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Spatial and Temporal Variations of Temperature in the Punjab Province, Pakistan

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Abstract: Identifying the temperature change at a regional level is one of the essential parameters to determine the intensity of climate change. The current investigation provides an examination of changing trends of temperature in the Punjab province from 1970 to 2019. Sen's slope estimator method is applied to monthly data of mean temperature (*Tmean*), maximum temperature (*T*max), and minimum temperature (*T*min) to calculate the rate of temperature change. Statistical methods were used to find out the level of significance in terms of negative or positive trends to examine the variability among various weather observatories. Moreover, predicted values have also been observed for a detailed analysis of temperature variability and trends. Significant and pronounced changes in the mean temperature (*T mean*) are distinguished all over the Punjab regions with an increasing trend from North to South Punjab. In the case of maximum temperature (Tmax), a faster rate of rising in temperature is observed over the Southern and Western regions of Punjab. In contrast, the minimum temperature (*T*min) shows an increasing trend in Central Punjab. The findings provide detailed insight to policymakers for the planning of mitigating efforts and adaptation strategies in response to climate change.

Keywords: Change rate, planning and adaptation, seasonal temperature, predicted, regions.

Introduction

The identification of spatial and temporal trends in temperature has become an established indicator to verify the occurrence of climate change at a global level. A continuous increase in the world average temperature has been confirmed by analyzing the temperature data of the last century, affirming the proposition of recent climate change. Such temperature changes, if not tackled properly, may cause irreversible damages to the ecosystem of the world. Seaman et al., (2014) indicated that climate change causes a direct impact on climate-reliant socio-economic and natural systems like rain patterns, water availability, agriculture, health, as well as the non-reliant institutional, political, economic, demographic, and technological sectors. Therefore, assessment of long-run patterns of temperature variability is adopted as a prerequisite to depict and predict the extent of climate change in many scientific studies (Qureshi, 2011; Frias et al., 2013; Bradbear and Friel, 2013, Abbas et al., 2016 a,b, Abbas et al., 2020).

Pakistan is considered the 5th most vulnerable country in perspective of climate change. This is likely due to resource scarcity, fragile topography, and the arid nature of prevailing climate conditions. The country has faced many catastrophic events of extreme climate like storms, floods, droughts, and land sliding in the last decades with huge losses of people and the economy. The calamities associated with climate change are forecasted to increase the intensity, duration, and frequency in the coming years (Ahmed and Schmitz, 2015). Pakistan is ranked 12th on the worldwide index of climate change vulnerability, with an economic loss of approximately 5 billion dollars (Khan et al., 2019). In Pakistan, a large segment of the population belongs to the agricultural sector (Asif, 2013; Abbas et al., 2018; Abbas and Mayo, 2021).

The investigation of temperature trends is of great importance as an increase in temperature significantly affects human well-b eing all over the world. According to IPCC (2014), comparatively, a large fluctuation in temperature is observed in the arid and semi-arid regions of the world. International Fund of Agriculture Development (IFAD, 2012) also reported that temperature is increasing faster in the regions of northern Pakistan, India, and western China (Mehrotra and Mehrotra, 1995; Abbas et al., 2021) while a similar rise in temperature has been reported in many other studies across the globe (Brown et al., 2008; Frías et al., 2012; Salman et al., 2018).

Many studies have attempted to investigate the trends and variability of temperature over Pakistan (Islam et al., 2009; Zahid and Rasul, 2011; Rio et al., 2013; Asif, 2013; Abbas, 2013; Iqbal et al., 2016; Jahangir et al., 2016; Aslam et al., 2017; Abbas et al., 2018; Khan et al., 2019; Nawaz et al., 2019; Mazhar and Shirazi, 2020). Rees et al., (2006) found a change of 0.6 °C average temperature in Pakistan during the last century. Khan et al., (2019) indicated that the maximum temperature is rapidly rising compared to the minimum temperature in Pakistan.

The review of previous literature indicates a lack of detailed research to investigate the recent trends and variations within the province. The present study provides a detailed insight into regional variations of temperature within the province of Punjab by dividing the province into four regions. These regions are also important in terms of variations in agricultural products. Therefore, the present study provides important details to recognize the climate change intensity in the Punjab province. The findings of the research are expected to lay the foundations of firm agriculture policy according to the variations in climate.

Study Area and site characterization – the Punjab regions

The province of Punjab lies between 27° to 34° north latitude and 69° to 75° east longitudes. It is administratively divided into 37 districts. Wilder (1999) has divided the Punjab province into four regions of Northern, Central, Southern, and Western Punjab. These regions are divided based on geographical boundaries, the flow of canals, and cropping patterns. Table 1 indicates the climate and geographic features of the distributed regions. In the context of Agriculture, the Northern region is a rain-fed area. The Central region is wet, and comparatively, the Southern region is a little drier than other regions. In the Southern plain region of Punjab, proper irrigation is necessary to carry out agricultural activities. Khan et al., (2019) also reported that maximum temperature is high as measured in the plain areas of Pakistan. Precisely, winter temperatures have been observed to be rising in central and south Punjab in different studies (Ahmed et al., 2014).

Figure 1 presents the location of the Pakistan Meteorological Department (PMD) observatories which provided the main datasets. It also presents the digital elevation of the province, with mountains on the northwestern and western sides of the province, while the remaining province is mostly flat land. Hanif et al., (2010) also reported that the climate in the regions of Punjab is dry. However, the northern zone is characterized by humid and sub-humid climates, while Central and Southern Punjab are categorized by tropical and coastal climates respectively (Hanif et al., 2010).

Table 1. Characteristics of classified regions of Punjab, Pakistan

Features	Northern	Central	Western	Southern
Latitude	33.10° - 34.09° N	30.12° - 33.09° N	28.52° - 33.49° N	27.89° - 30.05° N
Longitude	71.99° - 76.35° E	71.79° - 75.45° E	69.52° - 72.69° E	69.92° - 74.01° E
Climate types	Subtropical	Humid subtropical	Subtropical semiarid	Arid
Annual Tmax (°C)	31.45	30.75	31.77	32.70
Annual Tmin (°C)	19.44	18.89	16,90	18.58
Annual Tmean (°C)	26.67	24.87	24.57	25.68
Summer *T*max (°C)	35.34	36.61	38.04	39.88
Summer *T*min (°C)	25.74	26.69	24.32	27.79
Summer Tmean (°C)	30.89	31.99	31.80	33.44
Winter *T*max (°C)	19.70	21.90	22.40	22.50
Winter *T*min (°C)	9.43	8.380	10.40	11.40
Winter Tmean (°C)	15.23	14.63	15.93	16.23

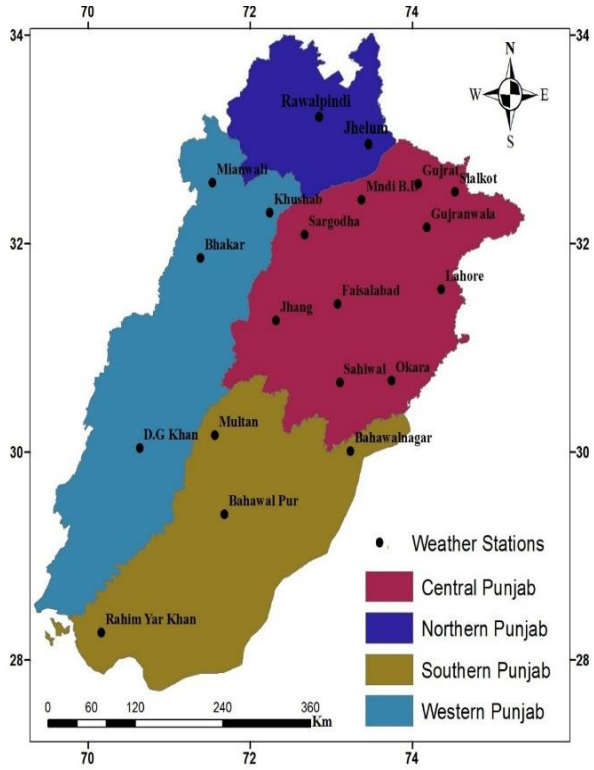

Fig. 1 Location map of investigating meteorological stations over Punjab regions, Pakistan.

Materials and Methods

Long-term Spatio-temporal trends and variability of temperature (*T*max, *T*min, and *T*mean) for a period of 50 years (1970-2019) were obtained from 20 meteorological stations from PMD (Fig. 1). Mann-Kendall (MK) technique is used to estimate the significant trend. Before applying the non-parametric test, the pre-whitening method is used to remove serial correlation to eliminate its influence in such a nonparametric test trend. This newly modified approach was utilized by this different research for representing trends of different meteorological and hydrological variables. De-trending of the time series has been done by assuming a linear trend as:

$$Y_i = x_i - (\beta \times i) \quad (1)$$

The calculated values are required to estimate the significance level. If the r1 value has a 5% of significance level, then it can be utilized but if it not 5% then all the statistical tests are applied to the original values of the given time. They can be obtained by the following equation:

$$\bar{Y}_i = Y_i - rY_{1-i} + (\beta \times i) \quad (2)$$

Mann–Kendall statistic (Zheng et al., 2019) has been utilized in this research work to evaluate the randomness against our resultant trends. Mk–test never assumes the distribution of the irregularly spaced data over a specific time.

The Mann –Kendall statistic Z_{mk} reads:

$$Z_{mk}\begin{cases}\frac{S-1}{Q_S} & if \quad S>0\\ 0 & if \quad S=0\\ \frac{S+1}{Q_S} & if \quad S<0\end{cases} \tag{1}$$

The MK test statistic *S* reads:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j-x_k) \tag{2}$$

In this equation, *n* = number of years, X_j and X_k = sample values where j indicates the annual time instants and k represent the seasonal time instants consecutively. The functional sgn (x_j-x_k) corresponds to the values 1, 0, or -1 as per sign difference (x_j-x_k), it is the functional indicator where j>k:

$$sgn(x_j-x_k)=\begin{cases}1 & if x_{j-}x_k>0\\ 0 & if x_{j-}x_k=0\\ -1 & if x_{j-}x_k<0\end{cases} \tag{3}$$

Z_{mk} values are used to represent the general trends of variables. In 1968, Sen developed a non-parametric technique to estimate the trend slope in the data that has linear trends according to time series. Sen's slope method is used to detect the rate of change in the temperature. The equation shows a slope of two kinds of observations in given time instants *k* and *j*:

$$Q_i=\frac{x_{j-}x_k}{j-k} \qquad Ifj>k \tag{1}$$

Sen's estimator is the median Q_{med}, of the N pairs of Q_i. In the procedure, N values of Q_i are ranked from smallest to largest and the Sen's estimator read:

$$Sen'sestimator=$$

$$\begin{cases}Q_{\left[\frac{(N+1)}{2}\right]} & if\ N\ was\ odd\\ \frac{1}{2}\left(Q_{\frac{N}{2}}+Q_{\left[\left(\frac{N+2}{2}\right)\right]}\right) & if\ N\ was\ even\end{cases} \tag{2}$$

For the two-decade period, the student t-test is utilized to determine the static significance of the mean values over a given time. The confidence level for both tests was set at 90%. we use a t-test as per the following equation.

$$t=\frac{\bar{X}_1-\bar{X}_2}{S_p\sqrt{\frac{1}{n1}+\frac{1}{n2}}} \tag{1}$$

$\bar{X}_1$ and $\bar{X}_2$ = mean values, n_1 and n_2 = observation numbers, s_1 and s_2 = standard deviations, where subscripts 1 and 2 show the time duration (1970-1998) and (1999-2019). S_p = pooled standard deviation that can be expressed with the following equation:

$$S_p=\sqrt{\frac{(n_1+1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}} \tag{2}$$

T- statistic can be measured by the below equation if variances of two-time durations are not similar,

$$t=\frac{\bar{X}_1-\bar{X}_2}{\sqrt{\frac{1}{n1}+\frac{1}{n2}}} \tag{3}$$

Results and Discussion

Assessment of annual and seasonal variability of Temperature

The Northern region of Punjab has more rainfall in the summer monsoon season and its variability is less found as compared to the Southern and Western Punjab (Fig. 2a). The Central Region of Punjab is attributed to the zone of high rainfall (Fig. 2b).

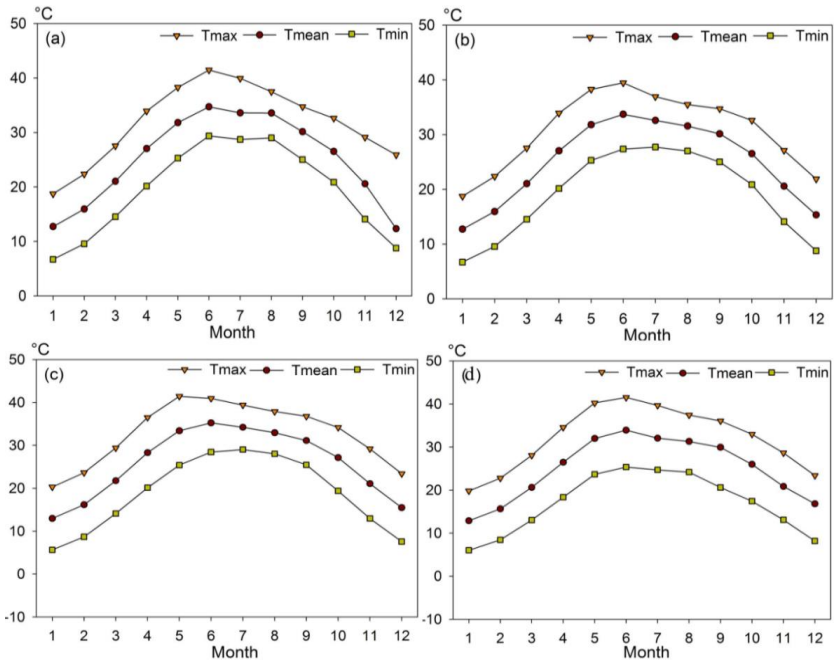

Fig. 2 Temporal patterns of temperature over the Punjab regions (a) Northern Punjab (b) Central Punjab (c) Western Punjab (d) Southern Punjab.

Comparatively, the Southern zone is a little drier than the Western region.

An arid region of Punjab, with more than 65% rural population is highly dependent on agriculture as shown in Fig. 2c. Western Punjab is characterized by High Tmax in June and July (Fig. 2d) which is mostly because of the influence of plain areas. The highest maximum temperature is found in the Southern and Western plain regions of Punjab province. Figure 3a (for annual temperature), 3b (for Kharif temperature trend), and 3c (for Rabi temperature trend) present the identified regions of the Punjab province with statistically significant trends at 0.05 levels of annual and seasonal basis.

From the analysis, it was shown that Tmax is increased at the tendency of 0.040 °C per year. In contrast, Tmin is found to increase at 0.050 °C per year in the Central zone of Punjab. The examination of the spatial extent of the area reveals that the trend direction of the Maximum temperature (Table 3) increased in Gujrat with a rate of 0.27 °C / year. Results stated that Gujrat district in Central and Khushab in Western Punjab, are the stations that exhibit a significant increasing trend as derived from the analysis of variance (Table 2).

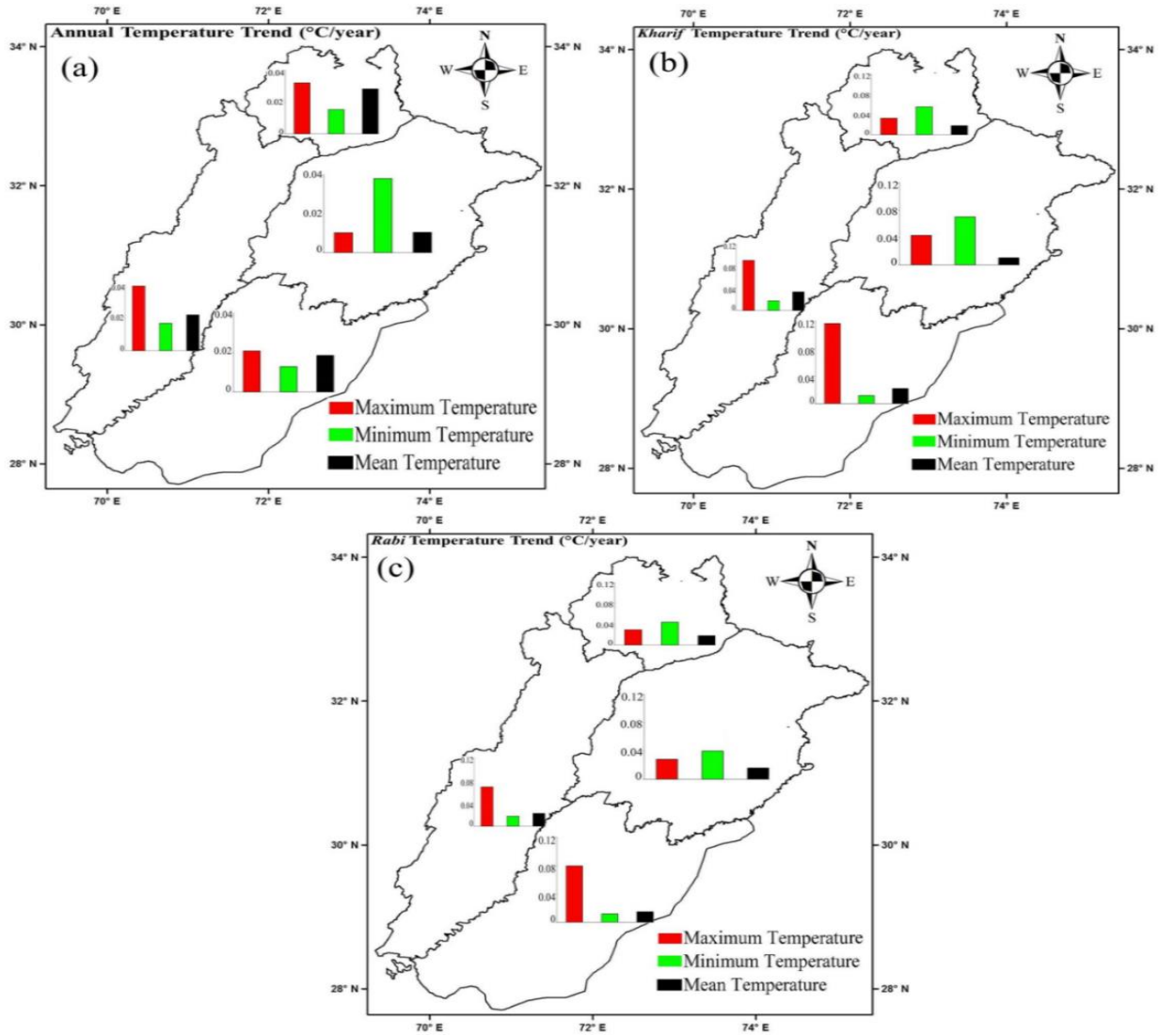

Fig. 3 Trends of temperature over the Punjab regions of Pakistan (a) Annual temperature (°C) (b) Kharif temperature (°C) (c) Rabi temperature (°C) from 1979-2019.

The spatial features of maximum, minimum, and mean temperature tendency of Northern, Central, Western and Southern regions are shown in tables 2 to 6. The Jhelum, Rawalpindi divisions and north Punjab depicted a minor rising trend of maximum temperature at 0.19 °C per year. The divisions witnessed a rising trend of the minimum temperature, which was a greater rise as related to the tendency of the maximum temperature of 0.45 and 0.33 °C with 0.62 and 0.396 respectively for Jhelum and Rawalpindi divisions. Significant and pronounced mean temperature changes are distinguished over central Punjab. Central Punjab is characterized by an increasing trend of 0.01 °C per year.

Table 2 F-values of mean, maximum, and minimum temperature in t and f test ºC (1979-2019).

Sr. no.	Punjab		Tmean		Tmax		Tmin	
	Region	Stations	F-value	Sig	F-value	Sig	F-value	Sig.
1	Northern	Jhelum	21.66	0.00	3.635	0.038	71.579	0.012
2		Rawalpindi	4.946	0.02	1.492	0.229	87.883	0.001
3	Southern	Multan	0.943	0.33	1.992	0.166	7.95	0.008
4		Bahawalnagar	10.465	0.00	3.53	0.069	15.382	0.001
5		R.Y khan	6.009	0.01	20.642	0	0.3991	0.532
6		Bahawalpur	2.548	0.11	0.381	0.541	4.387	0.043
7	Central	Gujrat	0.391	0.00	2.943	0.048	0.880	0.000
8		Sialkot	12.082	0.00	2.065	0.165	35.342	0.003
9		Gujranwala	5.636	0.00	8.346	0.006	1.019	0.319
10		M.Bahuddin	20.66	0.00	4.635	0.038	21.579	0.002
11		Sargodha	5.946	0.024	1.492	0.229	87.883	0.001
12		Lahore	4.96	0.001	1.382	0.247	24.99	0.002
13		Faisalabad	13.454	0.00	0.545	0.465	52.278	0.001
14		Sahiwal	40.707	0.002	50.268	0.005	20.58	0.003
15		Okara	1.949	0.171	0.31	0.581	1.98	0.167
16		Jhang	14.186	0.001	7.299	0.01	9.159	0.004
17	Western	Mianwali	0.085	0.002	8.643	0.004	17.313	0.035
18		Khushab	67.79	0.00	83.153	0.002	15.53	0.001
19		D.G khan	50.186	0.00	13.782	0.001	50.18	0.002
20		Bhakkar	4.226	0.047	0.305	0.584	11.189	0.003

A smooth increasing trend of minimum temperature from Southern Punjab to Central Punjab is noted, particularly Lahore in Central Punjab with R square 0.396 (Table 5). The minimum temperature also is observed in the D.G Khan in Southern Punjab. The results showed a higher increase in the mean temperature over Central Punjab in Sahiwal in comparison to Khushab in Western Punjab (Table 4). The maximum temperature indicated a positive and significant upward trend in all the districts except Lahore in central and Bahawalpur in west Punjab.

significant rise in minimum temperature, for the period under study were Gujrat, Sargodha, and Faisalabad, with F-value of 0.88, 87.883, and 52.278, with a p-value of 0.000, 0.001, and 0.001 respectively (Table 2). Amongst these divisions, Gujrat had a slightly less but significant increase in maximum temperature, with a p-value of 0.048. Overall, the Central region indicated the increase in minimum temperature at a faster rate. The minimum temperature in Central Punjab is observed to be high as compared to its maximum temperature which is the thickly populated area of Punjab, Pakistan. The excessive urbanization in

Table 3 Shows the Change rate and trend Sig of temperature ºC (1979-2019).

Sr. no.	**Region**	**Station**	**Tmean**		**Tmax**		**Tmin**	
			Change rate	Sig.	Change rate	Sig.	Change rate	Sig.
1	Northern	Jhelum	0.04	0.36	(0.01)	(0.19)	0.06	0.45
2		Rawalpindi	0.03	0.33	(0.01)	(0.19)	0.05	0.33
3	Southern	Multan	0.01	0.16	(0.01)	(0.22)	0.02	0.42
4		Bahawalnagar	0.03	0.46	0.02	0.29	0.03	0.54
5		R.Y khan	0.02	0.37	0.05	0.59	(0.01)	(0.10)
6		Bahawalpur	0.03	0.25	0.01	0.10	0.04	0.32
7	Central	Gujrat	0.00	0.09	0.02	0.27	(0.01)	(0.15)
8		Sialkot	0.02	0.49	0.01	0.16	0.04	0.69
9		Gujranwala	(0.02)	(0.36)	(0.03)	(0.42)	(0.01)	(0.16)
10		M.Bahuddin	(0.08)	(0.59)	(0.02)	(0.33)	(0.14)	(0.60)
11		Sargodha	0.07	0.36	(0.01)	(0.19)	0.06	0.85
12		Lahore	0.02	0.34	(0.01)	(0.19)	0.05	0.63
13		Faisalabad	0.02	0.51	0.01	0.12	0.04	0.76
14		Sahiwal	0.06	0.72	0.06	0.75	0.06	0.59
15		Okara	(0.01)	(0.22)	(0.00)	(0.09)	(0.01)	(0.22)
16		Jhang	(0.06)	(0.52)	0.03	0.40	(0.06)	(0.44)
17	Western	Mianwali	(0.02)	(0.05)	(0.02)	(0.43)	0.03	0.56
18		Khushab	0.07	0.80	0.19	0.83	(0.06)	(0.54)
19		D.G khan	0.05	0.76	0.03	0.52	0.06	0.76
20		Bhakkar	0.02	0.32	(0.01)	(0.09)	0.03	0.48

From the detailed investigation, the maximum temperature in Gujranwala, Sargodha, and Sahiwal divisions was found to present a significant upward trend. In central Punjab, divisions with the most

this region caused large areas to be converted into housing schemes, infrastructures, industrial zones, and heavy roads, which increases the minimum temperature. Moreover, the use of many vehicles

instigates the excessive combustion of fossil fuels and petroleum products, producing a high number of carbon-containing gases in the atmosphere, which in turn, causes the increase in Tmin more as compared to Tmax. So, the Tmin was observed to be significant in this region.

The largest warming trend is found in Southern Punjab with an annual trend of 0.024 °C per year observed in 2016, the warmest year with a positive anomaly of 0.8 °C. The maximum temperature showed a high, increasing trend of 0.0020 °C and 0.039 °C per year in Southern Punjab. The maximum temperature in the Multan division was found to depict a significant upward trend. Similarly, for Southern Punjab, Bahawalnagar depicted the most significant rise in minimum temperature, with an F-value of 15.382, and significance values of 0.001, while the same division presented an insignificant rise in maximum temperature. West Punjab presented a rising trend of both maximum and minimum temperature, with Mianwali, Khushab, and D. G. Khan where a rise is noted in minimum temperature with F-value of 17.313, 15.53, and 50.18, and a significance value of 0.035, 0.001, and 0.002, respectively. These divisions also depicted a significant increase in maximum temperature (Table 2). Western Punjab is found to have a trend of 0.019 °C / year, and 2014 being the warmest year, noticeable by a positive change of 1.23 °C. The maximum temperature showed a high, increasing trend of 0.0020 °C and 0.039 °C / year in Western Punjab.

On average, the rising trend of minimum temperature is observed within the range of 0.013 to 0.018 °C per year in the Southern and Western Punjab. *Kharif and Rabi* season also showed a similar trend to that observed for annual temperature (Fig. 2b, 2c). The

Table 4 Observed and predicted R^2 value of the mean temperature ^oC (1979-2019).

Sr. no.	Region	Station	R	R^2	Adjusted R^2	Predicted R^2
1	***Northern***	Jhelum	0.133	0.115	0.042	0.23
2		Rawalpindi	0.521	0.262	0.222	0.02
3	***Southern***	Multan	0.156	0.024	-0.001	0.025
4		Bahawalnagar	0.465	0.216	0.195	0.021
5		R.Y khan	0.37	0.137	0.114	0.023
6		Bahawalpur	0.251	0.063	0.038	0.025
7	***Central***	Gujrat	0.091	0.008	-0.018	0.026
8		Sialkot	0.491	0.241	0.221	0.02
9		Gujranwala	0.359	0.129	0.106	0.023
10		M.Bahuddin	0.593	0.352	0.335	0.017
11		Sargodha	0.355	0.126	0.103	0.023
12		Lahore	0.34	0.115	0.092	0.023
13		Faisalabad	0.511	0.262	0.242	0.02
14		Sahiwal	0.719	0.517	0.504	0.013
15		Okara	0.221	0.049	0.024	0.025
16		Jhang	0.521	0.272	0.253	0.019
17	***Western***	Mianwali	0.047	0.002	-0.024	0.026
18		Khushab	0.8	0.641	0.631	0.01
19		D.G khan	0.756	0.572	0.561	0.011
20		Bhakkar	0.316	0.1	0.076	0.024

Table 5 Observed and predicted R^2 value of the minimum temperature ^oC (1979-2019).

Sr. no	Region	Stations	R	R2	Adjusted R2	Predicted R2
1	***Northern***	Jhelum	0.749	0.62	0.713	0.013
2		Rawalpindi	0.429	0.396	0.38	0.011
3	***Southern***	Multan	0.416	0.173	0.151	-0.002
4		Bahawalnagar	0.573	0.268	0.27	0.026
5		R.Y khan	0.102	0.01	-0.016	0.018
6		Bahawalpur	0.322	0.103	0.08	0.021
7	***Central***	Gujrat	0.15	0.023	-0.003	0.022
8		Sialkot	0.694	0.481	0.459	0.024
9		Gujranwala	0.162	0.026	0.002	0.017
10		M.Bahuddin	0.602	0.362	0.345	0.007
11		Sargodha	0.849	0.72	0.713	0.016
12		Lahore	0.629	0.396	0.38	0.011
13		Faisalabad	0.761	0.579	0.568	0.023
14		Sahiwal	0.593	0.351	0.334	0.025
15		Okara	0.223	0.05	0.025	0.011
16		Jhang	0.441	0.194	0.173	0.022
17	***Western***	Mianwali	0.559	0.313	0.295	0.026
18		Khushab	0.539	0.29	0.272	0.017
19		D.G khan	0.756	0.572	0.561	0.02
20		Bhakkar	0.447	0.227	0.207	0.023

examination of the spatial extent of the area reveals that the trend direction of the Maximum temperature (Table 3) showed an increase in the Khushab district with a rate of 0.87 °C / year. A significant R square of 0.352 was observed in the Khushab district for maximum temperature.

Assessment of regional changes in Maximum and minimum temperature

presented a rising trend in minimum temperature but a decreasing trend in maximum temperature for the future. The findings present an alarmingly increasing trend of minimum temperature rise from South to Central Punjab, and from Central to North Punjab, it would start decreasing again. The findings also highlight central Punjab's divisions in Sargodha and Faisalabad, to be undergoing the greatest increase in minimum temperature followed by D.G. Khan of

Table 6 Observed and predicted R^2 value of the maximum temperature ^oC (1979-2019).

Sr. no	Region	Stations	R	R^2	Adjusted R^2	Predicted R^2
1	***Northern***	Jhelum	0.177	0.045	0.01	0.025
2		Rawalpindi	0.129	0.054	0.012	0.026
3	***Southern***	Multan	0.223	0.161	0.025	0.136
4		Bahawalnagar	0.291	0.05	0.06	-0.01
5		R.Y khan	0.593	0.084	0.335	-0.251
6		Bahawalpur	0.1	0.103	-0.016	0.119
7	***Central***	Gujrat	0.268	0.072	0.048	0.024
8		Sialkot	0.224	0.05	0.025	0.025
9		Gujranwala	0.424	0.18	0.159	0.021
10		M.Bahuddin	0.33	0.109	0.085	0.024
11		Sargodha	0.194	0.038	0.123	-0.085
12		Lahore	0.187	0.035	0.01	0.025
13		Faisalabad	0.119	0.014	-0.012	0.026
14		Sahiwal	0.755	0.686	0.558	0.128
15		Okara	0.09	0.564	-0.018	0.582
16		Jhang	0.401	0.101	0.139	-0.038
17	***Western***	Mianwali	0.43	0.185	0.164	0.021
18		Khushab	0.832	0.352	0.678	-0.326
19		D.G khan	0.514	0.008	0.247	-0.239
20		Bhakkar	0.089	0.226	-0.18	0.406

The predicted R square, showing the trend of mean, maximum or minimum temperature in the future, presented the fact that in north Punjab, both maximum and minimum temperature trends were showing a positive increase. But for South Punjab, a different scenario was observed with Rahim Yar Khan and Bahawalnagar, experiencing a decreasing trend in maximum temperature, with predicted R square values of -0.251 and -0.01 respectively. However, they both depicted a positive increasing trend in minimum temperature, with predicted R square values of 0.018 and 0.026 respectively, for Rahim yar khan and Bahawalnagar, in south Punjab.

In Central Punjab, a negative trend in maximum temperature was observed for Sargodha and Jhang with predicted R square values of -0.085 and -0.038 respectively. Whereas, for both divisions, a positive rising trend was observed for minimum temperature with predicted R^2 values of 0.016 and 0.022, respectively. In Western Punjab, Khushab and D.G. Khan will present a decrease in maximum temperature trend in the future, with predicted R^2 values of -0.326 and -0.239 respectively, for both divisions, while, for both divisions rising positive trend was observed for future, with predicted R^2 values of 0.017 and 0.02, respectively.

Therefore, we can conclude, that three out of four regions, i.e., Central, Western and Southern Punjab Western Punjab. In South Punjab, the minimum rising temperature can prove to be problematic for the Rabi crop, where the early maturity of the crop might lead to a reduction in grain size.

This steady rise in minimum temperature can lead to further land degradation of this region which would lead to the intensification of the region in general. Central Punjab is a plain area, yet due to heavy population concentration and rapid urbanization, this region experiences minimum temperature rise, in the reported time. More and more people are likely to shift to Central Punjab for employment, better health, and educational facilities. Subsequently, large forest areas are converted into housing schemes, industrial zones, and transportation. The maximum temperature in Southern and Western Punjab is observed high as compared to the Central and Northern Punjab.

Conclusion

The purpose of this research is to investigate the spatial and temporal variations of temperature in Punjab Province, Pakistan from 1979-2019. Mann Kendalls and Slope methods were used to assess the spatiotemporal trends. Results revealed that significant positive trends were found in the minimum and mean annual temperature in the Northern and Central Punjab. In contrast, maximum temperature presented insignificant positive and negative trends instead of

high elevation regions. Furthermore, the minimum temperature is increasing rapidly as compared to a maximum temperature, which indicates a decrease in a diurnal temperature range (DTR). An increasing trend of maximum temperature near southern Punjab and Western Punjab was observed.

The findings of the present study can be helpful in policymaking regarding the updating of crop sowing and harvesting calendars that form the backbone of the economic sector of Punjab. The analysis also incorporated that investigated regions of Punjab suffering from large fluctuations in temperature (maximum and minimum) would further intensify the problem of increasing water requirements under warming situations and declined its availability from a highly erratic pattern of rainfall.

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