**	-0.018	-6.1
6	Gurdaspur	**1.422**	**22.2**	**0.219**	**34.5**	0.951	19.1	0.051	41.6	-0.036	-5.4
7	Hoshiarpur	1.113	17.5	**0.168**	**31.1**	0.794	15.6	0.041	35.9	-0.060	-10.1
8	Jalandhar	**1.201**	**23.4**	**0.144**	**33.0**	**0.968**	**23.2**	0.038	40.5	-0.064	-14.8
9	Kapurthala	**1.269**	**25.7**	**0.148**	**33.6**	**1.034**	**26.0**	0.035	39.7	-0.059	-13.5
10	Ludhiana	**1.203**	**25.4**	**0.127**	**34.3**	**0.967**	**24.8**	0.034	41.1	-0.048	-12.5
11	Mansa	**1.11**	**31.4**	**0.107**	**35.6**	**0.877**	**30.2**	**0.029**	**47.3**	-0.005	-1.9
12	Moga	**1.389**	**36.2**	0.124	35.1	**1.153**	**37.3**	**0.033**	**47.2**	-0.022	-6.7
13	Mukatsar	**0.824**	**27.2**	0.088	28.1	**0.657**	**27.3**	**0.021**	**45.0**	-0.011	-4.2
14	Nawanshahr	1.022	17.2	**0.146**	**33.0**	0.724	14.8	0.032	29.5	-0.062	-12.0
15	Patiala	**1.199**	**22.8**	**0.143**	**38.4**	**0.913**	**20.9**	0.036	35.4	-0.046	-11.1
16	Rupnagar	0.863	13.5	**0.15**	**33.9**	0.632	12.0	0.024	20.4	-0.083	-15.3
17	Sangrur	**1.346**	**33.2**	**0.125**	**37.1**	**1.108**	**33.3**	**0.033**	**46.6**	-0.010	-3.2

Moga district experienced the maximum increase (37.3%) and Rupnagar experienced the minimum increase (12.0%) during the monsoon season.

The results of Mann-Kendall test applied to annual and seasonal rainfall over different districts (Table 2) indicates that the majority of districts show increasing significant trend in seasonal (except winter) or annual rainfall. Out of the 17 districts studied, annual rainfall of only three districts (Hoshiarpur, Nawanshahr and Rupnagar) showed non-significant trend. Monsoon rainfall also indicated positive significant trend for all the districts except four districts (Gurdaspur, Hoshiarpur, Nawanshahr and Rupnagar). Some of the districts with large increasing trend of rainfall in term of % of mean/100 year (Mansa, and Bhatinda) receive annual rainfall below 400 mm. The increasing trend in pre-monsoon and post-monsoon rainfall was found significant for 12 and 8 districts, respectively. The decreasing rainfall in winter season was found non-significant for all the districts. Any reduction in winter rainfall is not good for Punjab which is a producer of large quantity of wheat (a Rabi crop).

CONCLUSIONS

Global climate change will increase rainfall variability and unpredictability. Increase in flooding as well as droughts due to global warming also poses a major hazard to the safety of dams and production of food. Keeping this in view, the trend detection analysis of rainfall for the different districts of Punjab, where long series data is available, was carried out.

All the districts have experienced increasing rainfall trends in annual, monsoon, pre-monsoon and post-monsoon season. Winter rainfall is found decreasing over all the districts. The increase in annual rainfall over different districts varied between 1.458 mm/year (for Amritsar district) to 0.824 mm/year (for Mukatsar district), whereas for monsoon rainfall, the increase varied from 1.223 mm/year for Amritsar to 0.657 mm/year for Mukatsar district. In future, the variability of rainfall is likely to increase in Punjab. Further, the increase was, in general, higher for the districts in north-west and smaller for the districts in south-east. Rainfall has a rising trend at some districts which currently receive low annual rainfall. The increasing trend in annual and monsoon rainfall over majority of districts was found statistically significant. Although the decreasing rainfall in winter season was found to be non-significant for all the districts, any reduction in winter rainfall is not good for Punjab which is a key wheat producing state of India.

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