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Research Article

Evaluating Rainfall and Groundwater Trend in Different Agroclimatic Zones of Punjab using Mann Kandall and Sen's Slope

ARPNA[1], K.K. GILL[1]*, SAMANPREET KAUR[2], S.S. SANDHU[1] AND CHETAN SINGLA[2]

[1]*Department of Climate Change & Agril. Meteorology, PAU, Ludhiana-141004, Punjab*
[2]*Department of Soil Water Engineering, PAU, Ludhiana, Punjab*

ABSTRACT

The rainfall data of 68 years (1951-2018) and groundwater level data of 24 years (1998-2018) for the different districts of Punjab, India was analysed with the non-parametric Mann Kandall test and Sen's slope estimator methods to observe the increasing or decreasing trend and rate of increase or decrease of rainfall and groundwater levels. It has been observed that the Mann Kandall test showed the decreasing trend of rainfall during the months of January, July, August and an increasing trend of rainfall has been noticed during February, April, May, June and September. The Sen's slope estimator showed that the rate of increase was maximum during the month of June. The groundwater data showed the fall in groundwater level in all the districts except in Mukatsar. The maximum decreasing trend (Z statistics value) and the rate of fall in groundwater has been recorded at Mansa and Sangrur districts, respectively. The regression relationship has also been developed between rainfall and groundwater for different zones of the state.

Key words: Rainfall, Groundwater, Agroclimatic zones, Regression, Mann Kandall, Punjab

Water is the essential part for the growth of human society and quantity or accessibility of water in any area mainly depends upon rainfall and groundwater of that region. Precipitation plays key role in agriculture. Studies have shown that with the increase in global warming there will be a reduction in availability of freshwater (Mondal *et al.*, 2012). Every additional 0.5°C of temperature will increase the extreme rainfall and drought events. Annual rainfall and summer monsoon precipitations are projected to increase while the south west monsoon has declined over the last few decades. (IPCC, 2021). Developing nations like India are more vulnerable toward climate change as they don't have many resources to tackle with disasters and agriculture play dominant role in their economy (Majumder *et al.*, 2016). It has been observed that there will be 10-30 per cent decline in the water availability and average runoff till the middle of 21st century. Extreme events of the rainfall are increasing over time while the frequency of rainfall is falling (Mukherjee *et al.*, 2005 and Goswami *et al.*, 2006). Increasing trend of temperature and increasing trend of rainfall was observed from north east to south west during 1974-2013 in Punjab (Kingra *et al.,* 2017). Decreasing trend of rainfall in south Asia while the increasing trend of annual as well as monsoonal rainfall was found in central Asia (IPCC, 2014). Punjab which is known as bread basket or food bowl of India is also experiencing the fluctuation in temperature as well as in rainfall over the last few decades. Various studies have shown that heavy amount of precipitation is received during the monsoon season and the scarcity of water is there during non-monsoon season (Jain and Kumar, 2012).

*Corresponding author,
Email: kkgill@pau.edu

In view of all the above problems, the present study was planned to understand the rainfall trends in different agroclimatic zones of Punjab by using Mann Kandall test.

Methodology

Study area

Punjab is divided into 5 agroclimatic zones i.e., Sub-mountain zone, Undulating plain zone, Western plain zone, Western zone and Central plain zone which are lying between 30°09′ to 31°06′ N latitude and 74°55′ to 76°23′ E longitude respectively and 211-355 m above the mean sea level. The study involved 20 districts of the state situated in different agroclimatic zones as given below:

1) Sub- Mountain undulating zone - Gurdaspur and Hoshiarpur
2) Undulating plain zone- Rupnagar, Shaheed Bhagat Singh Nagar and Sahibzada Ajit Singh Nagar
3) Central plain zone- Amritsar, Fatehgarh sahib, Jalandhar, Kapurthala, Patiala, Tarn Taran and Ludhiana
4) Western Plain zone- Ferozepur and Faridkot
5) Western zone- Muktsar, Mansa, Barnala, Moga, Bathinda and Sangrur

Data collection and analysis

The rainfall data from 1951-2018 and groundwater data from 1998-2018 of different districts were collected from India Meteorological Department, Pune and Department of Soil and Water Engineering, PAU, respectively. The rainfall data was taken on daily basis and then sum up on monthly basis for further analysis but groundwater data was taken during the monsoon season on annual basis. Rainfall data has been analysed on the monthly basis while the groundwater data was analysed on yearly basis to check trend in all the districts by using Mann Kandall test by the following formula:

$$S(\text{sum}) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sign}\,(xj - xi)$$

Where sign (xj-xi) = 1,

If (xj-xi)>0; 0, if (xj-xi) =0; -1 if (xj-xi) <0

A positive value of S indicates an increasing trend, and a negative value indicates a decreasing trend. This test also assumes that, if the given data has tied values then we need to find variance (S) which calculated by:

$$\text{Variance}(S) = \text{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) \sum_{p=1}^{g} tp(tp-1)(2tp+5) \right]$$

Where, n is the number of data points, g is the number of tied group and t_p is the number of data points in the p^{th} group.

However, it is necessary to perform the statistical analysis for the significance of the trend and the normal Z-statistics is computed as:

$$\text{If } S > 0,\ Z = \frac{S-1}{\sqrt{\text{Var}(s)}}$$

If S= 0, Z= 0

$$\text{If } S < 0,\ Z = \frac{S+1}{\sqrt{\text{Var}(s)}}$$

The trend is said to be decreasing and increasing if Z is negative and positive, respectively for the trend to be significant the computed Z-statistics should be greater than the z-value corresponding to the 5% level of significance. If the computed Z-statistics is less than the z-value corresponding to the 5% level of significance, then there is no trend.

Results and Discussion

The rainfall data was analysed using Mannkendall and Sen's slope estimator method for rainfall during 1951-2018 (68 years) and ground-water during 1998-2018 (20 years) for different agroclimatic zones of Punjab.

Sub mountain undulating zone

Rainfall

Sub mountain undulating zone covers two districts i.e., Gurdaspur and Hoshiarpur. It has been found that rainfall trend in Gurdaspur district showed significant increase and decrease during the month of June (2.32) and July (-4.04), respectively (Table 1). The Sen's slope estimator also indicated a

Table 1. Z statistics value for rainfall in different agroclimatic zones of Punjab during 1951-2018

Districts	Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sub-mountain undulating zone												
Gurdaspur	-1.74	1.59	-0.49	1.29	1.30	2.32*	-4.04*	-1.66	0.14	-0.57	0.31	-1.17
Hoshiarpur	-0.92	0.60	-0.11	2.54*	2.06*	2.65*	-1.78	0.78	0.58	-1.21	-0.59	-0.02
Undulating plain zone												
Rupnagar	-1.11	1.08	0.56	3.04*	1.75	2.33*	-1.07	3.33*	0.16	-0.97	0.43	0.76
SAS Nagar	-0.52	1.25	0.43	2.46*	1.95	3.45*	0.37	-0.08	1.62	-0.05	1.34	0.25
SBS Nagar	-1.75	0.52	-0.75	2.78*	1.26	0.21	-2.29*	-0.65	0.20	-0.89	-0.06	-0.43
Central plain zone												
Amritsar	-0.29	2.17*	0.10	2.08*	1.88	2.61*	0.01	-0.33	1.26	-0.22	0.14	-0.83
Fatehgarh sahib	-0.50	1.23	0.45	2.73*	1.95	2.87*	-0.91	0.59	1.18	-0.11	0.69	0.78
Jalandhar	-0.05	1.75	-0.45	2.50*	1.07	2.73*	-0.40	0.20	1.05	0.61	0.14	-0.25
Kapurthala	-0.04	1.77	-0.41	2.56*	1.10	2.69*	-0.28	0.40	1.12	0.67	0.09	-0.30
Ludhiana	-0.60	1.11	-0.78	1.79	1.11	1.13	0.48	-0.65	1.43	-0.21	0.08	0.65
Patiala	-0.59	1.01	0.17	2.11*	1.67	3.08*	0.06	-0.63	1.49	-0.24	1.23	0.21
Tarn Taran	-0.10	1.53	0.08	1.64	1.12	2.42*	-1.21	-1.64	1.10	0.01	0.00	-0.17
Western plain zone												
Faridkot	-0.84	0.43	-0.83	1.02	0.56	1.43	-2.91*	-2.67*	1.19	-1.13	-0.73	-0.14
Firozpur	-1.29	0.61	-0.98	0.58	0.67	1.16	-2.43*	-2.67*	1.09	-0.94	-0.82	-0.25
Western zone												
Barnala	0.14	0.53	-0.55	1.51	1.61	2.01	-1.60	-1.93	1.52	0.43	1.12	0.25
Bhatinda	0.24	0.90	0.44	2.18*	2.39*	1.99*	-1.73	-1.72	2.91*	0.50	0.17	0.33
Mansa	0.66	0.87	-0.34	1.69	1.26	0.81	-2.80*	-2.44*	0.05	-1.20	-0.05	0.64
Moga	-0.52	-0.07	-1.34	2.10*	0.19	0.71	-1.78	-1.74	1.06	-0.27	0.23	-0.17
Muktsar	0.24	2.07*	0.09	1.90	2.00*	3.67*	-1.02	-1.30	1.11	-0.69	-0.42	0.38
Sangrur	0.64	1.72	0.34	2.29*	1.72	0.89	-1.72	-1.21	0.90	-0.37	0.84	0.90

*Significant at 5 per cent level of significance

significant increase during June (0.74 mm/year) and decrease during July (3.82 mm/year) (Table 2).

At Hoshiarpur, the significant increase in rainfall trend has been observed in April (2.54), May (2.06) and June (2.65) (Table 1). Whereas, the significant rate of increase and decrease was maximum during the month of June (0.94 mm/year) and July (1.34 mm/year), respectively (Table 2).

Groundwater

In the Submountain undulating zone, the Mann Kandall trend analysis indicated higher value in Hoshiarpur district than Gurdaspur district. The higher value signifies the higher falling trend in groundwater levels. The annual rate of decrease in groundwater in Hoshiarpur was 0.47 cm/year and in Gurdaspur was 0.08cm/year (Table 3).

Undulating plain zone

Rainfall

Undulating plain zone covers the three districts i.e., Shaheed Bhagat Singh Nagar, Sahibzada Ajit Singh Nagar and Rupnagar. The significant increase has been recorded during April (3.04 mm/year), June (2.33 mm/year) and August (3.33 mm/year) at Rupnagar, during April (2.46 mm/year) and June (3.45 mm/year) at SAS Nagar and during April (2.78 mm/year) at SBS Nagar. The significant decrease in rainfall trend has been noticed in the month of July (-2.29 mm/year) at SBS Nagar (Table 1).While the rate of increase was maximum and significant in the month of August (2.71 mm/year), June (1.20 mm/year) and April (0.15 mm/year) and decrease during July (0.98 mm/year), and July (1.60 mm/year) at Rupnagar and SBS Nagar, respectively.

Table 2. Sen's slope for rainfall in the different agroclimatic zones of Punjab during 1951-2018

Districts	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sub-mountain undulating zone												
Gurdaspur	-0.55*	0.43*	-0.11	0.13*	0.14*	0.74*	-3.82*	-2.12*	0.10	0	0	-0.03*
Hoshiarpur	-0.18*	0.09	0	0.19*	0.22*	0.94*	-1.34*	0.47	0.21	-0.02*	0	0
Undulating plain zone												
Rupnagar	-0.20*	0.18*	0.08	-0.23*	-0.20*	0.99*	-0.98*	2.71*	0.09	0	0	0
SAS Nagar	-0.06	0.15*	0.05	0.14*	0.19*	1.20*	0.30	-0.07	0.88*	0	0	0
SBS Nagar	-0.34*	-0.06	-0.10	0.15*	0.08*	0.05	-1.60*	-0.42	0.05	0	0	0
Central plain zone												
Amritsar	-0.02	0.29*	0.01	0.13*	0.13*	0.72*	0.01	-0.15	0.41*	0	0	0
Fatehgarh sahib	-0.06	0.13*	0.04	0.10	0.13*	0.97*	-0.57*	0.34	0.46*	0	0	0
Jalandhar	0	0.23*	-0.05	0.11*	0.06*	0.70*	-0.24	0.15	0.38	0	0	0
Kapurthala	0	0.24*	-0.04	0.12*	0.06*	0.71*	-0.16	0.24	0.40*	0	0	0
Ludhiana	-0.07	0.13*	-0.1	0.08*	0.06*	0.33*	0.31	-0.44	0.70*	0	0	0
Patiala	-0.07	0.11	0.01	0.09*	0.15*	1.13*	0.02	-0.51	0.79*	0	0	0
Tarn Taran	0	0.14*	0	0.07*	0.05	0.47*	-0.67*	-0.70*	0.35	0	0	0
Western plain zone												
Faridkot	-0.05*	0.02	-0.05	0.01	0.01	0.30	-1.25*	-1.02*	0.24	0	0	0
Firozpur	-0.06*	0.03	-0.05*	0.00	0.01	0.16	-1.34*	-0.99	0.17	0	0	0
Western zone												
Barnala	0	0.02	0	0	0.03*	0.34*	-0.70	-0.93*	0.33*	0	0	0
Bhatinda	0	0.02	0	0.03*	0.05*	0.32*	-0.74*	-0.67*	0.74*	0	0	0
Mansa	0	0.01	0	0	0.02	0.14	-1.15*	-0.87*	0	0	0	0
Moga	-0.02	0	-0.12*	0.07*	0.00	0.13	-0.83*	-0.86*	0.33*	0	0	0
Muktsar	0.0	0.08*	0	0.0	0.03	0.60*	-0.51*	-0.50*	0.20*	0	0	0
Sangrur	0.01	0.09*	0	0.06	0.07	0.20	-0.96*	-0.55*	0.21*	0	0	0

*Significant at 5 per cent level of significance

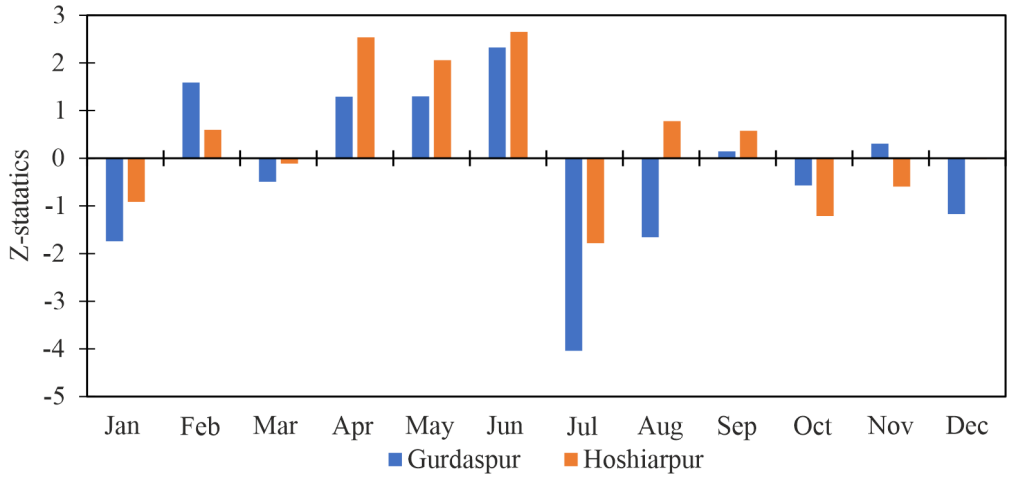

Fig. 1. Monthly rainfall trend using the Mannkendall test for sub-mountain undulating zone

Table 3. Groundwater trend analysis using Mannkendall and Sen's slope estimator during 1998-2018

Zones	Districts	Z statistics value	Sen slope (Q)
Sub-mountain undulating zone	Gurdaspur	2.36*	0.08*
	Hoshiarpur	4.96*	0.47*
Undulating plain zone	Rupnagar	4.52*	0.27*
	SAS Nagar	4.42*	0.45*
	SBS Nagar	4.94*	0.40*
Central plain zone	Amritsar	6.28*	0.39*
	Fatehgarh sahib	5.43*	0.70*
	Jalandhar	6.33*	0.59*
	Kapurthala	4.44*	0.47*
	Ludhiana	5.48*	0.49*
	Patiala	6.20*	0.85*
	Tarn Taran	5.43*	0.45*
Western plain zone	Faridkot	5.89*	0.21*
	Ferozpur	4.19*	0.17*
Western zone	Barnala	6.03*	0.91*
	Bathinda	6.00*	0.33*
	Mansa	6.40*	0.42*
	Moga	6.00*	0.81*
	Mukatsar	-0.45*	0.00
	Sangrur	4.71*	1.01*

*Significant at 5 per cent level of significance

Groundwater

In undulating plain zone, the Mann Kandall test showed the maximum decline at SBS Nagar (4.94 cm/year) followed by Rupnagar (4.52 cm/year) and SAS Nagar (4.42 cm/year). The rate of increase in groundwater depletion was highest in SAS Nagar (0.45 cm/year) followed by SBS Nagar (0.40 cm/year) and Rupnagar (0.27 cm/year) (Table 3).

Central Plain zone

Rainfall

Central plain zone covers 7 districts viz., Amritsar, Fatehgarh Sahib, Jalandhar, Kapurthala, Ludhiana, Patiala and Tarn Taran. The Mannkendall values showed that a significant increasing trend in rainfall has been exhibited during February (2.17 mm/year), April (2.08 mm/year) and June (2.61 mm/year) at Amritsar, during April and June at Fatehgarh Sahib, Jalandhar, Kapurthala and Patiala and during June (2.42 mm/year) at Tarn Taran (Table 1). No month in the central zone showed significant decrease in rainfall trend (Table 1). Maximum and significant rate of increase in rainfall has been noticed during the month of June at Amritsar (0.72 mm/year), Fatehgarh sahib (0.97 mm/year), Jalandhar (0.70 mm/year), Kapurthala (0.71 mm/year), Patiala (1.13 mm/year) and Tarn Taran (0.47 mm/year) while the Ludhiana showed maximum and significant rate of increase in the month of September (0.70 mm/year). The significant rate of decrease has been experienced during July (0.57 mm/year) at Fatehgarh Sahib and during July (0.67 mm/year) and August (0.70 mm/year) at Tarn Taran.

Groundwater

In central zone, Mann Kandall values specified the maximum value in Jalandhar (6.33 cm/year) followed by Amritsar (6.28 cm/year), Patiala (6.20

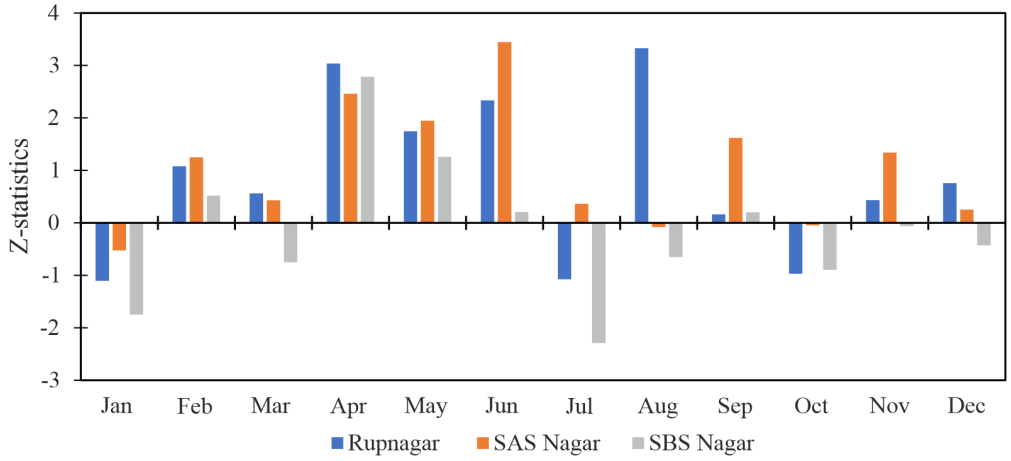

Fig. 2. Rainfall trend using the mannkendall test for undulating plain zone

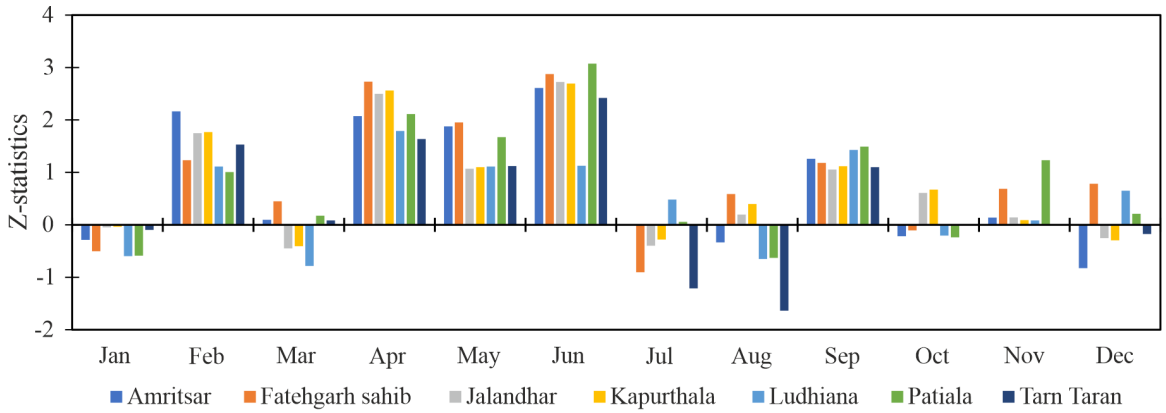

Fig. 3. Rainfall trend using the Mann Kandall test for central plain zone

cm/year), Ludhiana (5.48 cm/year), Fatehgarh Sahib, Tarn Taran (5.43 cm/year) and Kapurthala (4.44 cm/year). The maximum value of Mann Kandall showed that in central zone the maximum fall of groundwater has been observed at Jalandhar. The rate of maximum fall was observed at Patiala (0.85 cm/year) followed by Fatehgarh Sahib (0.70 cm/year) and Jalandhar (0.59 cm/year) and least rate of fall has been recorded at Amritsar (0.39 cm/year) (Table 3).

Western plain zone

Rainfall

Western plain zone covers two districts of the state i.e., Ferozpur and Faridkot. Both the districts of the western plain zone indicated the significant decrease in the rainfall trend during the month of July and August while the statistically significant increase has not been recorded in any month (Table 1). It was also clear from Sen's slope estimator, the significant rate of decrease in rainfall has been found in the month of July (1.25 mm/year) followed by August (1.02 mm/year) at Faridkot and rate of decrease in rainfall observed in Faridkot was 1.34mm/year in July and 0.99 mm/year in August.

Groundwater

In this zone the maximum fall in groundwater has been found in Faridkot followed by Ferozpur which is evident from the Mann Kandall test values of 5.89 and 4.19, respectively. The Sen's slope estimator also showed that the maximum groundwater depletion in Faridkot (0.21 cm/year) followed by Ferozpur (0.17 cm/year) (Table 3).

Western zone

Rainfall

Western zone covers 6 districts i.e., Bathinda, Barnala, Mansa, Moga, Muktsar and Sangrur. It has been noticed that, the significant increase in rainfall

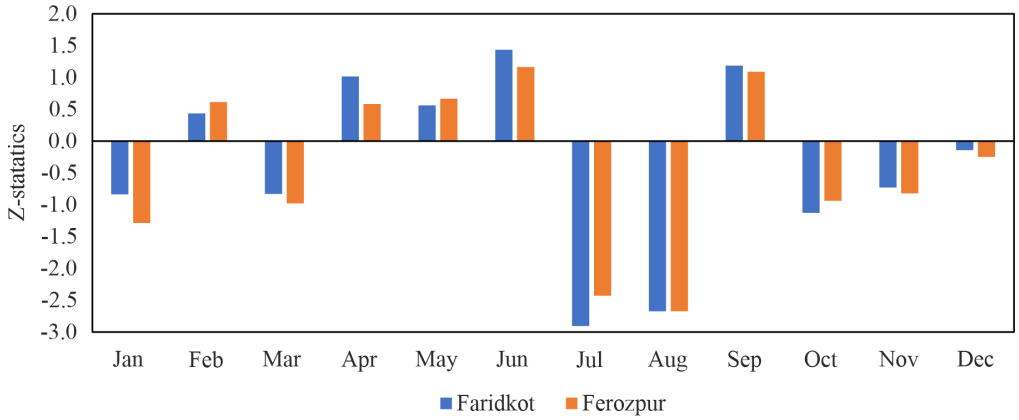

Fig. 4. Rainfall trend using the mannkendall test for western plain zone

trend was observed in the months of April (2.18), May (2.39 mm/year), June (1.99 mm/year) and September (2.91 mm/year) at Bhatinda, during the month of April at Moga (2.10 mm/year) and Sangrur (2.29 mm/year) and during February (2.07 mm/year), May (2.00 mm/year) and June (3.67 mm/year) at Mukatsar. However, no significant increase in any month was found in Mansa and Barnala. The significant decrease was observed in the month of July (-2.80 mm/year) and August (-2.44 mm/year) at Mansa district only (Fig. 5).

Sen's slope indicated that the maximum and significant rate of increase was observed during the month of June at Barnala (0.34 mm/year) and Mukatsar (0.60 mm/year), during September in Bhatinda (0.74 mm/year), Moga (0.33 mm/year) and Sangrur (0.21 mm/year). Among the months, the significant rate of decrease was maximum during the August at Barnala (0.93 mm/year) and Moga (0.86 mm/year), during July at Bhatinda (0.74 mm/year), Mansa (1.15 mm/year), Mukatsar (0.51 mm/year) and Sangrur (0.96 mm/year).

Groundwater

In western zone, the Mann Kandall trend analysis showed the maximum value in Mansa (6.40 cm/year) followed by Barnala (6.03 cm/year) Bathinda (6.00 cm/year) and Moga (6.00 cm/year) and Sangrur (4.71 cm/year). Mukatsar district showed the negative value in the trend which indicates that groundwater level in the district has increased in the last 20 years instead of going down. Sen's slope estimator showed that the groundwater depletion has been recorded maximum at Sangrur (1.01 cm/year) followed by Barnala (0.91cm/year) and Moga (0.81 cm/year) (Table 3).

Regression equation between groundwater and rainfall during 1998-2018

Regression equations between groundwater and rainfall data was established during the two decades (1997-2017) in the different 5 agroclimatic zones of Punjab. It has been observed the significant trend was recorded in the districts of Undulating plain zone, Central plain and Western plain zone. Whereas, no significant trend was noticed in the districts of sub-mountainous undulating and western zone.

During the Ist decade, it has been observed that regression equation between groundwater and rainfall showed significant increase at 5% level of significance in Faridkot ($R^2 = 0.57$) and during IInd decade significant decrease was recorded at Patiala ($R^2 = 0.78$) followed by SAS Nagar. The regression equation between rainfall and groundwater over the last 20 years (1998-2018) exhibit the significant increase has been found in Faridkot and decrease in Patiala followed by SAS Nagar, respectively.

Singla *et al.* (2022) concluded that, in the districts of central Punjab consistent drought during 2013-17 resulted in the over-exploitation of groundwater to such an extent that abstraction far exceeded the recharge and the rainfall and high PET increased the groundwater depth. So, the groundwater depletion in the central zone increased after 2013.

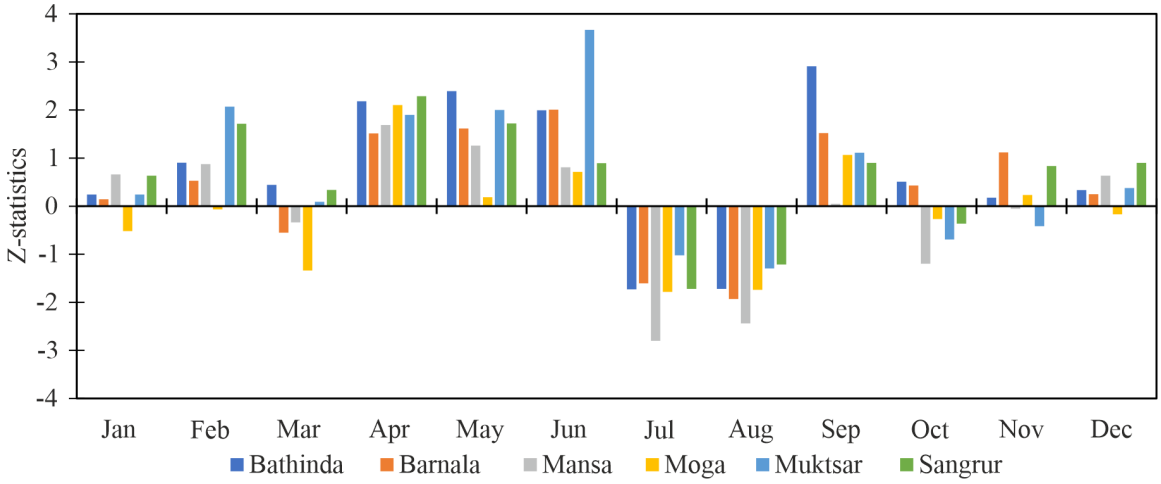

Fig. 5. Rainfall trend using the mannkendall test for western zone

Table 4. Regression equation between groundwater and rainfall during 1998-2018

Zones	Districts	Decade-I (1997-98 to 2006-07)		Decade-II (2007-08 to 2016-17)		1998-2018	
		Equation	R^2	Equation	R^2	Equation	R^2
Undulating plain zone	SAS Nagar	Y = -62.48x + 1480.6	0.30	Y = -31.87x + 1341.9	0.56*	Y = -27.65x +1266.4	0.56*
Central plain zone	Patiala	Y = -9.28x + 1174.6	0.04	Y = -51.75x + 1989.1	0.78*	Y = -27.84x +1439.4	0.57*
Western plain zone	Faridkot	Y = 255.55x - 1294.1	0.57*	Y = 31.01x + 180.43	0.12	Y = 60.11x - 13.12	0.31*

*Significant at 5 per cent level of significance

Conclusion

It can be concluded that the Mann-kendall test exhibited the significant decreasing trend in rainfall during the month of July at Gurdaspur, SBS Nagar, Faridkot, Ferozpur and Mansa, during August at Faridkot, Ferozpur and Mansa. Likewise, the significant increasing trend of rainfall has been experienced in the months of February at Amritsar and Mukatsar, during April at all locations except Gurdaspur, Ludhiana, Tarn Taran, Faridkot, Ferozpur, Barnala, Mansa and Mukatsar**,** during May at Hoshiarpur, Bhatinda, Mukatsar, during June at all locations except SBS Nagar, Ludhiana, Faridkot, Ferozpur, Barnala, Mansa, Moga and Sangrur, during August at Rupnagar and during September at Bhatinda. The Sen's slope estimator showed that the significant rate of increase and decrease has been found maximum during June and July in most of the districts, respectively. The groundwater data showed the decreasing trend of water level in all the districts except Mukatsar and the maximum rate of fall in groundwater has been observed in Western zone (Sangrur followed by Barnala and Bathinda).

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