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L E T T E R S

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ANALYSIS OF METEOROLOGICAL PARAMETER CHANGES USING MANN-KENDALL STATISTICAL TESTS IN INDIAN PUNJAB

1. Punjab occupies 1.53% total geographical area in the country. The climate of Punjab is semi-arid (Dhillon *et al*., 2019). It is difficult to identify the influence and consequences of climate change. Increase in temperature and reduction in precipitation intensity are two indicators of global warming (Gocic and Trajkovic, 2013). Temperatures have been increasing for the last 40 years and precipitation has also been effected in Punjab (Anon, 2018). As per recent data, 90% irrigation is done by groundwater and 10% is irrigated by canal water. It has been estimated that more than 90% of water is consumed in agriculture sector. So, effective use of available groundwater for agriculture is a question mark. Punjab is highly dependent on agriculture for its economy. In fact, Punjab leads with the highest productivity in the country for all the major crops like rice, wheat, cotton and maize and its contribution of cereal crops to the central pool is 25 to 60 percent in different years. But agriculture is highly dependent on rainfall and groundwater.

The average water table depth for Punjab state was found to be 7.41 m in year 1998 and 14.84 m in 2013, indicating an annual fall rate of 47.6 cm per year. Also, the per cent area with water table depth > 10 m was 24.7% in 1998 and has increased to 71.4% by 2013 (Brar *et al*., 2016). Analysis of 138 blocks reveals that 109 are overexploited, 2 critical, 5 semi-critical and only 22 are safe blocks (Anonymous, 2018). The situation in the study area is even more serious as all the blocks are over exploited, lesser percentage area of canal irrigation. The 5-year moving average rainfall from 1974 to 2008 indicated a general decrease in rainfall for Punjab (Kaur *et al.*, 2012). The state has witnessed a rise of 0.3 - 0.9 °C in maximum temperature and a 0.3-1.2 °C increase in minimum temperature during 1980-2010 (Kaur *et al*., 2011).

The climatic behavior is very important in the water resource management in short, medium and long term. There is a need to assess the trend of climate parameters so that sustainable use of water resources can be made for agriculture which is the backbone of Punjab economy and

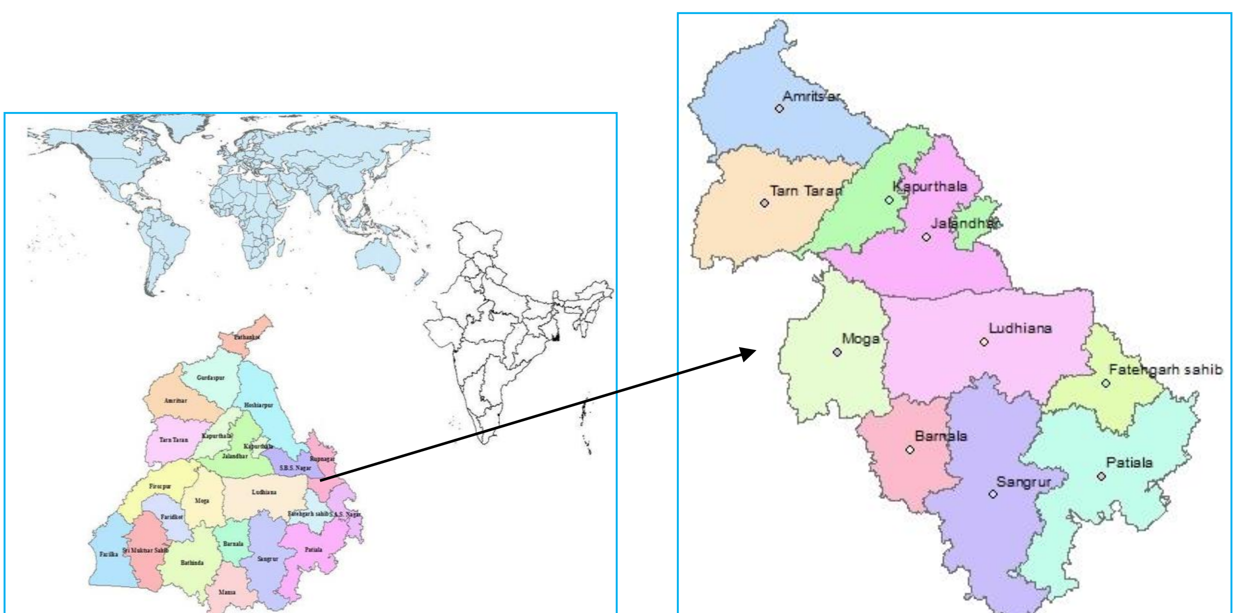


Fig. 1. Location map of study area

TABLE 1

Geographic characteristics of sites used in the study

Station Name	Longitude (E)	Latitude (N)	Elevation (m.a.s.l.)
Amritsar	74° 52'	31° 38'	234
Tarantaran	74° 55′	31° 27′	227
Kapurthala	75° 22′	31° 22′	229
Ludhiana	75° 51′	30° 54′	262
Sangrur	75° 49'	30° 13'	237
Moga	75° 10′	30° 48′	226
Barnala	75° 32′	30° 22′	238
Fatehgarh Sahib	76° 22'	30° 38'	246
Jalandhar	75° 34′	31° 19′	243
Patiala	76° 22'	30° 20'	351

increasing temperatures, there is a lot of stress on water resources. So, it is very necessary to study the trend of meteorological variables for better utilization of resources. There are few studies in Central Punjab have estimated the variability of precipitation and temperature trends for a period greater than 15 years. The motive of this study is to analyze the variability in rainfall, maximum and minimum temperature and rice area at 10 locations in Central Punjab during 1998-2017.

2. *Study areas and data collection* - Broadly, Indian Punjab can be classified into three zones. The North-East zone comprises shivalik foot hill area with high rainfall (900-1100 mm) and less temperature. The location map of the study area is presented in Fig. 1. The Central Punjab comprises 10 districts namely (Table 1) and having an area of 18,000 sq km, which represents about 36% of the total area of the state. In the present study, series of annual maximum (*T*max) and minimum (*T*min) air temperatures and precipitation were examined. The full weather datasets were collected from 10 weather stations from Central Punjab for the period 1998-2017. Their geographic description is given in Table 1.

2.1. *Trend analysis methods* - In this study, two non-parametric methods (Mann-Kendall and Sen's slope estimator) were used to detect meteorological variables' trends.

2.1.1. *Mann-Kendall trend test*- Mann-Kendall is a recommended non-parametric test for statistical significance of trends in environmental datasets (Irannezhad *et al*., 2016; Subash *et al*., 2011; Yue *et al*., 2002; Tabari and Marofi, 2011; Domonkos and Tar, 2013; Silva *et al*., 2013; Silva *et al*., 2013). This test is commonly used to detect monotonic tendencies in series of environmental data (Pohlert, 2016) with no assumption

TABLE 2

Trend classification according to the value of Z_s for α = 0.05 (5%)

Categories	Scales
Significant trends of increase	$Z_s > 1.96$
Non-significant trends of increase	$0 < Z_s > 1.96$
No trend	$Z_s = 0$
Non-significant trends of reduction	$-1.96 < Z_s < 0$
Significant trends of reduction	$Z_s < -1.96$

of normality is required (Helsel and Hirsh, 2002). The Mann-Kendall (Mann, 1945; Kendall, 1975) is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{1}$$

where, n is the number of data points, x_i and x_j are the data values in the time series i and j ($j > i$), respectively and sgn (x_j - x_i) is the sign function as :

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } (x_j - x_i) > 0 \\ 0, & \text{if } (x_j - x_i) = 0 \\ -1, & \text{if } (x_j - x_i) < 0 \end{cases} \tag{2}$$

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i-1)(2t_i+5)}{18} \tag{3}$$

where, n is the number of data points, P is the number of tied groups, the sign (∑) indicates the summation over all tied groups and t_i is the number of data values in the *P*th group. If there are not tied groups, this summary process can be ignored (Kisi and Ay, 2014). A tied group is a set of sample data having the same value. In cases where the sample size $n > 10$, the standard normal test statistic Z_S is computed as :

$$Z_S = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}}, & \text{if } S < 0 \end{cases} \tag{4}$$

Positive values of Z_S indicate increasing trends while negative Z_S values show decreasing trends. Testing trends is done at the specific α significance level. The Mann-Kendall is based on rejecting or not the null hypothesis (H_0), that there is no trend in the data series, adopting a level of significance (α). This test was applied to annual rainfall, T_{max} and T_{min} in order to identify trends according to Table 2.

2.1.2. *Sen's slope estimator* - Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for} \quad i = 1, ..., N \tag{5}$$

where, x_j and x_k are the data values at times j and k ($j > k$), respectively.

If there is only one data in each time period, then $N = \frac{n(n-1)}{2}$, where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as :

$$Q_{med} = \begin{cases} Q_{\frac{N+1}{2}}, & \text{if } N \text{ is odd} \\ \dfrac{Q_{\left(\frac{N}{2}\right)} + Q_{\frac{N+2}{2}}}{2}, & \text{if } N \text{ is even} \end{cases} \tag{6}$$

The Q_{med} sign reflects data trend, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability. The confidence interval about the time slope (Hollander and Wolfe, 1973; Gilbert, 1987) can be computed as follows:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{\text{Var}(S)}$$

where, Var(S) is defined in Eqn. (3) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. Then, $M_1 = (n - C_\alpha)/2$ and $M_2 = (n + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max}, are the M_1th largest and the (M_2+1)th largest of the N ordered slope estimates (Gilbert, 1987). The slope Q_{med} is statistically different than zero if the two limits (Q_{min} and Q_{max}) have similar sign. Sen's slope estimator has been widely used in hydrometeorological time series (Gocic and Trajkovic, 2013).

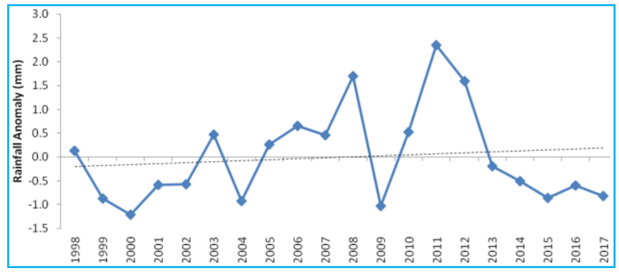


Fig. 2. Annual normalized rainfall for Central Punjab between 1998 and 2017 (Singla *et al*., 2022)

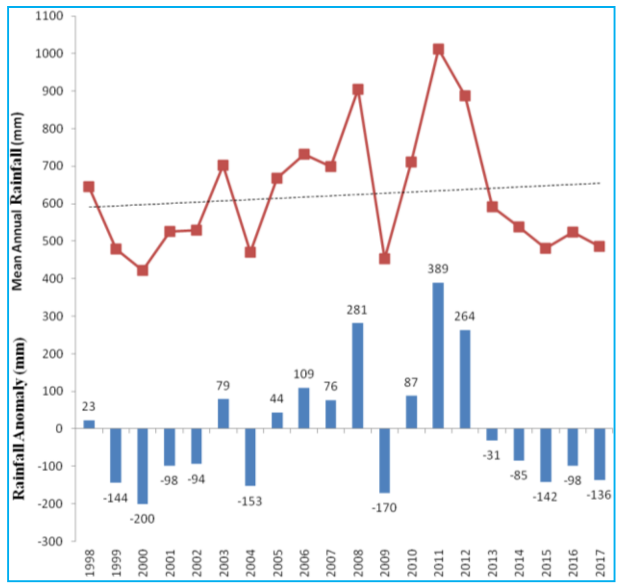
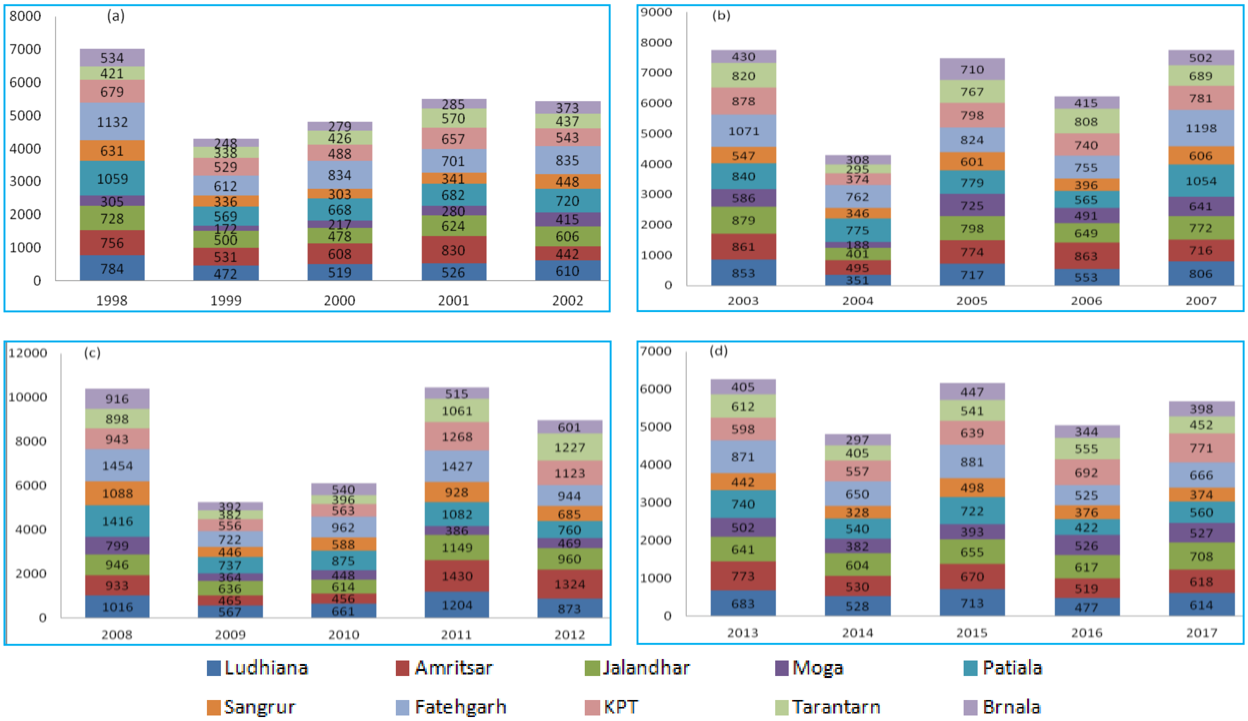


Fig. 3. Rainfall anomaly and mean annual rainfall for Central Punjab between 1998 and 2017 (Singla *et al*., 2022)

3. The Mann-Kendall test and Sen's slope estimator were applied to the time-series 1998-2017 for rainfall, T_{max}, T_{min} for detection of monotonic trends.

3.1. *Rainfall trends* - The rainfall trend analysis using Mann-Kendall and Sen's tests is presented in this section. The rainfall data between 1998 and 2017 from 10 rainfall stations are used for trend analysis for Central Punjab as shown in Fig. 2. The figure shows that only the annual normalized precipitation depth of 3 years (2008, 2011 and 2012) were above one; thus, those years are considered rainy for the region. The normalized precipitation depths below -1 were recorded in years 1999 and 2004 and thus can be classified as very dry years. The mean annual rainfall and the rainfall anomaly for Central Punjab from 1998 to 2017 are presented in Fig. 3. The average annual rainfall is 649 mm, the highest values were 1041 and 1045 mm recorded in years 2008 and 2011 respectively. The least annual rainfall was 429 mm in



Figs. 4(a-d). Annual rainfall district wise (a) 1998 to 2002 (b) 2003 to 2007 (c) 2008 to 2012 and (d) 2013 to 2017

TABLE 3

Results of the statistical tests for rainfall over the period 1998-2017

Station Name	Z_s	Q_{med}	Q_{min}	Q_{max}
Amritsar	0.03	0.598	-15.913	18.595
Tarantaran	**1.01**	7.809	-12.692	35.177
Kapurthala	**1.33**	7.566	-7.602	29.721
Ludhiana	0.81	5.582	-11.082	20.252
Sangrur	0.42	2.157	-10.464	15.553
Moga	**1.91**	11.730	-1.497	21.937
Barnala	0.94	4.411	-6.936	17.953
Fatehgarh Sahib	-0.49	-7.626	-20.034	14.010
Jalandhar	0.94	5.125	-6.438	18.016
Patiala	-0.75	-5.225	-23.368	7.726

2004. The period 2013-17 registered below average rainfall in Central Punjab. The district wise pattern shows that Ludhiana and Jalandhar recorded the highest values in 2008 and 2011 and the lowest in 2004 as same as Central Punjab. The output of the analyzed rainfall series is summarized in Table 3. According to the results of Sen's slope estimator, the increasing trend in annual precipitation series was detected at Tarantaran, Kapurthala, Ludhiana, Moga, Barnala and Jalandhar, while other stations had negative or no trends. Results of the applied Mann-Kendall, showed that the majority of the trends in the annual rainfall series were not significant,

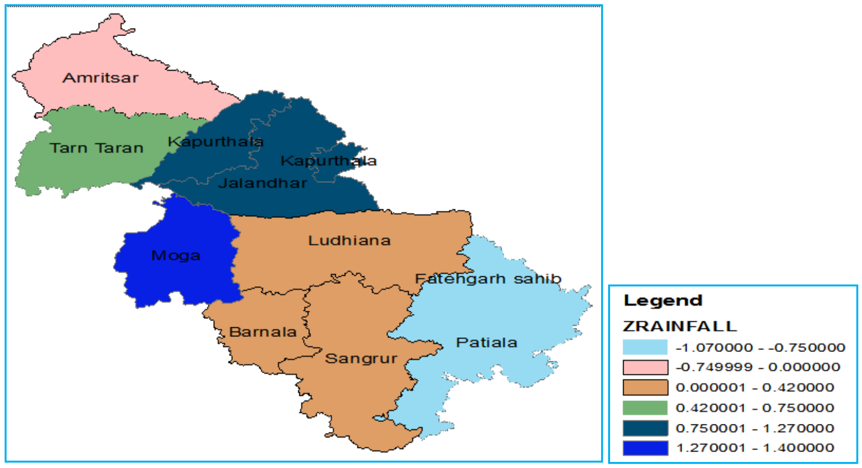


Fig. 5. Spatial Distribution of rainfall by Mann Kendall Analysis

Minimum Temperature **Maximum Temperature**

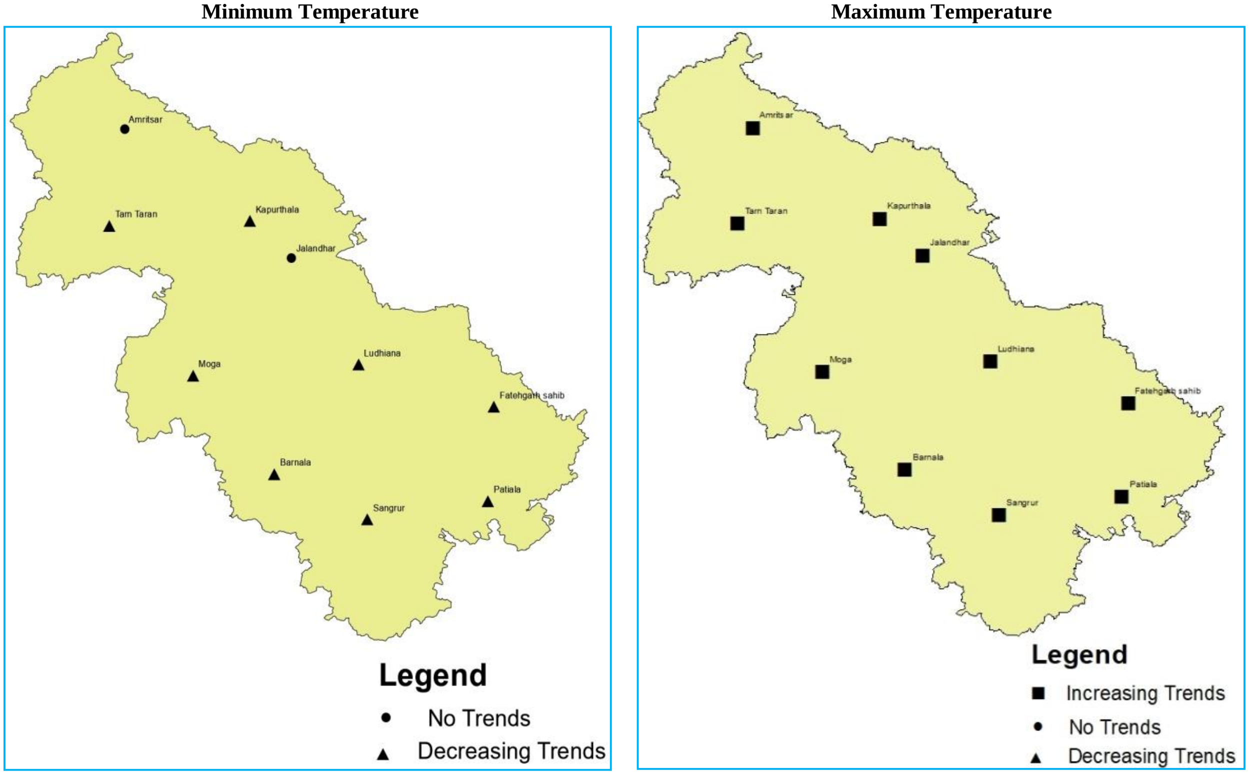


Fig. 6. Spatial distribution of study area with increasing, decreasing and no trends by the Mann-Kendall

while the decreasing trend was found at Fatehgarh and Patiala (Fig. 5). Brázdil *et al.* (2012) did not find any significant change in the annual and seasonal time series of precipitation amounts over the period 1882-2010 in the Czech Republic.

3.2. *Analysis of* T_{min} *and* T_{max} - Results of applying statistical tests for annual T_{max} over the period 1980-2010 are presented in Table 5. The significance level adopted in this study was $\alpha = 0.05$ (5%). On the annual time scale, all the stations showed insignificant increasing trends (Fig. 6). Neither significant positive or negative trends were detected by the trend tests. Patiala registered the greater magnitude of T_{max} increase according to the Sen and Mann-Kendall Method (Z_s = 1.4, Q_{med} = 0.067). Analysis of T_{min} indicated insignificant decreasing trends.

TABLE 4

Results of the statistical tests for maximum temperature over the period 1998-2017

Station Name	Z_s	Q_{med}	Q_{min}	Q_{max}
Amritsar	1.27	0.039	-.047	0.150
Tarantaran	1.14	0.045	-.049	0.146
Kapurthala	1.27	0.047	-.051	0.165
Ludhiana	1.33	0.054	-.045	0.144
Sangrur	1.33	0.062	-.047	0.145
Moga	1.2	0.05	-.054	0.146
Barnala	1.14	0.056	-.052	0.155
Fatehgarh Sahib	1.33	0.062	-.036	0.157
Jalandhar	1.27	0.052	-.055	0.161
Patiala	1.4	0.067	-.041	0.155

TABLE 5

Results of the statistical tests for minimum temperature over the period 1998-2017

Station Name	Z_s	Q_{med}	Q_{min}	Q_{max}
Amritsar	0.0	-0.004	-.086	0.084
Tarantaran	-0.03	-0.006	-.091	0.070
Kapurthala	-0.1	-0.001	-.091	0.078
Ludhiana	-0.1	-0.008	-.109	0.070
Sangrur	-0.68	-0.025	-.120	0.064
Moga	-0.16	-0.018	-.117	0.075
Barnala	-0.49	-0.015	-.121	0.071
Fatehgarh Sahib	-0.29	-0.013	-.110	0.067
Jalandhar	0.0	-0.001	-.096	0.077
Patiala	-0.23	-0.006	-.113	0.058

Sangrur registered the greater magnitude of T_{min} reduction according to the Sen and Mann-Kendall Method (Table 5) ($Z_s = 1.4$, $Q_{med} = 0.067$).

4. Rainfall pattern changes have serious effects on human society and are the focus of investigation in agriculture. Changes in precipitation trends are not uniform. There is large scale exploitation of groundwater for irrigation purposes, causing a sharp decline in groundwater depth. This paper presented trends computed from 1998 to 2017 of annual rainfall, T_{max}, T_{min} obtained from 10 stations in Central Punjab. The analysis was obtained by the non-parametric Mann-Kendall and Sen's methods. The Mann- Kendall test did not show a significant change in the annual rainfall but showed an increasing trend at Tarantaran, Kapurthala, Ludhiana, Moga, Barnala and Jalandhar. The nonparametric statistical tests applied to a series of annual T_{max} revealed an increasing trend in all of the investigated stations. The author suggests building necessary human and institutional capacity to improve a climate and hydro-geological knowledge base to address the impacts of climate change on groundwater resources.

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Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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