Eco. Env. & Cons. 30 (October Suppl. Issue) : 2024; pp. (S44-S52)
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ISSN 0971–765X

DOI No. http://doi.org/10.53550/EEC.2024.v30i06s.007

Analysis of Long-term Precipitation Trends in Punjab, India

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(Received 5 March, 2024; Accepted 7 May, 2024)

ABSTRACT

Freshwater is a synonym to life, as life is not possible without water. The variability in climate patterns can have long-term implications and cascading affects which can lead to agricultural instability, water scarcity, habitat loss, wild fires and extreme weather events. The present study evaluates the trends of precipitation in Punjab spatially and temporally. The trends are studied through Mann-Kendall Test and Sen's Slope Estimator Test. The results demonstrate statistically significant decreasing trends in annual and monsoon rainfall in Punjab. The significant variations in annual and monsoonal rainfall can easily translate into increased water demand in domestic, agricultural and industrial sectors. Climate variability and erratic monsoon can act major water stressors in Punjab. Groundwater replenishment is another effect of climate change which can alter surface water and base flows in a region. With the projections of variability in rainfall patterns, environmental malady like desertification can take over Punjab.

Key words: *Kharif, Non-Parametric, Precipitation, Trends, Variability*

Introduction

Water is a predominant element on our planet earth, capable of reshaping atmosphere, hydrosphere, cryosphere, and biosphere. Therefore, water is affected by climate through various mechanisms. Climate can be defined as complex system, which affects atmosphere, hydrosphere, lithosphere and cryosphere" (IPCC, 2007). The foremost genesis of changes in climate can be anticipated due to anthropogenic causes like deforestation, increase in greenhouse gases, industralisation, urbanisation and burning of fossils fuels, which has led to variations in global patterns of temperature, precipitation, humidity and base flow of various gigantic rivers. The global mean air temperatures have risen by 0.85 °C from 1880 to 2010 over land and oceans due to burning of fossil fuels which further lead to increase in greenhouse gases such as carbon dioxide, nitrous oxide, methane, ozone and chlorofluorocarbons (IPCC, 2013).

The water availability in India is swiftly approaching the critical stress level due to increase in water demand for agrarian, industrial and domiciliary needs. Climate Change is expected to increase tumbling effects on water resources due to population explosion, urbanisation, land use changes, and escalation in agricultural and irrigational demands. Climate changes can also exacerbate monsoon patterns which can also affect the economy of India. Thus, the debacle of water scarcity could threaten the livelihood of approximately 1.3 billion popula-

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(Assistant Professor)

tions, residing in the ten river basins, having their origin in the Hindu Kush- Himalayan Mountains (ICIMOD, 2009).

Several researchers like Singh and Jain (2002) and Immerzeel *et al.* (2010) have suspected decrease in snow cover and glacial melts which can easily manifest into water shortages. Singh and Jain (2002); Kulkarni *et al.* (2007) and Dutta *et al.* (2012)have observed that the glaciers in Himachal Pradesh have been suspected to climate change due to low precipitation, which can affect water availability downstream in Punjab. Thus, rainfall variability can affect food security and aggravate drought events on large scale. The delayed and erratic monsoon coupled with high temperatures can prominently increase groundwater exploitation to meet the requirements of water. The variability in precipitation patterns can pose adverse effects on hydrological cycle affecting water availability, groundwater depletion and groundwater contamination.

Similar trends have been detected by Kumar *et al.* (1992); Bhutiyani *et al.* (2007) and Bhutiyani *et al.* (2008) in their studies showing significant climate variability in mean winter maximum and minimum temperature in Punjab. Hingane *et al.* (1985), Bhutiyani *et al.* (2007) and Sidhu *et al.* (2011) also witnessed substantial rise in winter temperatures in northwest India. It represents warming scenario and significant decrease in winter rainfall, which can bring noteworthy reduction in yields of cotton and wheat and higher vulnerability to pest attacks (Chandna *et al.*, 2009 and Jalota *et al.*, 2009). Further, decrease in annual rainfall can also steer decline in maize and rice yields, due to water stress and recurrent occurrence of droughts in Kharif season (Mathauda *et al.*, 2000; Kumar *et al.*, 2004; Sidhu *et al.*, 2011 and Yadav *et al.*, 2012). Furthermore, Panda *et al.* (2019), Kuttippurath *et al.*, (2021), Bora *et al.* (2022) and Kakkar *et al.* (2022) have found significant changes in long term patterns of rainfall implying changes in climate in India.To tackle the challenges and to alleviate the repercussions of climate change especially rainfall variability, there is need to adopt an adaptive approach to reduce the risk and vulnerabilities of climate change for better decision-making and cope with extreme weather events.

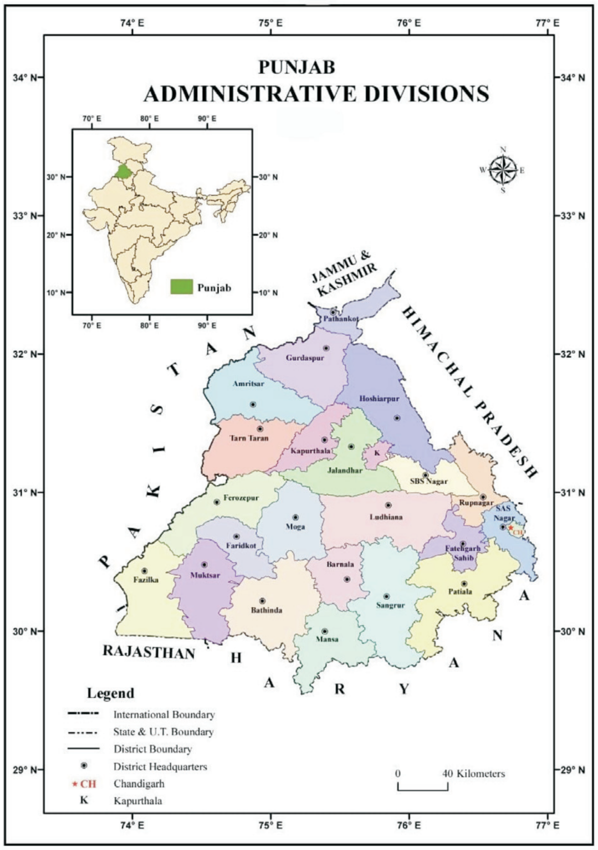
Study Area

The Punjab state derives its name from two Persian words: *panj* and *ab*, which means land of five rivers. Situated in the northwestern part of India, the state extends from 29º 33' N to 32º 32' N latitudes and from 73º 54' E to 76º 50' E longitudes as shown in Map 1. The state covers a geographical area of 50,362 square kilometers, which accounts 1.57 per cent of the total area of the country. The climate of Punjab can be broadly defined as warm temperate continental type of climate, which describes that Punjab state is located in the interior of the continent and is characterized with extreme seasons. There is considerable variability in the annual temperature; with high range of 21 ºC. Precipitation is highly erratic, depending on monsoons and western disturbances. There is occurrence of pre-monsoon showers in the late April and May, which are localized thunderstorms in nature, generated due to local convective systems. Punjab experiences a pronounced dry season with 70 per cent of rainfall in three months of the year from mid-July to September.

Materials and Methods

The study analyses annual and seasonal rainfall trends for 17 meteorological stations which are Gurdaspur, Amritsar, Jalandhar, Hoshiarpur, Kapurthala, Rupnagar, Ludhiana, Ferozepur, Faridkot, Sangrur, Bathinda, Moga, SBS Nagar, Muktsar and Patiala. The data was collected from India Meteorological Department, Chandigarh for 60 years (1961-2020). The rainfall data for Rupnagar and Faridkot was available from 1970 and 1975, respectively. Whereas, rainfall data of Moga, SBS Nagar and Muktsar was available from 1995. For the comprehensive study, the climate of Punjab was divided into four seasons viz. Winter Season (December, January and February), Pre-monsoon Season (March, April and May), Monsoon Season (June, July, August and September) and Post-monsoon Season (October and November).

In addition to mean, the standard deviation and coefficient of variation were also computed, which indicates the amount of fluctuation in the variable from mean values over the period of time. The annual and seasonal trends and patterns of rainfall has been analysed using non-parametric test which are Mann Kendall test and Sen's Slope Estimator test. Mann Kendall test is deployed to determine statistically significant trend, whereas, Sen's slope Estimator test is used to identify the slope of the trend (Nasher and Uddin, 2013). The Mann-Kendall test is extensively used to analyse the statistical significant trends in hydrological climate variables, with refer-



Source: Census of India, 2011

Map 1. Administrative Divisions of Punjab

ence to climate change (Kumar *et al.*, 2010 and Bora *et al.*, 2022). It checks null hypothesis of no trend versus the alternative hypothesis of existing increasing or decreasing trends (Jain and Kumar, 2012). The Excel template MAKSENES (Mann Kendall test for trend and Sen's Slope Estimator Test), developed by researchers of Finnish Meteorological Institute, has been used for the computation of trends. The Mann Kendall test statistics is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

where, x_j and x_k are the annual values in years *j* and *k*, *j* >*k*, respectively, and n' is the number of data values less than 10, and sgn(x_j–x_k) is calculated as follows:

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k > 0 \\ -1 & if\ x_j - x_k > 0 \end{cases}$$

Under the hypothesis of independent and randomly distributed variables when n is 10 or more, the statistic *S* is approximately normally distributed with zero mean and the variance Var(*S*) as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

where, q is the number of tied groups and tp is the number of data values in the pth group. The values of S and VAR(S) are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases}$$

A positive value of Z indicates an upward trend and negative value of Z indicates downward trend. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where, $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKSENES, the significant levels are 0.01, 0.05, 0.1.

To estimate the magnitude of the trend, slope is computed using non-parametric Sen's slope estimator test. The Sen's method can be used in cases where the trend can be assumed to be linear:

$$f(t) = Qt + B$$

where Q is the slope, B is a constant and t is time. To derive an estimate of the slope Q, the slopes of all data pairs are calculated using the equation

$$Q_i = \frac{x_j - x_k}{j - k}$$

where *j*>*k* .

If there are *n* values, *xj* in the time series we get as many as $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator of slope is the median of these *N* values of Q_i. The *N* values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

$$Q = Q_{[(N+1)/2]},\ if\ N\ is\ odd$$

or

$$Q = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right),\ if\ N\ is\ even$$

A 100(1-α) per cent two-sided confidence interval about the slope estimate is obtained by the non-parametric technique based on the normal distribution. Therefore, a positive value of Q_i represents an increasing trend, while, negative value of Q_i represents a decreasing trend.

Results and Discussion

Annual Rainfall Trends

The annual rainfall trends shows district Gurdaspur receives maximum rainfall (912 mm), followed by Rupnagar (803.4 mm) and Hoshiarpur (796 mm). Whereas, district Mansa receives minimum rainfall of 223.1 mm. The highest standard deviation was observed in the district Gurdaspur (204.7 mm) whereas, lowest was found in Mansa district (93.7 mm) as shown in Table 1. The Mann Kendall test shows statistically significant decreasing trends in district Amritsar, Hoshiarpur, Ludhiana, Bathinda and Mansa at 0.05 significance level. While, in district Ferozepur, Jalandhar and Sangrur statistically significant decreasing trends are found at 0.01 significance level. District Gurdaspur exhibits statistically significant decreasing trend at 0.1 significance level. The negative slopes are evident in Amritsar (-1.75 mm/year), Gurdaspur (-1.72 mm/year), Jalandhar (-1.35 mm/year), Hoshiarpur (-1.3 mm/year), Ludhiana (-1.25 mm/year), Patiala (-1.22 mm/year), Ferozepur (-0.7 mm/year), Kapurthala (-0.6 mm/year), Sangrur (-0.5 mm/year), Fatehgarh Sahib (-0.4 mm/year), Bathinda (-0.3 mm/year) and Mansa (-0.3 mm/year). The districts showing positive slopes are Faridkot (1.2 mm/year) Rupnagar (0.5 mm/year), Moga (0.5 mm/year), Muktsar (0.3 mm/year) and SBS Nagar (0.3 mm/year).

Seasonal Rainfall Trends

Mean Winter Rainfall Trends

The highest mean winter rainfall is received by district Gurdaspur (34.7 mm) followed by Hoshiarpur (29.05 mm) and Rupnagar (24.15 mm) as shown in table 2. The lowest rainfall was received by district Moga (8.04 mm) and Mansa (5.62 mm). The highest standard deviationwas observed in district Gurdaspur (15.7 mm), followed by Hoshiarpur (14.9 mm) and SBS Nagar (13.29 mm). The highest coefficient of variation was observed in Ferozepur (0.7 per cent), followed by Fatehgarh Sahib and Patiala. The lowest coefficient of variation of 0.4 per cent was

Table 1. Annual Mean Rainfall Trends Using Mann Kendall Test and Sen's Slope Estimator Test in Districts of Punjab from 1961-2020

Meteorological Station	Annual Mean Rainfall (mm)	Standard Deviation (mm)	Coefficient of Variation (per cent)	Mann-Kendall Test	Sen's Slope Estimator Test (mm/year)
Amritsar	540	167.1	0.3	**-2.49***	-1.75
Bathinda	358.3	109.9	0.3	**-2.56***	-0.3
Faridkot	429.9	122.3	0.2	0.45	1.2
Fatehgarh Sahib	549.7	164.3	0.3	-0.27	-0.4
Ferozepur	321.6	118.1	0.3	**-2.72****	-0.7
Gurdaspur	912	204.7	0.12	**-1.65+**	-1.72
Hoshiarpur	796	178.3	0.2	**-2.46***	-1.3
Jalandhar	663.03	200.2	0.3	**-2.6****	-1.35
Kapurthala	558	165.8	0.2	-0.77	-0.6
Ludhiana	557	138.3	0.2	**-2.18***	-1.25
Mansa	223.1	93.7	0.4	**-2.57***	-0.3
Moga	307.2	110.7	0.3	0.94	0.5
Muktsar	343.3	99.4	0.2	0.57	0.4
Patiala	670	156.1	0.2	-0.83	-1.22
Rupnagar	803.4	108	0.1	0.7	0.5
Sangrur	410.6	110	0.2	**-2.64****	-0.5
SBS Nagar	628.9	116.6	0.2	0.51	0.3

** Statistical significance of 0.01
* Statistical significance of 0.05
+ Statistical significance of 0.1
Source: Researcher's calculations based on IMD Data, 1961-2020

observed in district Amritsar, Gurdaspur, Kapurthala and Ludhiana. The Mann-Kendall test shows statistically significant decreasing trends in Ferozepur at 0.1 significance level and in district Hoshiarpur and Jalandhar at 0.01 significance level. The increasing trends were evident in district SBS Nagar at 0.5 significance level.

The mean winter seasonal rainfall shows positive change in slope in the district Kapurthala (0.09 mm/year), Gurdaspur (0.08/year mm/year), SBS Nagar (0.6 mm/year), Bathinda (0.05 mm/year), and Sangrur (0.02 mm/year). Whereas, negative slopes are witnessed in mean winter seasonal rainfall in district Faridkot (-0.33 mm/year), Fatehgarh Sahib (-0.26 mm/year), Mansa (-0.13 mm/year), Moga (-0.13 mm/year), Ferozepur (-0.09 mm/year), Patiala (-0.08 mm/year), Ludhiana (-0.08 mm/year), Amritsar (-0.05 mm/year), Jalandhar (-0.04 mm/year), Rupnagar (-0.04 mm/year), Muktsar (-0.01 mm/year) and Hoshiarpur (-0.01 mm/year).

Mean Pre-monsoon Rainfall Trends

The highest mean pre-monsoon rainfall is received by district Gurdaspur (26.9 mm), followed by Rupnagar (20.39mm) and Jalandhar (19.9mm) while Mansa (6.98 mm) received lowest rainfallas shown in Table 2. The highest standard deviation was observed in Gurdaspur (14.3mm), followed by Moga (11.92 mm), SBS Nagar (10.7 mm). The highest coefficient of variation was observed in Moga (1 per cent), followed by district Bathinda and Mansa (0.7 per cent). The lowest coefficient of variation was observed in district Amritsar, Kapurthala, Ferozepur with a value of 0.4 per cent.The statistically significant increasing trend was observed in district Faridkot at 0.01 significance level, whereas significant decreasing trend was observed in district Jalandhar at 0.5 significance level.The pre-monsoon seasonal rainfall shows positive change in slope in district Fatehgarh Sahib (0.34 mm/year), SBS Nagar (0.25 mm/year), Moga (0.19 mm/year), Rupnagar (0.18 mm/year), Faridkot (0.09 mm/year), Kapurthala (0.07 mm/year), Sangrur (0.04 mm/year) and Ludhiana (0.01 mm/year). Whereas, negative slopes are experienced in district Muktsar (-0.18 mm/year), Jalandhar (-0.11 mm/year), Mansa (-0.10 mm/year), Bathinda (-0.06 mm/year), Gurdaspur (-0.05 mm/year), Ferozepur (-0.05 mm/year), Hoshiarpur (-0.03 mm/year), Amritsar (-0.02 mm/year) and Patiala (-0.01 mm/year).

Mean Monsoon Rainfall Trends

The highest mean monsoon rainfall is received by district Gurdaspur (175.6mm), followed by Rupnagar (162.3 mm) and Hoshiarpur (158.6 mm). While district Mansa (45.76 mm) received the lowest mean monsoon rainfall. The highest standard deviation was observed in district Gurdaspur (46.2 mm), followed by Hoshiarpur (43.11 mm) and Jalandhar (41.88 mm) as shown in Table 2. The highest coefficient of variation was observed in Ferozepur, Kapurthala, Moga and Mansa (0.4 per cent), while lowest was found in Rupnagar with 0.1 per cent. The mean monsoon rainfall trends show decreasing trends in all districts except Rupnagar, Faridkot, Muktsar and Moga. The significant decreasing trends were evident in district Gurdaspur at 0.1 significance levels and district Hoshiarpur, Jalandhar, Ludhiana at 0.5 significance level. While, district Amritsar, Sangrur, Bathinda, Ferozepur and Mansa show decreasing trend at 0.01 significance level. The mean monsoon rainfall shows positive slopes in district Faridkot (0.69 mm/year), Moga (0.63 mm/year), Muktsar (0.44 mm/year) and Rupnagar (0.13 mm/year). The negative slopes are observed in district Mansa (-2.01 mm/year), Fatehgarh Sahib (-1.2 mm/year), Amritsar (-0.79 mm/year), Hoshiarpur (-0.76 mm/year), Jalandhar (-0.72 mm/year), Gurdaspur (-0.7 mm/year), Bathinda (-0.67 mm/year), Sangrur (-0.65 mm/year), Ludhiana (-0.6 mm/year) Ferozepur (-0.58 mm/year), SBS Nagar (-0.55 mm/year) and Patiala (-0.32 mm/year). No trend was observed in district Kapurthala.

Mean Post-monsoon Rainfall Trends

The highest mean post-monsoon rainfall is received by district Rupnagar (12.38 mm), followed by Gurdaspur (12.3 mm), Jalandhar (9.54 mm) and Kapurthala (9.2 mm). While lowest mean post-monsoon rainfall was received by district Mansa (1.14 mm). The highest standard deviation was observed in Rupnagar (23.38 mm), followed by Ludhiana (14.1 mm) and Kapurthala (13.94 mm). The highest coefficient of variation was observed in district Rupnagar (1.9 per cent), followed by district Faridkot (1.68 per cent) and Ludhiana (1.6 per cent). The lowest coefficient of variation was observed in district Kapurthala (0.2 per cent) and Jalandhar (0.1 per cent). The mean post monsoonal rainfall trends show statistically significant decreasing trends in

Table 2. Seasonal Mean Rainfall Trends using Mann-Kendall Test and Sen's Slope Estimator Test in Districts of Punjab from 1961-2020

Meteorological Station	Seasons	Mean Rainfall (mm)	Standard Deviation (mm)	Coefficient of Variation (per cent)	Mann-Kendall Test	Sen's Slope Estimator Test (mm/year)
Amritsar	Winters	17.52	8.36	0.4	-0.62	-0.05
	Pre-monsoon	19.16	8.43	0.4	-0.46	-0.02
	Monsoon	100.79	35.66	0.3	-2.79**	-0.79
	Post-monsoon	7.41	7.73	1.04	0.28	0.01
Bathinda	Winters	10.62	6.6	0.63	0.92	0.05
	Pre-monsoon	11.36	7.9	0.7	-0.99	-0.06
	Monsoon	71.68	25.54	0.3	-2.94**	-0.67
	Post-monsoon	3.64	3.58	0.98	-1.66+	-0.03
Faridkot	Winters	14.13	7.6	0.5	-0.88	-0.33
	Pre-monsoon	13.58	8.95	0.6	2.67**	0.09
	Monsoon	84.25	28.16	0.3	0.63	0.69
	Post- monsoon	6.9	11.57	1.68	0.27	0.02
Fatehgarh Sahib	Winters	16.56	10.7	0.6	-0.76	-0.26
	Pre-monsoon	14.49	8.43	0.6	1.33	0.34
	Monsoon	112.98	38.43	0.3	-0.39	-1.2
	Post- monsoon	6.99	7.82	1.12	1.18	0.16
Ferozepur	Winters	10.3	8.01	0.7	-1.95+	-0.09
	Pre-monsoon	11.66	5.39	0.4	-1.21	-0.05
	Monsoon	62.68	25.26	0.4	-2.72**	-0.58
	Post- monsoon	2.57	3.01	1.17	-1.22	-0.01
Gurdaspur	Winters	34.7	15.7	0.4	0.56	0.08
	Pre-monsoon	26.9	14.3	0.5	-0.6	-0.05
	Monsoon	175.6	46.2	0.2	-1.82+	-0.7
	Post- monsoon	12.3	10.9	0.8	0.78	0.04
Hoshiarpur	Winters	29.05	14.9	0.5	-3.19**	-0.01
	Pre-monsoon	19.8	9.9	0.5	-0.54	-0.03
	Monsoon	158.6	43.11	0.2	-2.05*	-0.76
	Post- monsoon	8.9	7.8	0.8	-0.9	-0.04
Jalandhar	Winters	20.9	11.6	0.5	-2.66**	-0.04
	Pre-monsoon	19.9	9.97	0.5	-1.97*	-0.11
	Monsoon	131.07	41.88	0.3	-2.09*	-0.72
	Post-monsoon	9.54	9.91	0.1	-3.05**	-0.11
Kapurthala	Winters	20.02	9.9	0.4	1.11	0.09
	Pre-monsoon	17.9	10.1	0.4	1.05	0.07
	Monsoon	112.9	32.4	0.4	0	0
	Post-monsoon	9.2	13.94	0.2	0.4	0.01
Ludhiana	Winters	16.27	7.98	0.49	-1.23	-0.08
	Pre-monsoon	15.54	8.03	0.5	0.11	0.01
	Monsoon	112.35	31.49	0.2	-2.06*	-0.6
	Post-monsoon	8.52	14.1	1.6	0.11	0.01
Mansa	Winters	5.62	3.68	0.6	-0.91	-0.13
	Pre-monsoon	6.98	4.85	0.7	-0.75	-0.1
	Monsoon	45.76	21.47	0.4	-2.69**	-2.01
	Post- monsoon	1.14	1.24	1.09	-0.94	-0.03
Moga	Winters	8.04	4.76	0.5	-0.39	-0.13
	Pre-monsoon	11.85	11.92	1.0	0.9	0.19
	Monsoon	62.18	27.61	0.4	0.6	0.63
	Post- monsoon	2.18	2.44	1.1	0.3	0.03
Muktsar	Winters	10.1	5.93	0.5	-0.15	-0.01

	Pre-monsoon	11.93	7.98	0.6	-0.75	-0.18
	Monsoon	68.98	23.09	0.3	0.63	0.44
	Post- monsoon	2.8	4.3	1.5	-0.73	-0.05
Patiala	Winters	16.47	9.86	0.6	-1.13	-0.08
	Pre-monsoon	16.97	9.46	0.5	-0.09	-0.01
	Monsoon	129.1	37.05	0.2	-0.99	-0.32
	Post- monsoon	8.71	11.42	1.3	-0.62	-0.02
Rupnagar	Winters	24.15	12.24	0.5	-0.36	-0.04
	Pre-monsoon	20.39	10	0.5	1.59	0.18
	Monsoon	162.3	28.31	0.1	0.4	0.13
	Post- monsoon	12.38	23.38	1.9	-0.49	-0.03
Sangrur	Winters	11.79	7.11	0.6	0.25	0.02
	Pre-monsoon	12.51	6.13	0.5	0.78	0.04
	Monsoon	82.82	25.47	0.3	-2.83**	-0.65
	Post- monsoon	3.75	3.65	0.9	-1.86+	-0.04
SBS Nagar	Winters	22.8	13.29	0.5	2.26*	0.6
	Pre-monsoon	19.3	10.7	0.5	0.88	0.25
	Monsoon	123.9	30.8	0.2	-0.39	-0.55
	Post- monsoon	6.6	9.4	1.4	0.48	0.04

** Statistical significance of 0.01
* Statistical significance of 0.05
+ Statistical significance of 0.1
Source: Researcher's calculations based on IMD Data, 1961-2020

mean post-monsoon rainfall in Jalandhar at 0.01 significance level while, district Sangrur and Bathinda depict decreasing trend at 0.1 significance level. The post-monsoon rainfall shows positive slopes in district Fatehgarh Sahib (0.16 mm/year), Gurdaspur (0.04 mm/year), SBS Nagar (0.04 mm/year), Moga (0.03 mm/year), Faridkot (0.02 mm/year), Kapurthala (0.01 mm/year), Amritsar (0.01 mm/year) and Ludhiana (0.01 mm/year). Whereas, negative slope are observed in district Jalandhar (-0.11 mm/year), Muktsar (-0.05 mm/year), Hoshiarpur (-0.04 mm/year), Sangrur (-0.04 mm/year), Bathinda (-0.03 mm/year), Mansa (-0.03 mm/year), Rupnagar (-0.03 mm/year), Patiala (-0.02 mm/year) and Ferozepur (-0.01 mm/year) as shown in Table 2.

Conclusion

It can be concluded that the significant decreasing trends are witnessed in annual mean rainfall in the major part of Punjab. The decline in average mean rainfall was detected in Amritsar, Bathinda, Ferozepur, Jalandhar, Gurdaspur, Hoshiarpur, Fatehgarh Sahib, Mansa, Ludhiana, Patiala and Sangrur districts. The increase in annual mean rainfall was witnessed in district Kapurthala, Moga, Muktsar, Rupnagar and Faridkot. The seasonal rainfall trends show decreasing trends in all seasons in majority of districts. Significant decreasing winter rainfall trends are witnessed in district Jalandhar, Ferozepur and Hoshiarpur. Similarly, district Gurdaspur, Jalandhar, Ferozepur, Hoshiarpur, Ludhiana, Sangrur, Amritsar, Bathinda and Mansa display significant decreasing trends in mean monsoon rainfall. The mean pre-monsoon rainfall also show significant decreasing trend in district Jalandhar. While, district Jalandhar, Bathinda and Sangrur shows significant decreasing trends in mean post-monsoon rainfall. Significant increasing trends were only observed in district SBS Nagar in mean winter rainfall and district Faridkot in mean pre-monsoon rainfall.

The variability in rainfall patterns can have significant impact in agrarian economy of Punjab. The southwestern part of Punjab shows decrease in rainfall in both monsoon and post-monsoon season, which can easily manifest into drought like conditions. With significant decline in annual and monsoonal rainfall, there can be distinct changes in groundwater replenishment and hydrogeology of Punjab which, can further intensify chronic water shortages in the state. The fluctuation in stream flows and escalation in glacial retreats can lead to decline in production of Kharif crop due to dearth of water availabity for agricultural production. Especially, Rice which is a water guzzling crop can be adversely affected due to changes in rainfall patterns in monsoon season.

The role of climate change in water crisis is uncertain and unpredictable. Various climate change projections reveal alteration in rainfall dynamics leading to climatic variability, through phenomena of floods and droughts. In the face of growing water scarcity and induced climatic changes, the demand of freshwater resources will rise by 55 per cent between 2000 and 2050 (OECD, 2012). Increased freshwater scarcity, exacerbated by climate change, can easily be translated into increased cost of water for agriculture, economies and domestic activities (Planning Commission, 2011). According to UK Meteorology, if climate change scenarios are not addressed properly in near future, can lead to severe droughts every year by 2100 (United Nations, 2007). Climate change is a cross-cutting challenge which requires effective policies, mitigation, adaptation and focuses on efforts to have sustainable development.

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