SPATIO -TEMPORAL ANALYSIS OF PRECIPITATION IN PUNJAB PROVINCE, PAKISTAN

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Abstract- The monthly ground-based precipitation data from 39 stations were utilized to analyze the variation in Punjab Province from 1960-2019. The Mann–Kendall method was employed to evaluate precipitation spatial-temporal trends. There are also major periods, from 1974 to 1977 and 2009 to 2015, with rising yearly precipitation. The southern Punjab area noted a greater value of the coefficient of variation (CoV) for yearly precipitation. Summer & winter season showing increasing trend on overall stations. In contrast, autumn and spring show a decreasing trend for many stations. It can be found that the Punjab province has become wetter in summer and winter from the period of 1961 to 2019.

Keywords- Precipitation, Punjab, Spatio-temporal analysis, Stations data.

1 Introduction

The world climate seems to be varying at an exceptional rate. Punjab province of Pakistan is facing severe climatic catastrophes such as floods and droughts. It is extremely affected by the social, environmental and economic losses due to climate change [1]. It should be emphasized that 2005 and 2010 saw the majority of the catastrophic floods. It affects many people, land, crops, and property. Over 450 medical management centres, nearly a million homes, and nearly 90% of the regions used for food restoration were all destroyed [2]. According to a study, the 2010 flood in the Chenab and Jhelum was the worst since it caused more damage than the tidal wave disasters of 2004, 2005, and 2009, the earthquake catastrophes in Pakistan, and the earthquakes in the Caribbean countries combined [3]. Drought is also frequent in Pakistan, influencing social, economic, and environmental society [4]. Droughts have become more common and intense over the past 20 years. It has the worst effect on Punjab province's economy the most from 1998 to 2001 [5]. The drought from 2000 to 2002 is considered the worst since it caused many fatalities, widespread migrations, agricultural failures, and a water crisis. 2.2 million persons were impacted nationwide [6].

Precipitation is an essential factor that significantly affects the likelihood of severe climatic occurrences. Therefore, it is essential to comprehend precipitation properties properly as it forms the foundation of analyses of drought and flooding. Numerous research on precipitation trends has been conducted [7], [8]. Precipitation trends throughout the long or short term are mostly identified utilizing two approaches, i.e., Mann Kendall test and Sen's slope [9], [10]. Additionally, few articles on the study of precipitation, flooding, and drought in this area have been published [1]. Few studies have concentrated on this basin's long- and short-term precipitation study [11]. Therefore, a long term and thorough examination of precipitation variability for the Punjab province, Pakistan, is required.

This research examines the precipitation series' spatial and temporal variation. This study aims to: (1) get the fundamental properties of precipitation at various time scales; (2) get the trend and variations in precipitation, and (3) analyze extreme precipitation occurrences from 1961 to 2019.

2 Study Area

Punjab Province (Figure 1) is located at 31°79'48'' Latitude and 74°12'36'' Longitude with a total area of about 205,344 square kilometers and covers almost 26% of Pakistan. Punjab is the second largest province of Pakistan. This province's climate consists of tropical and costal climates, with annual mean precipitation of less than 400 mm [12]. In the cool zone, the yearly average temperature ranges from less than 7 to 12 degrees centigrade to more than 25 degrees centigrade in the scorching lowlands. The wet season, known as the monsoon, lasts from July -September. The sub-mountain area averages 960 mm of annual rainfall, whereas the plains receive 460 mm [13]. The ratio of rainfall fluctuates by around 50 mm/month in the rest of the months. Thus, irrigation water from canals is utilized to grow crops during this period.

The monthly climatic data for all stations is extracted from spatial data and downloaded from the **NASA Earth science data** website. Table 1 shows the statistics from 1961 to 2019 of 39 ground stations in Punjab. These stations were chosen depending on their past temporal analysis, consistency, and totality of data; their locations are shown in Figure 1.

Table 1 Overview of 39 ground-based observation data in terms of annual and monthly mean precipitation

Cities	Maximum [mm]	Minimum [mm]	Monthly Mean Precipitation [mm]	Annually Mean precipitation [mm]	Standard Deviation [mm]	Cv
Islamabad	621.87	0.88	80.55	966.57	82.17	1.02
Bahawalnagar	137.64	0.75	16.71	200.47	21.82	1.31
Bahawalpur	154.84	0.60	13.27	159.23	17.89	1.35
Rahimyar Khan	149.25	0.74	13.22	158.66	17.45	1.32
Dera Ghazi Kha	173.66	0.71	18.78	225.39	23.84	1.27
Layyah	119.52	0.48	15.54	186.53	19.04	1.22
Muzaffargarh	135.20	0.59	14.43	173.15	19.30	1.34
Rajan Pur	173.35	0.91	16.16	193.97	21.91	1.35
Faisalabad	195.42	0.74	29.68	356.22	37.15	1.25
Jhang	133.58	0.65	22.14	265.74	26.15	1.18
Toba Tek Singh	144.60	0.67	22.12	265.44	27.04	1.22
Gujarat	329.50	0.57	43.56	522.77	50.66	1.16
Gujranwala 1	307.94	0.58	45.06	540.71	54.09	1.20
Gujranwala 2	354.63	0.57	48.27	579.22	57.13	1.18
Gujrat	563.93	0.72	69.17	830.08	84.12	1.22
Hafizabad	266.92	0.55	36.85	442.21	43.38	1.18
Narowal 1	547.96	0.79	76.28	915.37	96.34	1.26
Narowal 2	402.14	0.74	57.78	693.36	72.68	1.26
Sialkot	524.90	0.76	69.25	831.03	86.67	1.25
Kasur	196.60	0.59	32.03	384.30	40.30	1.26
Lahore	240.22	0.68	40.82	489.78	50.64	1.24
Nankana Sahib	212.93	0.59	32.39	388.63	39.74	1.23
Okara 1	153.64	0.63	25.00	300.03	32.26	1.29
Okara	179.86	0.62	26.58	318.91	33.68	1.27
Sheikhupura	258.98	0.61	40.27	483.26	49.11	1.22
Khanewal	99.37	0.44	14.05	168.61	17.63	1.25
Lodhran	109.94	0.40	10.97	131.63	14.07	1.28
Multan	117.05	0.38	11.87	142.48	15.74	1.32
Pakpattan	137.09	0.58	19.15	229.79	23.73	1.24
Sahiwal	144.56	0.61	21.30	255.58	26.87	1.26
Vehari	98.89	0.60	13.98	167.71	17.40	1.24
Attok	278.79	0.55	45.00	540.05	40.78	0.91

Chakwal	284.49	0.56	41.12	493.47	40.86	0.99
Jhelum	411.55	0.57	53.46	641.50	59.50	1.11
Rawalpindi	511.13	0.74	68.07	816.89	67.00	0.98
Bhakkar	116.24	0.47	19.42	233.07	21.64	1.11
Khushab	179.53	0.65	29.03	348.32	31.03	1.07
Mianwali	196.10	0.48	32.11	385.31	32.90	1.02
Sargodha	226.45	0.66	31.93	383.22	36.94	1.16

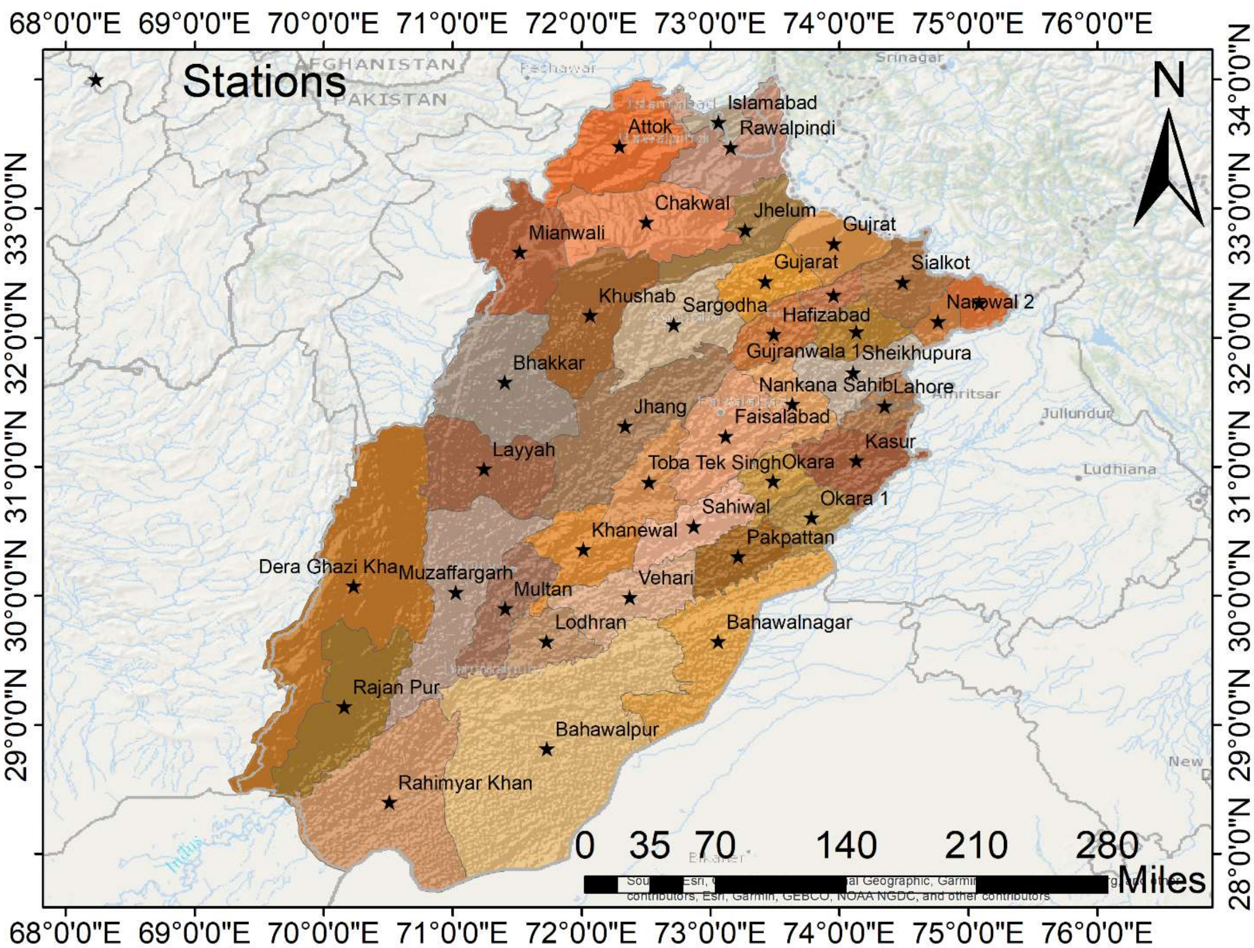

Figure 1: Study area of Punjab province, Pakistan, with the network of 39 ground-based observations

3 Methods

3.1 Mann-Kendal test (MK Test)

In the current investigation, the non-parametric trend diagnosis MK test was employed. Trends in metrological temporal data series have been extensively detected using the MK test [14], [15]. The approach is resilient against outliers and missing numbers and is less susceptible to abrupt breakpoints [16]. The test is susceptible to a serial correlation which might impact the test outcomes [17], [18]. The sequential correlation strategy was used in the present study to assess the statistical significance of trends in the climatic data set before the MK test was run. The MK test whole process is described by [19], [20]. The standardized MK statistic "S" is calculated as:

$$S = \sum_{z=i+1}^{m} sgn(y_z - y_m) \qquad (1)$$

$$sgn(y_z - y_m) = \begin{cases} +1 & y_z > y_m \\ 0 & y_z = y_m \\ -1 & y_z < y_m \end{cases} \qquad (2)$$

where m is the series length, and y_z, y_m is the sequential values of data. If n is greater or equal to 10, then the S statistic is typically dispersed, and the variance is given by

$$E(S) = 0$$

$$Variance(S) = m(m-1)(2m+5) - \sum_{i=1}^{n} s_i(s_i - 1)(2s_i + 5)/18 \qquad (3)$$

where n is the number of tied groups, and s_i is the size of the $i$sth sth group. The test statistic Z is computed by:

$$Z = \begin{cases} \frac{(S-1)}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{(S+1)}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad (4)$$

The MK test Z statistics have a null hypothesis of no trend and follow the normal distribution with an average of 0 and a variation of 1[21]. The statistics Z positive and negative values indicate rising and falling tendencies.

4 Results

4.1 Features of average annual precipitation of all ground-based stations

The average annual precipitation is 131.63 to 966.57 mm for 39 ground-based stations from 1961 to 2019 (Table 1). The Bahawalpur and Rajan pur stations, situated in the province's southern region, had the largest coefficient of variation (CoV) of the average annual precipitation. In contrast, Attock station had the lowest CoV, measuring 0.91 (north of the Punjab province). The yearly mean precipitation for 39 meteorological stations is shown in **Figure 2**.

As **Figure 2** demonstrates, there are significant fluctuations in the yearly precipitation between 1961 and 2019. In Southern Punjab, the year with the most precipitation, 404 mm, was recorded at the Dera ghazi khan station, and the year with the least 69 mm, was recorded at the Lodhran station. While in central and northern Punjab, the maximum & minimum precipitation were recorded at Narowal (with at least 1390) & Pakpattan (with at least 141) and Islamabad (with at least 1390) & Bhakkar (with at least 149).

In Northern Punjab, like Islamabad (1976, 2006, 2010, 2015), and Central Punjab, like Sialkot (2006) and Narowal (1988, 1990, 1995, 1997, 2006) are stations with annual precipitation above 1200 mm. There are also two major periods, from 1974 to 1977 and 2009 to 2015, in which most station's yearly precipitation is mostly rising. These finding are in line with the outcomes of [22].

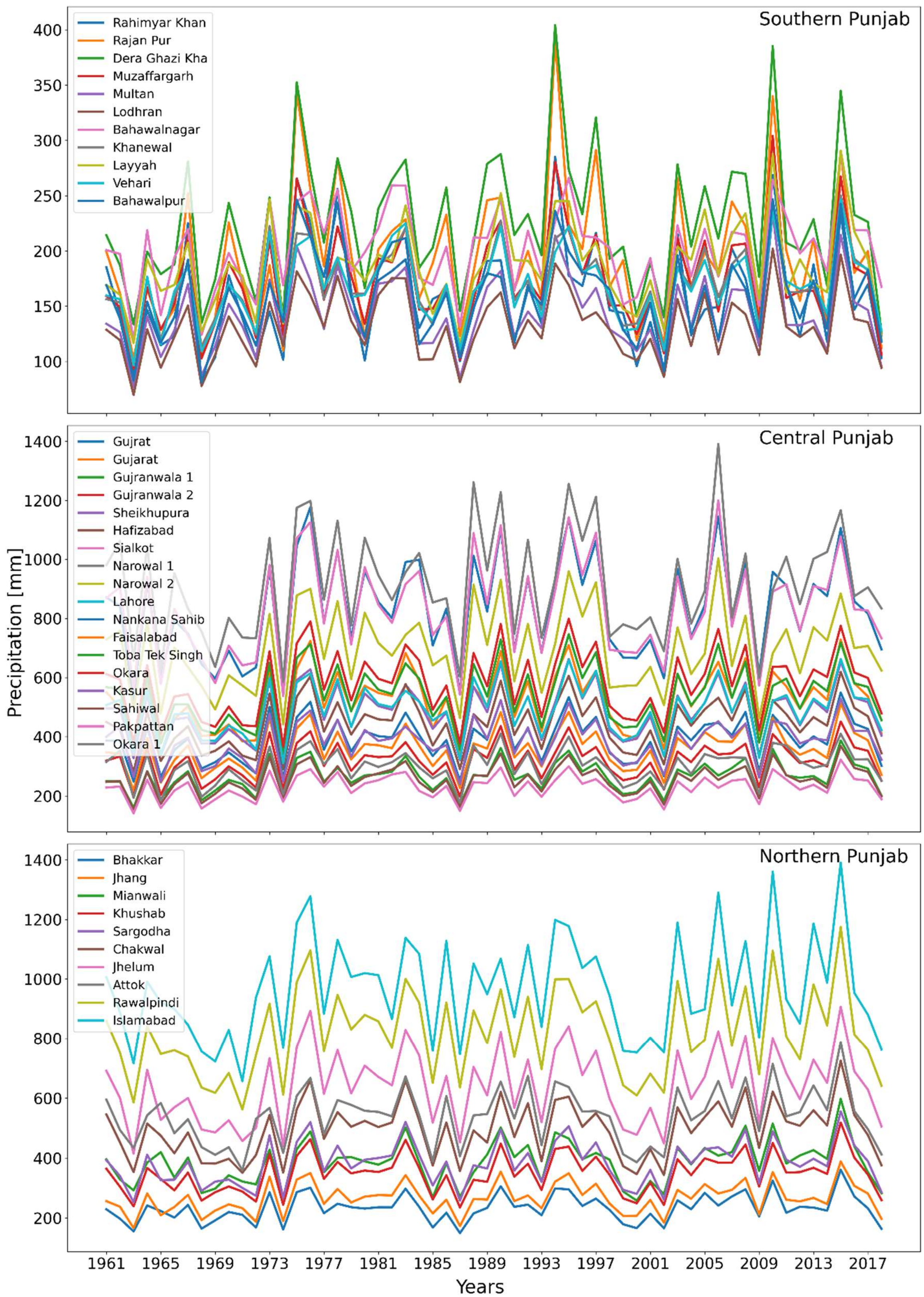

Figure 2: Annual averaged precipitation series for 39 ground-based stations

4.2 Statistical characteristics of monthly precipitation for all ground-based stations

Some statistical details of the monthly precipitation series at 39 ground-station stations are reported in Table 1. The average annual precipitation is 10.97 to 80.55 mm for 39 ground-based stations from 1961 to 2019. The maximum mean monthly precipitation is found in Dera Ghazi Khan (Located in southern Punjab), Narowal (Central Punjab), and Islamabad (Northern Punjab). The minimum mean monthly precipitation is found in Multan (Located in southern Punjab), Hafizabad (Central Punjab), and Bhakkar (Northern Punjab). The Bahawalpur and Rajanpur station, situated in the southern province region, had the largest coefficient of variation (CoV), 135% of the average annual precipitation, while the Attack station had the lowest CoV, measuring 91 % (in the north of the Punjab province). The percentage is greater than 100% because the data points are very distant from the mean.

The statistical information on average monthly precipitation for every station from 1961 to 2019 is presented in **Table 2**. The station in north Punjab (Islamabad) had the highest average monthly precipitation in August, and the minimum average monthly precipitation was observed in November. Similarly, the station in central Punjab (Narowal station) also had the highest maximum monthly precipitation in August, while the lowest precipitation is found in November, respectively. On the contrary, the station in the south (Multan station) had the lowest average monthly precipitation in April and maximum in July. The results are consistent with the outcomes of [22].

Figure 3 depicts the temporal distribution of this basin's average monthly precipitation (as determined by the Thiessen Polygon technique). More precipitation is observed in July and August and less from October to December, which is intense in spring and summer.

Table 2 Monthly mean precipitation of all ground-based stations data from 1960 to 2019

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Islamabad	56.3	72.9	73.1	60.8	36.5	58.6	210.6	236.1	91.8	22.5	14.9	32.4
Bahawalnagar	6.7	9.9	9.7	6.4	6.2	16.2	62.4	47.6	25.4	2.2	2.4	5.2
Bahawalpur	5.3	8.3	8.1	6.4	6.5	15.1	51.4	32.6	18.1	1.3	2.4	3.8
Rahimyar Khan	5.4	8.1	11.5	8.7	6.7	13.5	40.9	40.1	16.9	1.3	1.8	3.8
Dera Ghazi Kha	10.7	12.4	16.9	13.9	9.6	18.7	55.4	58.2	16.9	3.3	2.2	7.2
Layyah	8.1	10.6	12.6	10.2	6.7	13.0	49.5	47.5	18.1	2.0	1.9	6.2
Muzaffargarh	7.4	10.6	9.0	7.2	6.0	12.8	49.4	45.1	16.1	2.1	1.4	6.0
Rajan Pur	8.9	11.2	11.6	9.0	7.8	17.7	46.4	51.8	19.8	2.5	1.7	5.5
Faisalabad	15.7	17.2	18.4	12.3	10.8	30.7	95.0	98.4	41.7	4.9	3.0	8.2
Jhang	10.6	14.3	16.4	12.6	10.3	22.5	70.9	67.3	26.9	3.9	2.6	7.3
Toba Tek Singh	10.5	13.1	13.9	10.8	7.9	25.1	69.1	71.0	30.4	3.6	2.5	7.5
Gujarat	27.6	31.8	31.0	22.8	19.0	38.7	129.2	140.3	55.7	7.8	5.9	13.0
Gujranwala 1	26.8	29.1	26.6	18.6	18.0	46.8	140.0	145.5	63.7	7.7	5.4	12.4
Gujranwala 2	31.0	33.3	30.4	20.6	18.5	45.9	144.2	155.9	70.6	8.1	6.1	14.5
Gujrat	42.5	47.9	46.6	28.7	23.8	57.3	217.7	223.3	99.5	13.1	9.0	20.6
Hafizabad	22.3	25.4	24.2	19.4	16.9	35.4	108.3	120.6	48.3	6.5	4.5	10.3
Narowal 1	55.6	46.5	42.4	20.4	19.1	67.9	246.4	250.4	120.8	17.0	7.5	21.3
Narowal 2	35.4	36.1	31.9	18.5	18.1	61.4	189.4	192.8	77.0	10.4	6.6	15.7
Sialkot	43.4	42.9	39.7	23.5	21.4	64.0	223.5	227.5	105.1	11.9	7.6	20.4
Kasur	16.9	15.6	16.8	9.5	10.3	32.8	102.5	101.2	60.5	7.2	3.2	7.8
Lahore	20.1	22.4	24.2	16.1	15.1	44.4	141.1	125.4	58.1	9.4	4.5	8.9
Nankana Sahib	18.2	19.8	19.2	14.1	13.3	33.6	99.6	107.8	45.4	5.9	3.5	8.1
Okara 1	12.4	11.2	12.2	5.8	7.7	23.3	79.5	72.6	61.1	4.1	2.9	7.3
Okara	14.9	14.1	14.7	7.8	8.9	27.4	84.9	86.1	46.0	3.9	3.0	7.2

Sheikhupura	21.8	24.7	24.0	17.2	16.4	43.0	130.7	129.2	54.4	7.7	4.6	9.6
Khanewal	6.5	10.9	8.1	5.3	6.7	14.8	47.4	42.9	15.4	2.1	2.0	6.3
Lodhran	5.2	10.1	7.2	4.1	6.2	9.3	41.7	26.1	13.4	1.4	2.0	5.0
Multan	6.0	10.3	7.2	4.5	5.8	9.9	44.9	32.7	12.0	1.9	1.6	5.8
Pakpattan	9.5	11.9	12.3	7.0	6.8	20.1	68.1	54.7	27.7	2.1	3.0	6.5
Sahiwal	11.0	12.7	13.6	7.4	7.2	22.5	70.9	68.1	29.7	2.6	2.7	7.2
Vehari	6.4	10.8	8.2	5.7	6.9	14.6	45.1	44.1	16.2	2.0	2.1	5.9
Attok	37.8	46.5	51.8	39.5	23.9	25.9	96.2	124.1	54.1	12.8	7.7	19.7
Chakwal	29.2	34.7	38.6	30.4	23.8	31.7	99.7	121.7	52.6	10.4	6.1	14.6
Jhelum	35.5	42.1	41.4	30.7	23.9	44.4	154.9	165.0	66.6	11.3	7.9	17.8
Rawalpindi	49.9	62.5	62.6	51.0	33.7	52.2	172.2	192.8	80.5	19.8	12.7	27.0
Bhakkar	10.0	14.2	20.1	13.6	9.4	17.7	57.9	54.7	23.8	3.0	2.3	6.1
Khushab	15.9	21.4	28.1	19.5	17.2	25.1	82.4	84.8	34.9	6.1	3.9	9.1
Mianwali	17.7	25.2	38.6	26.8	19.1	22.0	76.0	97.6	40.9	8.3	3.5	9.7
Sargodha	16.9	22.2	25.9	20.4	19.0	26.4	95.3	103.6	33.6	6.2	4.0	9.7

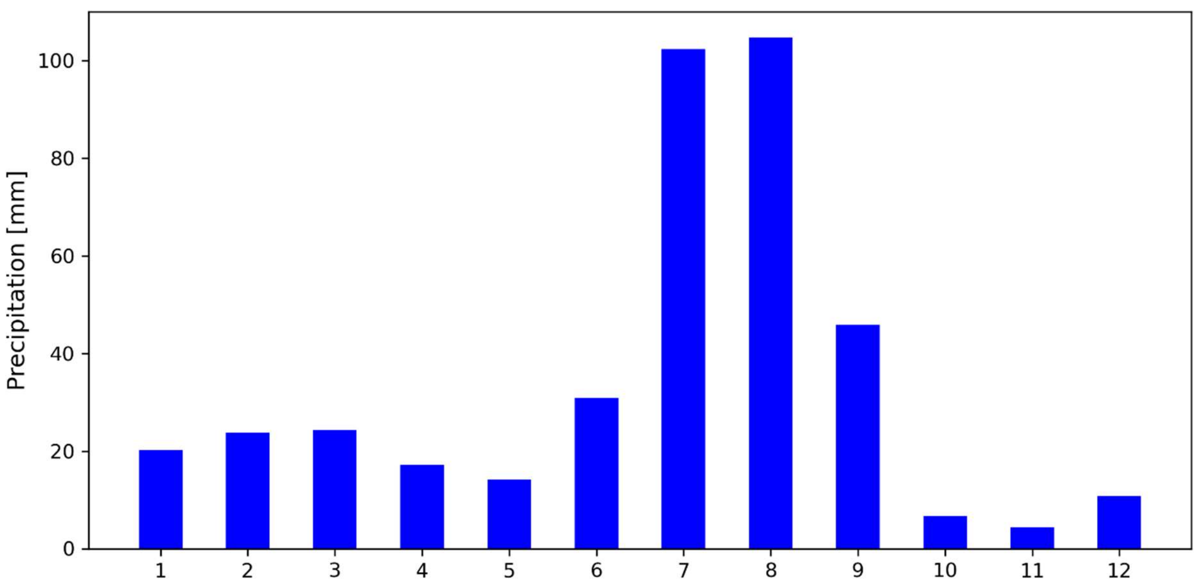

Figure 3 Temporal trend analysis of ground-based precipitation year data from 1961 to 2019

4.3 Trends analysis of precipitation for all ground-based stations

Precipitation spatial trends for different seasons and the whole year from 1961 to 2019 are exhibited in **Figure 4**, where 0.05, showing the significant level.

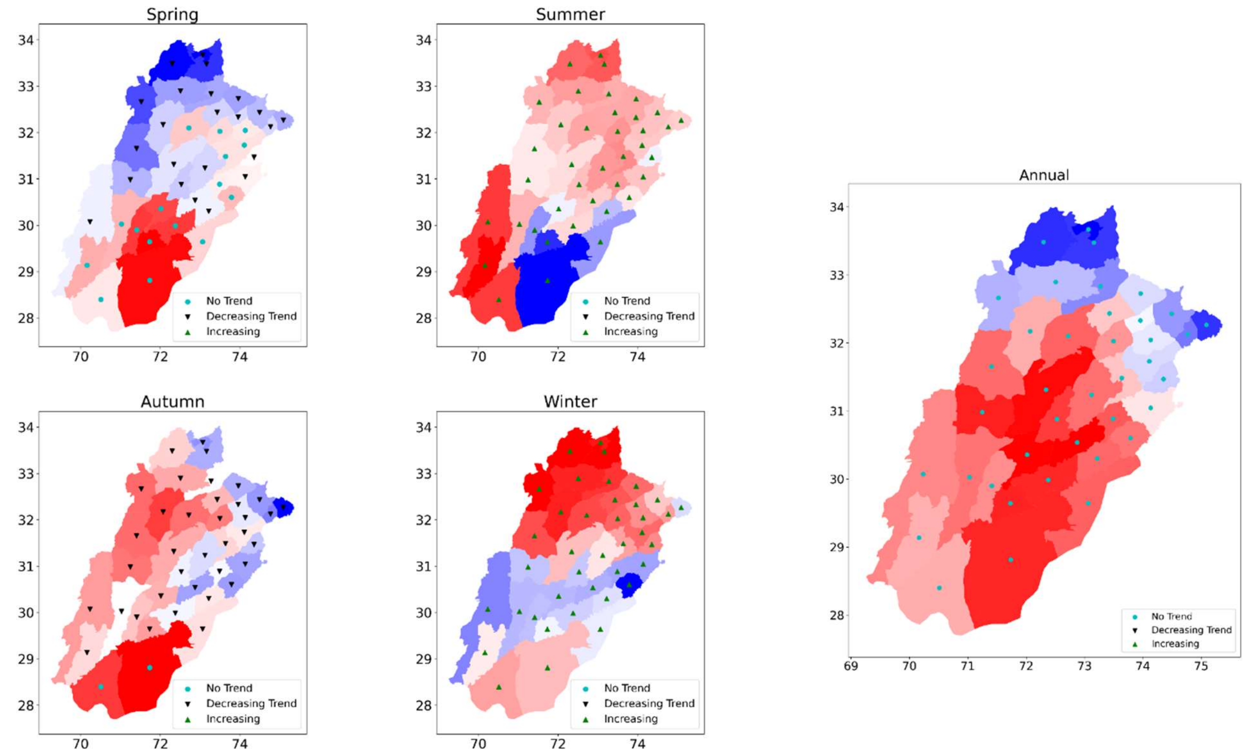

Figure 4 Spatial trends of precipitation for different seasons and a whole year

If |Z| is greater than 1.96, then the precipitation distribution is significant. When Z>1.96, it shows an increasing trend; when Z<-1.96, it shows a decreasing trend. If the Z is less than 95 percent confidence level, it will be exhibited in terms of increasing or decreasing trends.

As in figure 4, the summer & winter seasons show an increasing trend in overall stations. In comparison, autumn and spring exhibit a decreasing trend for many stations. It is also noted that 37 stations show a significant decrease in autumn while 2 have no significant trend. Twenty-three stations noted a significant decrease in spring, while 26 have no significant trend. Moreover, no significant trend was found on an annual scale. These trends are consistent with the outcomes of [23], which showed that India's rainfall trend decreased between 1949 and 2012. Our findings concur with [24], who discovered negative trends in Iran's southeast and northwest between 1951 and 2009. This demonstrates that there has been a decline in precipitation in this South Asian region, which is also indicated as having "mostly decreased" in the Fifth Assessment Report of the Inter-Governmental Panel on Climate Variation [25]. The findings here demonstrate the need for good water resource management in the Punjab province, which have the biggest populations and make up the majority of Pakistan's overall agricultural output and the country's Gross Domestic Product.

5 Conclusion

In this study, the precipitation variations between 1961 and 2019 were evaluated. The annual precipitation decreased from south to north. Some stations like Islamabad, Sialkot, and Narowal have annual precipitation exceed from 1200 mm. The majority of occurrence falls from 1974 to 1977 and 2009 to 2015 with increasing precipitation. The higher variation is noted in south Punjab in contrast to northern Punjab. The monthly precipitation follows the same trend from south to north. High precipitation was observed from July to August, while low precipitation was noted from October to December. Seasonal precipitation shows the different trends in different regions of Punjab. Winter and summer exhibit an overall increasing trend, while a decreasing trend is noted in spring and autumn. Understanding these trends and adhering to the recommended adaption techniques is necessary. Therefore, a better understanding Pakistan's climate extreme (such as floods and droughts) will lessen their negative effects in the future.

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