Journal of Himalayan Earth Sciences Volume 48, No. 2, 2015 pp.42-61

Assessment of temperature and rainfall trends in Punjab province of Pakistan for the period 1961-2014

M. Shahzad Khattak and Sajjad Ali
Department of Agricultural Engineering,
University of Engineering and Technology, Peshawar.

Abstract

The objective of this study was to assess trends in maximum and minimum temperatures and total monthly rainfall in the Punjab province of Pakistan. Non parametric Mann-Kendall and Sen's slope techniques were employed to find trend strength and magnitude. Serial correlation in data was removed by using TFPW (Trend Free Pre-Whitening) approach. Monthly data of maximum and minimum temperatures and total rainfall was obtained from Regional Meteorological Office (Lahore) for nine districts of Punjab for the period 1961- 2014. The maximum temperature showed a significant increasing trend at Rawalpindi and Faisalabad with a Sen Slope of 0.010°C /year, while significant increasing trends at eight stations were observed in minimum temperature on annual basis. All stations have experienced increasing trends in rainfall out of which only two stations have shown significant trend annually. Overall in Punjab, maximum temperature has shown a significant upward trend in spring (0.028°C /year) and downward trend in summer season (-0.013°C /year). While in minimum temperature, significant increasing trends were observed in all seasons excluding summer. A significant increasing trend in rainfall was observed in summer (1.79 mm/year), autumn and on annual basis (3.23mm/year). The results indicate that spring season is warming and the decreasing trend in summer temperature is caused by increasing trend of rainfall in the province.

Keywords: Mann-Kendall test; Sen's slope; TFPW; Temperature; Rainfall; Punjab.

1. Introduction

The concentration of various long lived greenhouse gases (CH_4,NO_x) especially carbon dioxide and halocarbons is increasing at very high rate mainly due to human driven activities such as burning of fuels, agriculture and type of land use (Deforestation). According to IPCC (Inter Governmental Panel on Climate Change) report issued in 2014, the concentration of CO_2 rose from 280 ppm (pre developed era) to 391 ppm in 2011. The disturbance in environment is going beyond the limit primarily due to uncontrolled emission of various gases towards upper atmosphere. The sun rays coming to earth are being blocked by CO_2 that acts like impermeable cover around atmosphere. Human activities and type of land use also contribute to the type and amount of runoff flowing over land surface. The most pronounced and harmful aspect of this increase in concentration of CO_2 is the continuous rise in temperature with the passage of time. According to IPCC (2007) report eleven out of twelve warmest years occurred between 1996 to 2005 while latest report stated that the 30 warmest years in global history occurred between 1983 to 2012 (IPCC, 2014).The latest report of IPCC in 2014 revealed that a rise of 0.85 °C occurred in average global air surface temperature from 1880 to 2012 and this value is greater than average rise of 0.6 °C which occurred from 1901 to 2000. These Figures indicate that the rate of global warming is increasing in a haphazard manner.

Observed data from 1900 to 2005 showed that precipitation increased in eastern parts of North and South America, northern Europe and northern and central Asia whereas in the Sahel, the Mediterranean, southern Africa and parts of southern Asia it has decreased (IPCC, 2007). However for the longest common period of record (1901–2008), all of the datasets exhibit increases in the globally averaged precipitation (IPCC, 2013). From 2000 to 2100 the mean global temperature is likely to increase with different rates under different carbon emission scenarios like A1B, A2 and A1FI for future projections (IPCC, 2007) Among all, AIFI is the most intense scenario and B1 is the lowest and each covers a different change in global mean temperature as shown in Figure 1. Higher the concentration of CO_2 with the passage of time, greater will be the rise in average global temperature in the absence of mitigation strategies. The gradual change in average global temperature has brought so many complexities associated with it. The rise in average global temperature is likely to cause change in natural hydrological cycle and hence precipitation and atmospheric moisture (IPCC, 2001a and 2001b). The water balance on the earth surface is affected mainly by precipitation causing significant changes in water resources (IPPC, 2001a and 2001b).

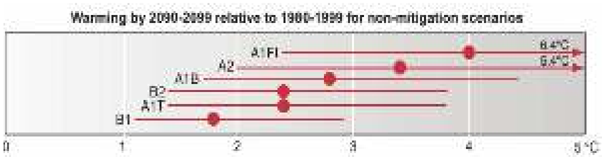


Fig. 1. Temperature rise associated with various carbon emission scenarios (Source: IPCC, 2007).

Different studies have been conducted to assess trends in hydro-meteorological variables in different parts of the world. A study carried out (Christopher et al., 2012) in Florida, USA using mean monthly data of maximum, minimum and mean temperature and rainfall of 22 climatic stations from 1895 to 2009. Results of this study were based on non-parametric Mann-Kendall test which revealed negative seasonal rainfall trends in Florida and increasing trends in mean and maximum temperature on seasonal and annual basis. Similar study for trend detection was conducted by Keggenhoff et al. (2014) by using extreme value of daily temperature and precipitation of 88 climatic stations across entire Georgia for the period 1971-2010. Results of the study revealed that warming trends were observed in maximum and minimum temperatures in most of climatic stations along with increasing trends in extreme precipitation events. Trends in daily temperature and precipitation in Philippines were studied by Thelma et al. (2014) using daily data of two variables from 50 weather stations for period 1951- 2010.Trends in data were estimated by applying non-parametric Mann-Kendall test without removing serial correlation. The results showed significant warming trends in mean annual temperature and mean minimum daily temperature in most parts of Philippines while increasing trends in annual rainfall were detected at few stations. Hua et al. (2007) assessed hydro-climatic trend in Hanjiang Basin of China, using daily data of temperature and precipitation of 14 climatic stations from 1951 to 2003.They used non-parametric Mann-Kendall test for trend detection and found that stream flow tend to decrease due to warming trends in temperature despite the fact that rainfall trends were constant. Rainfall trends in north-eastern part of Cuttack district, Orissa province of India were studied by Arun et al. (2012) and reported that six months namely January, May, June, September, October and November have positive trend in monthly precipitation while rest of the months have negative trends.

Different studies were conducted in Pakistan related to trend analysis of temperature and rainfall e.g. by Rio et al. (2013).They used long term monthly data of mean temperature from 37 climatic stations of Pakistan for the period 1952-2009.Trends in mean temperature were detected using statistical non-parametric techniques. Similar study was conducted by Salma et al. (2012) to estimate rainfall trends in different climatic zones of Pakistan. They used monthly rainfall data of 37 climatic stations for the period 1976-2005 and then applied statistical tests i.e. ANOVA (Analysis of Variation) and Dennett T3 tests. Results of this study indicated that rainfall in Pakistan is decreasing as 1.18mm/year. Another such study was conducted by Maida et al. (2011) to investigate frequency of extreme temperature and rainfall in Pakistan for the period 1965-2009 using daily data of maximum and minimum temperatures and rainfall of 41 climatic stations. They used non parametric KS test (Kalmogorov - Smirnov test) to find significance level of extreme events and found that throughout Pakistan extreme events of both maximum and minimum temperature are increasing particularly in Punjab, Northern areas, Balochistan, and Azad Kashmir. Thus Punjab is vulnerable to changes in most meteorological parameters with high frequency events. Various techniques were applied to detect trends in different regions of Pakistan related to historical climatic parameters e.g. Khattak et al. (2011) used non-parametric tests in Upper Indus Basin. Regression technique was applied by Fowler and Archer (2006) in the same region while Yaseen et al. (2014) used combination of parametric and non-parametric tests in Mangla watershed. It is worth noticing that none of the above mentioned studies has focused particularly on Punjab using non parametric techniques (Mann-Kendall and Sen's Slope) though some parts of Punjab were covered. They did not use the latest climatic record available and their studies did not cover entire area of Punjab. Thus it was necessary to conduct a comprehensive study to analyze trends in few meteorological parameters by using most recent data of different variables and selecting stations having long term data which cover the whole province. This study used meteorological data for the period 1960 - 2014. Mann-Kendall test is a robust technique used in the study and has been widely used by researchers throughout the world mentioned in next sections. From the above findings it can be concluded that mean temperature and precipitation have observed significant changes during last 50 years. During the 20th century most temperature indices have shown warming trends on global level and these trends have occurred in last the last fifty years mostly in minimum temperature. Increasing precipitation trends have been detected on global scale with more number of wet days, however dry periods have no spatial uniformity and it changes from region to region (Frich et al., 2002; Alexander et al., 2006). In this context it is very important to assess the behavior of various meteorological parameters at provincial level by using more robust technique. Punjab is the agricultural and industrial backbone of Pakistan as it engaged nearly 49% of the labor in agricultural and related activities and it produces 76% of the total annual grain production. It contributes 59% of total national GDP and is especially dominant in the Service & Agriculture sectors because 56.1% to 61.5% of the total agricultural products are produced in Punjab (Pakistan Bureau of Statistics, 2011). Wheat and cotton are the most grown crops including rice, sugarcane, millet, corn, oilseeds, pulses, vegetables, and fruits such as citrus. Thus it is important to analyze temperature and rainfall trends in Punjab which may affect the water availability for agriculture, domestic and industrial sectors. The objective of the study was to evaluate the temperature and rainfall trends of individual climate stations of Punjab and then to assess the overall climatic trend.

2. Study Area

Pakistan comprises of five provinces namely Khyber Pakhtunkhwa, Sindh, Punjab, Gilgit Baltistan, Balochistan and FATA (Federally administered Tribal area) as shown in Figure 2. The Jhelum, Chenab, Ravi, Bias and Sutlej are the major rivers which flow through the Punjab province of Pakistan. The total area of Pakistan is 79.6 million hectares in which only 29% is being cultivated. Thus the total cultivable area is 23.08 million hectares in which 80% area is irrigated by canals in Pakistan. Punjab contributes 57% of the total cultivated area and 69% of the total cropped area of Pakistan. Nearly 49% of the labour in Punjab is engaged in agricultural and related activities (Pakistan Bureau of Statistics, 2011).

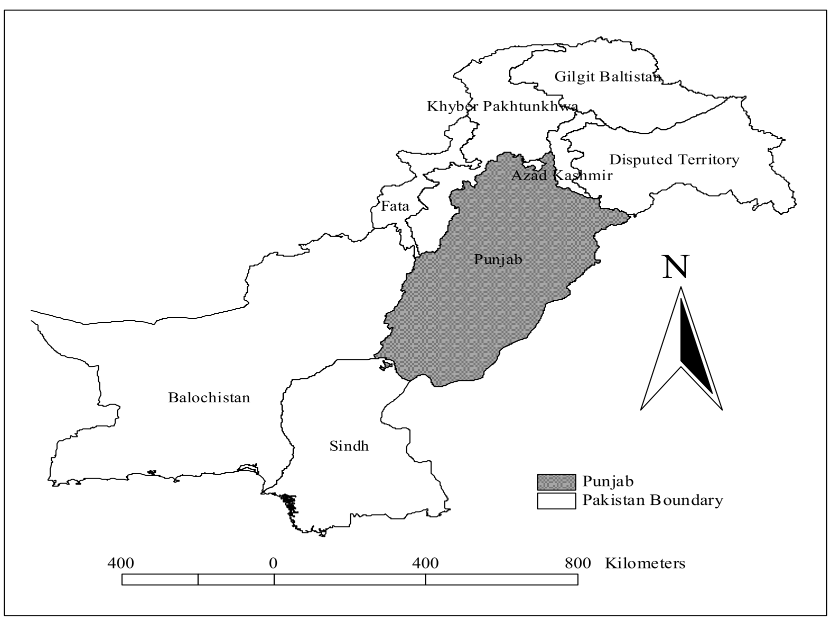


Fig. 2. Map of Pakistan showing study area.

Punjab contributes 59% of total national GDP in 2010 and is especially dominant in the Service & Agriculture sectors because 56.1% to 61.5% of the total Agricultural products come from Punjab (Pakistan Bureau of Statistics, (2011). Despite having dry climate, irrigation makes Punjab a rich agricultural land. Its canal-irrigation system established by the British is the largest in the world. Wheat and cotton are the most grown crops including cotton, rice, sugarcane, millet, corn, oilseeds, pulses, vegetables, and fruits such as citrus. Punjab produces 76% of the total annual food grain production in the country (Pakistan Bureau of Statistics, 2011).

Spatial distribution of mean annual maximum, minimum temperatures and rainfall in nine climatic stations are illustrated in Figure 3. Out of 9 stations, 8 stations are located in Punjab and one station lying in Khyber Pakhtunkhwa province. Five stations have mean annual maximum temperature in the range of 28-31°C and these stations lie in the north and middle Punjab while the southern station have a range of 31-33°C as shown in Figure 3a.This difference in maximum temperature is very slight yet it indicates that the temperature tends to increase as moving from north to south Punjab. In such areas more water is required to compensate high evaporation losses caused by maximum temperature. The mean annual minimum temperature range is almost uniform (range of 16-18°C) indicating the uniformity in Minimum temperature throughout Punjab except Rawalpindi as shown in Figure 3b. Mean annual rainfall in Punjab is spatially distributed like mean maximum temperature i.e. northern station receives much more rainfall as compared to stations that lie in the middle and southern region of Punjab. Jhelum and Sialkot receives greatest share of rainfall in the range of 768-965mm/year while Rawalpindi and Lahore receives 430-767 mm of annual rainfall as shown in Figure 3c.

Thus the northern region of Punjab receives more rainfall as compared to southern and humidity decreases from north to south. These figures clearly indicate that both Mean annual maximum temperature and rainfall have highest values in the north and lowest in the Middle and Southern region.

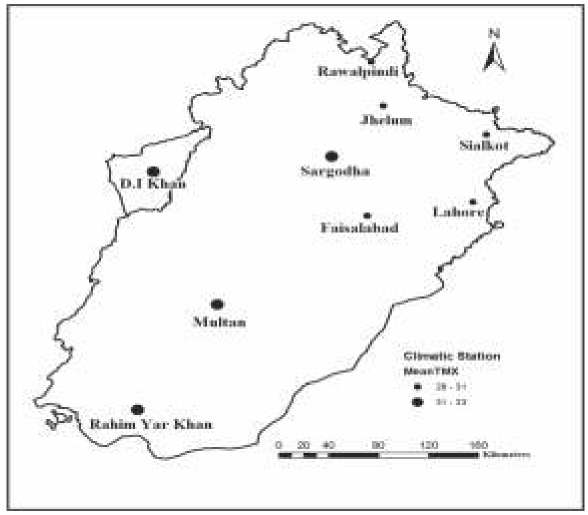


Fig. 3a. Spatial distribution of mean annual maximum temperature (°C) at nine climatic stations.

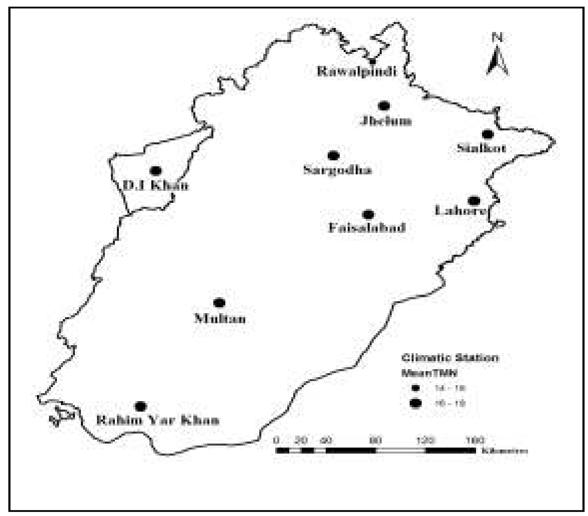


Fig. 3b. Spatial distribution of mean annual minimum temperature (°C) at nine climatic stations.

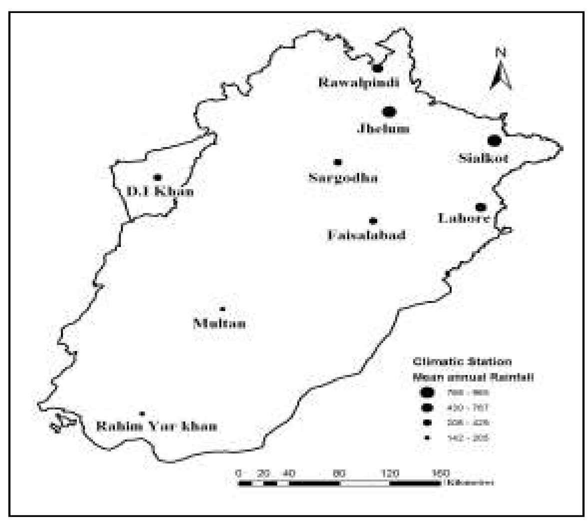


Fig. 3c. Spatial distribution of mean annual rainfall (mm) at nine climatic stations

3. Data and methodology

Historical data of Maximum and Minimum temperatures along with total monthly rainfall data for eight stations of Punjab province and one station (D.I Khan) of Khyber Pakhtunkhwa was obtained from Regional Meteorological Center, Lahore. The reason for including one station from another province is that it is located on the border of two neighboring provinces and it can represent the upper western part of Punjab. The period from 1961 to 2014 being latest was chosen for trend analysis. Only one station namely Rahim Yar khan had missing data from 1961 to 2000 as there was no observatory in that period. Seasonal data was derived by taking average of respective months i.e. December, January and February for winter, March, April and May for spring June, July and August for summer, September, October and November for autumn. For total seasonal and annual rainfall respective monthly values were added. All climatic stations with their geographic location and elevations are given in Table 1 and Figure 4. Parametric test is applied when data always belongs to normal probability distribution i.e. only capable to handle normal data. It is not suitable for detecting monotonic trend. Contrary to that Non -parametric test is the one which do not depend on the assumption that data belongs to any probability distribution. Mann-Kendall (Mann, 1945., Kendall, 1975) test is rank-based non-parametric test (distribution free) having high power to deal with non-normal data of hydrological events (Onoz and Bayazit, 2008). The test has low sensitivity to abrupt breaks due to inhomogeneous time series. In general the test is capable to handle non normal data of any hydrological process or extreme events. Mann-Kendall test has been widely used by various researcher for evaluating trends of various hydro-metrological parameters (Hua et al., 2007; Indrani et al., 2009; Yong et al., 2011; Arun et al., 2012; Christopher et al., 2012; Thelma et al., 2014; Khattak et al., 2011, 2015).

In time series analysis it is essential to consider autocorrelation or serial correlation, defined as the correlation of a variable with itself over successive time intervals, prior to testing for trends. Autocorrelation increases the chances of detecting significant trends even if they are absent and vice versa. Since serial or autocorrelation affect the results of Mann-Kendall test therefore we used Trend free pre-whitening (TFPW). Yue et al. (2002) found that the Pre-whitening technique affects the magnitude of true slope, the focal point of all trend identification studies. To overcome this problem, Yue et al. (2002) suggested the TFPW approach for taking into account the effect of serial correlation. TFPW has been documented as the most commonly used technique to incorporate the effect of serial correlation on the outcome of the trend identification tests (Khaliq et al., 2009). In this study, data series was tested for serial correlation effect at 10% significance level. The TFPW-MK procedure of Yue et al. (2002) was applied to detect a significant trend in a serially correlated time series. The non-zero slope (β) of a trend in sample data is estimated using the approach proposed by Theil (1950) and Sen (1968). The test statistic of Mann-Kendall (Zmk) is used as a measure of significance of trend. Upward trend is observed when Zmk has a positive value and vice versa. The strength of trend was classified on the basis of significance level (p-value). Annual trends of TMX, TMN and rainfall were classified into (a) VS: very strong ($0.0 < p \leq 0.01$), (b) S: strong ($0.01 < p \leq 0.05$), (c) W: weak ($0.05 < p \leq 0.10$), (d) L: little ($0.10 < p \leq 0.50$); (e) VL: very little ($0.50 < p \leq 1.0$) as used by Khattak et al. (2011) in their study.

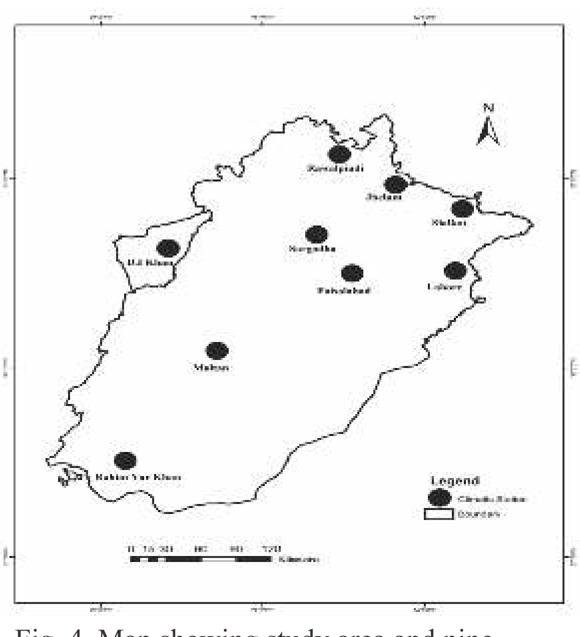


Fig. 4. Map showing study area and nine climatic stations.

Table 1. Showing climatic stations with location and elevation above mean sea level in meters.

S.No	Station	Latitude (deg)	Longitude (deg)	Elevation
1	Faisalabad	31.43	73.13	185.6
2	Lahore	31.55	74.33	214
3	Jhelum	32.93	73.73	287.19
4	Multan	30.2	74.43	121.95
5	Sargodha	32.05	72.66	187
6	Sialkot	32.51	74.52	255.1
7	Rahim Yar Khan	28.43	70.31	82.93
8	D.I Khan	31.81	70.93	171.2
9	Rawalpindi	33.6	73.1	487

Few preliminary tests on raw data namely, Pearson correlation coefficient (Linear trend test), Spearman Rank correlation test (linear trend test for ranked data) and Student-t statistic (two tail trend test) were conducted (Sonali et al., 2013).

These tests identified the monotonic trends in maximum, minimum and mean monthly temperatures along with total monthly rainfall on seasonal and annual basis with respect to time (Sonali et al., 2013). For all tests time (year of observation) was assumed as independent variable and parameters of interest as dependent variable (monthly temperature and rainfall etc). Pearson correlation coefficient measures how strong the linear relationship between two variables is and its value always lies between -1 and 1. It only tells whether relationship exists between two variables without giving idea of slope. Pearson correlation coefficient was calculated suggested by Sonali et al., (2013). For this study correlation was assumed to be of medium level when r=0.30-0.50 and high level when r=0.50-1 each indicating a different linear relationship between parameter and time.

Spearman Rank correlation coefficient is same as that of Pearson correlation coefficient with the difference that it is for ranked data. The ranked values of time and parameters are used instead of original values. It also assesses the strength of relationship between two non parametric variables using a monotone function. It can be calculated using the formula suggested by Sonali et al. (2013) where details can be seen as well. Using the values of spearman rho we calculated another statistic called Student-t statistic, a two tail test to check whether significant trend exists in ranked data or not. Student-t statistic was calculated using the equation suggested by Sonali et al. (2013)

4. Results and discussions

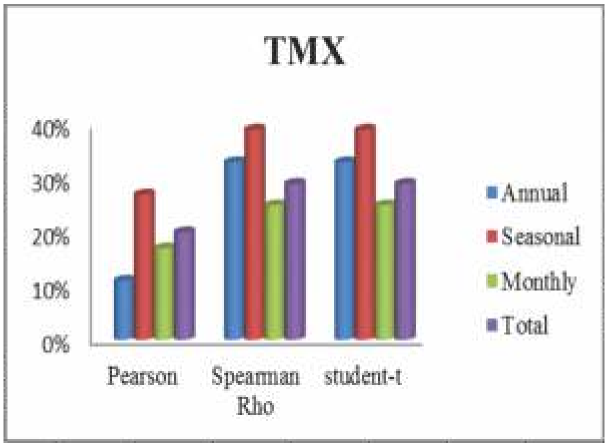
After examining raw data for consistency and homogeneity using various statistical tests at 10% significance level, we calculated values of Pearson correlation coefficient (rs), Spearman Rank correlation coefficient (ρ), Student-t statistic (tρ) and F-test statistic for maximum and minimum temperatures and monthly rainfall on monthly, seasonal and annual basis for nine data stations of Punjab province. For maximum temperature, medium level Pearson correlation (0.30-0.50) was 17%, 27% and 11% on monthly, seasonal and annual basis respectively. A high level Pearson correlation (0.50-1) of 1% only in monthly data was observed. Thus overall only 20% of results had significant values of Pearson correlation coefficient indicating little tendency of data being linear in nature. Similarly significant values of both spearman rho and student-t were 25%, 39% and 33% on monthly, seasonal and annual basis respectively. This exhibits that only 29% of entire results was significant. Normal data has little tendency of showing linear relationship with time while ranked data has more as indicated by the difference in their percentage as shown in Figure 5a.

Results of minimum temperature revealed that medium level Pearson correlation was 29%, 30%, and 44% on monthly, seasonal and annual basis respectively. A high level Pearson correlation of 29%, 47% and 56% in monthly, seasonal and annual data was observed. The overall percentage of significant values of Pearson correlation coefficient was 65% of all results. Similarly significant spearman rho and student-t values for maximum temperature were 65%, 75% and 89% on monthly, seasonal and annual basis respectively. Thus out of total results only 69% were significant. Contrary to maximum temperature, significant results for minimum temperature have high percentage on monthly, seasonal and annul levels. The percentage of overall significant test results indicates that minimum temperature has stronger tendency of establishing linear relationship with time and strongly follows student-t distribution as compared to maximum temperature on all levels as shown in Figure 5b.

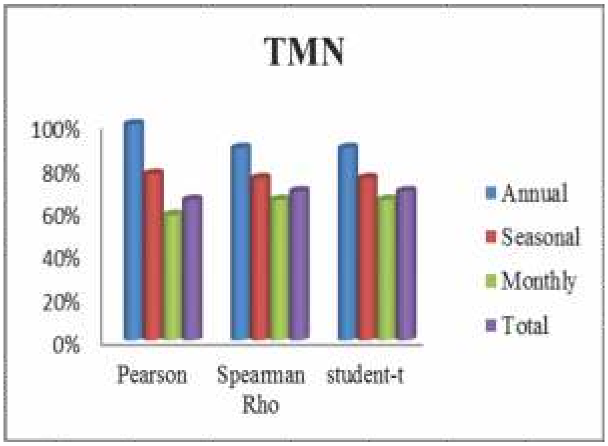
Since rainfall is a process with high uncertainty so its statistical results were quite different than that of temperature mentioned earlier. Among all results of Pearson correlations coefficient only 17% were significant. Medium level Pearson correlations were 13%, 17% and 22% on monthly, seasonal and annual basis respectively. High level Pearson correlations of 1%, 6% and 11% on monthly, seasonal and annual basis were observed respectively. It means that very little linearity exists in rainfall data and it appears mostly in annual data. Similarly significant values of both spearman rho and student-t for were 20%, 22% and 33% on monthly, seasonal and annual basis respectively. This means that only 22% of entire results were significant for spearman rho and Student-t statistic. In general rainfall data has lowest tendency of exhibiting linearity with respect to time as shown in Figure 5c.

4.1. Results of Lag-1 serial correlation coefficient

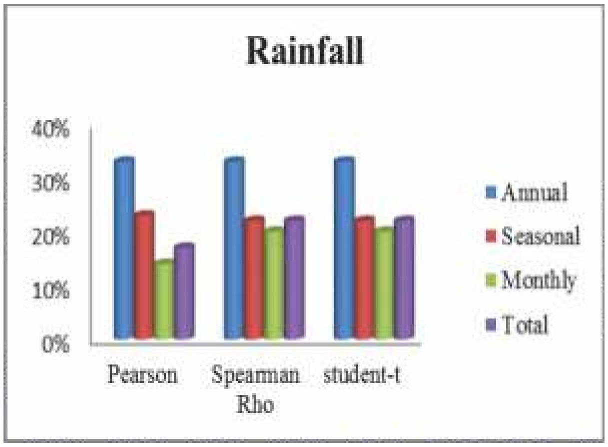
Using Trend Free Pre-Whitening technique (TFPW), serial correlation in data was calculated at 10% confidence level for maximum (TMX) and minimum (TMN) temperatures and rainfall on seasonal and annual basis from 1961 to 2014 for nine stations of Punjab. For maximum temperature only 12% results of Lag-1 correlation coefficient were significant in which more significant values were seen on annual basis as compared to seasons as shown in Table 2a.Highest positive value of Lag-1 correlation coefficient was 0.55



(a)



(b)



(c)

Fig. 5. Results of various statistics for (a) TMX (b) TMN and (c) rainfall showing percentage of significant values in monthly, seasonal, annual and total climatic data.

and highest negative value was –0.58 both observed at Rahim Yar Khan (abbreviated as R Y Khan).

Table 2a. Results of Lag-1 Correlation coefficient using TFPW for TMX.

Station	Wi*	Sp	Su	Au	An
Rawalpindi	NS	NS	NS	**0.23**	**0.30**
Faisalabad	NS	NS	NS	NS	NS
Lahore	NS	NS	NS	NS	NS
Jhelum	NS	NS	NS	NS	**0.27**
Multan	NS	NS	NS	NS	NS
R Y Khan	NS	NS	NS	NS	NS
Sargodha	NS	NS	NS	NS	NS
Sialkot	NS	NS	NS	NS	**0.35**
D.I Khan	NS	NS	NS	NS	NS

Bold values indicate results at 10% significance level while NS indicates insignificant values and the abbreviations have been used for various seasons such as Wi (Winter), Sp (Spring), Su (Summer), Au (Autumn) and An (Annual).

Minimum temperature showed that 23% result of Lag-1 correlation coefficient was significant. This indicated that minimum temperature is doubled in percentage significant values as compared to maximum temperature. More significant values were observed in summer and annual temperatures as shown in Table 2b. Highest positive value of Lag-1 correlation coefficient was 0.52 at Lahore and highest negative value was –0.71 at Rahim Yar Khan.

Thus in general April and annual temperatures have suffered more correlation in all respects. Minimum temperature has highest percentage of significant results of Lag-1 correlation coefficient and maximum temperature has comparatively little. Contrary to temperature rainfall exhibited completely different statistical behavior with very little significant values i.e. 13% results have statistical significance. More significant results were seen only in spring as shown in Table 2c. It was observed that highest positive value of Lag-1 correlation coefficient was 0.51 and highest negative value was -0.65 both observed at Rahim Yar Khan.

Table 2b. Results of Lag-1 Correlation coefficient using TFPW for TMN.

Station	Wi	Sp	Su	Au	An
Rawalpindi	NS	**0.26**	**0.45**	NS	**0.46**
Faisalabad	**0.23**	NS	NS	**0.25**	**0.36**
Lahore	NS	**0.37**	**0.33**	NS	**0.52**
Jhelum	NS	NS	**0.23**	NS	NS
Multan	NS	NS	**0.26**	NS	NS
R Y Khan	NS	NS	NS	NS	NS
Sargodha	NS	NS	**0.34**	NS	NS
Sialkot	NS	**0.37**	**0.50**	**0.39**	**0.46**
D.I Khan	**0.50**	NS	**0.28**	NS	**0.44**

Table 2c. Results of Lag-1 Correlation coefficient using TFPW for total rainfall (mm).

Station	Wi	Sp	Su	Au	An
Rawalpindi	**0.28**	NS	NS	**0.32**	**0.41**
Faisalabad	NS	NS	NS	NS	**0.30**
Lahore	NS	**0.25**	NS	NS	NS
Jhelum	NS	**0.28**	NS	NS	NS
Multan	NS	NS	**-0.29**	NS	NS
R Y Khan	NS	NS	NS	NS	NS
Sargodha	NS	NS	NS	NS	NS
Sialkot	NS	**0.22**	NS	NS	NS
D.I Khan	NS	**0.25**	NS	NS	NS

Bold values indicate results at 10% significance level while NS indicates insignificant values and for other abbreviations see Table 2a.

4.2. Trends in temperature and rainfall

Mann-Kendall test statistic together with respective significance level (p-value) and magnitude of trend slope (°C /year) were calculated for Pre-Whitened maximum, minimum and mean temperatures and rainfall (mm/year) on monthly, seasonal and annual basis for individual climatic station and for the whole province.

4.2.1. Trends in maximum temperature at climatic stations

On annual basis two stations, Rawalpindi and Faisalabad have significant increasing trend while two stations Lahore and Sialkot) have significant decreasing trend in Maximum temperature (Table 3a and Fig. 6). In general six out of nine stations showed warming trend and three stations indicated cooling trend. Six stations have trends classified as very little (VL), two have little (L) and one has weak (W). The highest decreasing trend occurred at the rate of -0.015°C /year in Sialkot (Strong) while highest positive trend was observed in Rawalpindi at the rate of 0.011°C /year (Weak) on annual basis. On seasonal basis 3 out of nine stations have shown weak (W) trend and other six have strong (S),little (L) and very little(VL) trends in spring i.e. spring has warming trend. Both summer and autumn showed significant decreasing trend (cooling trend) at three stations namely Lahore, Multan and Sialkot. Thus warming on annual level is mainly caused by warming trend in spring and cooling mainly by decreasing trends in summer and autumn season. Warming trends in annual maximum temperature have occurred mostly in the two north-eastern (Lahore and Sialkot) districts while spring warming can be seen throughout the study area. Cooling trends in summer and autumn were observed in the same north-eastern region. Thus same region has suffered increasing trend in spring and decreasing trends in summer and autumn.

4.2.2. Trends in minimum temperature at climatic stations

Six out of nine stations have indicated significant positive trends classified as very strong, two have strong and one has little on annual basis, the highest in Sargodha at the rate of 0.050°C /year (Table 3b and Fig. 7). In general stronger warming trends in minimum annual temperature as compared to maximum temperature were observed (Fig. 7). Significant increasing trend in autumn at all stations (5 Stations very strong) and in winter and spring at eight stations (Mostly strong and very strong) were seen. At three stations summer revealed significant positive trends (only one station very strong). Among these trends the highest of all was observed in Lahore in winter at the rate of 0.068 °C /year with $p<0.0001$ (Very strong). Thus stronger warming in winter, spring and autumn contributed to overall stronger annual warming in the province. Rawalpindi suffered negative changes (warming trends) both on seasonal and annual basis. The warming tendency on seasonal and annual levels was stronger as compared to maximum temperature. It was observed that Rawalpindi suffered increasing warming trends in both maximum and minimum temperatures where all seasons have shown highest seasonal and annual warming in TMN. It can be concluded that warming trends in TMN are uniformly distributed throughout the climatic stations.

Contrary to temperature, rainfall has shown a very low percentage of significant results (Table 3c and Fig. 8). In general all stations have increasing trends on annual level in which Rawalpindi (3.62mm/year, very strong) and D.I Khan (1.96mm/year, strong) have revealed significant values. Significant positive trends in autumn were seen only at four stations and this is the real cause of rise in rainfall on annual basis at these stations. General positive (Mostly weak and little) trends in winter, spring and summer at all stations were observed with significant values only at Rawalpindi.

Thus it can be concluded that Punjab experienced general increasing trends in rainfall on annual basis mainly because of positive trends in autumn (mostly strong). Among all climatic stations Rawalpindi is the only station which has seen highest positive trends in rainfall at all levels despite having greatest warming trend in temperature. Like temperature, increasing rainfall trends can also be observed in extreme north (Rawalpindi) of Punjab. Thus the north and north-eastern districts of Punjab are the victims of significant change in the annual and seasonal rainfall trends.

4.2.3. Overall trends in temperature and rainfall in Punjab

Results revealed that maximum temperature has significant increasing trend in spring (0.028°C /year, $p=0.020$) categorized as strong and decreasing (Weak) trend in summer (-0.013°C /year, $p=0.058$) and other seasons having insignificant values including annual level. The increasing trend in spring is because of the warming trend in the month of May while cooling trend in summer is caused by decreasing trends in June, July and August. For minimum temperature there are significant increasing trends in winter (0.033°C /year, p<0.0001), spring (0.032°C /year, p=0.002), autumn (0.032°C /year, p<0.0001) and annual level (0.025°C /year, p<0.0001) i.e. winter, autumn and annual have very strong trends. It also means that minimum temperature has stronger tendency of rise as compared to maximum temperature on seasonal and annual levels. The apparent reason for these higher increasing trends are the increasing significant trends in eight months except April, June, July and August as shown in Table 4a,b.

Table 3a. Results of MK statistic (Zmk) with significance level (p) and trend slope for TMX at climatic stations.

Station	Static	Wi	Sp	Su	Au	An
Rawalpindi	Z_{mk}	1.29	2.73	-0.29	0.43	1.87
	p-value	0.197	**0.006**	0.771	0.671	**0.061**
	Slope	0.014	0.040	-0.002	0.002	0.011
Faisalabad	Z_{mk}	-0.76	2.73	0.01	0.05	1.66
	p-value	0.446	**0.006**	0.988	0.958	**0.096**
	Slope	-0.007	0.038	0.000	0.000	0.010
Lahore	Z_{mk}	-1.45	1.86	-3.31	-2.14	-1.71
	p-value	0.148	**0.063**	**0.001**	**0.033**	**0.087**
	Slope	-0.014	0.018	-0.029	-0.014	-0.007
Jhelum	Z_{mk}	0.24	2.30	-0.90	-0.96	0.32
	p-value	0.811	**0.022**	0.367	0.339	0.748
	Slope	0.002	0.033	-0.008	-0.007	0.002
Multan	Z_{mk}	-1.31	1.93	-2.19	-1.98	-0.27
	p-value	0.191	**0.053**	**0.028**	**0.048**	0.788
	Slope	-0.009	0.024	-0.015	-0.013	-0.001
Sargodha	Z_{mk}	-1.06	2.43	-0.87	-1.45	0.82
	p-value	0.289	**0.015**	0.387	0.148	0.412
	Slope	-0.011	0.038	-0.007	-0.012	0.004
Sialkot	Z_{mk}	-1.57	0.78	-2.19	-2.47	-2.57
	p-value	0.117	0.438	**0.029**	**0.013**	**0.010**
	Slope	-0.013	0.012	-0.020	-0.014	*-0.015*
Rahim Yar Khan	Z_{mk}	-1.77	-0.31	-0.67	-0.12	0.31
	p-value	0.076	0.760	0.501	0.902	0.760
	Slope	-0.095	-0.043	-0.028	0.000	0.009
D.I Khan	Z_{mk}	0.17	1.99	-0.92	-0.86	0.78
	p-value	0.864	**0.047**	0.359	0.390	0.433
	Slope	0.001	0.031	-0.006	-0.004	0.004

Bold values indicate significance results at 10% significance level

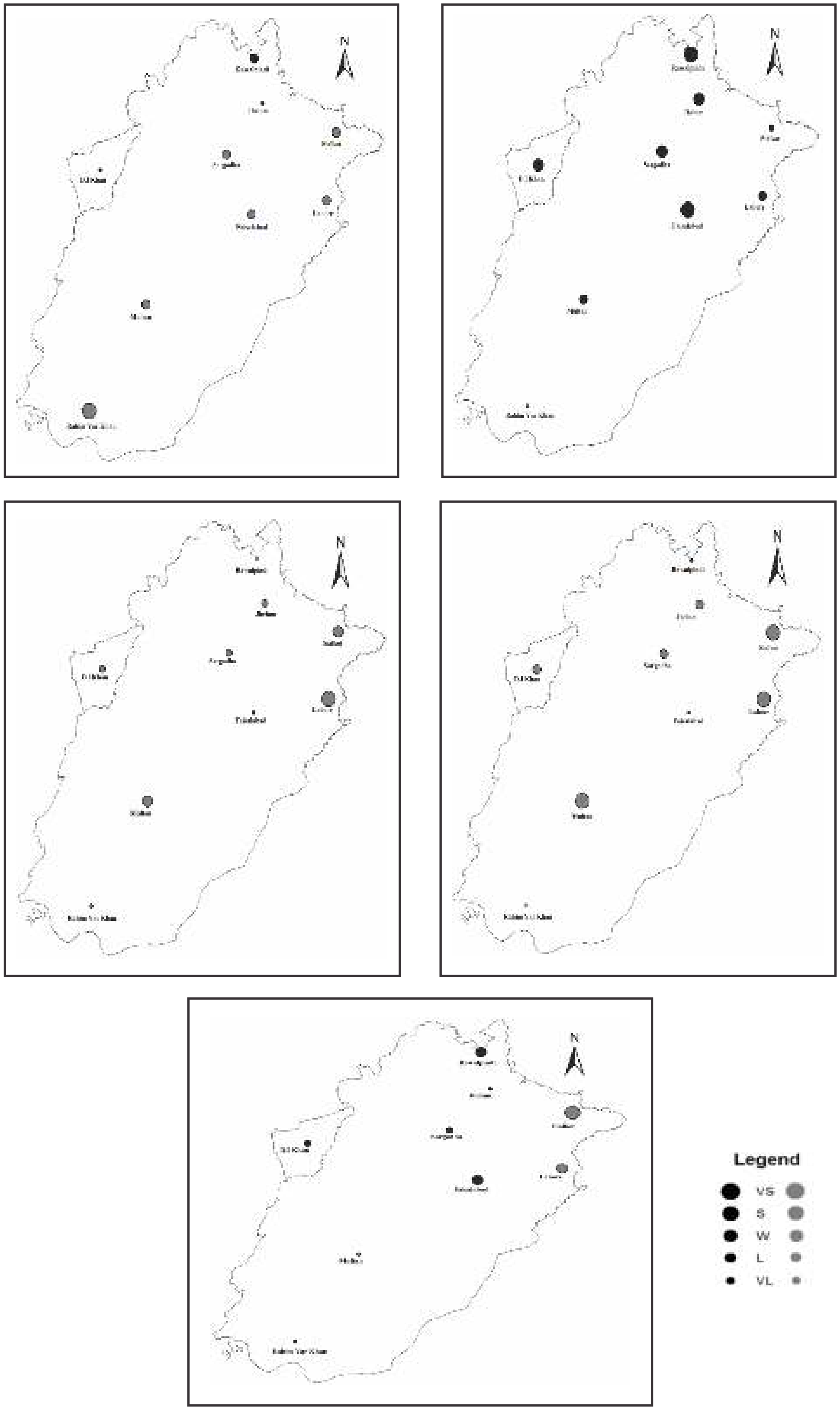


Fig. 6. Showing spatial distribution of changing trends of maximum temperature (TMX) in: (a) winter, (b) spring, (c) summer, (d) autumn, and (e) annual over the period 1961–2014. In the key—VS: very strong ($0.0 < p \leq 0.01$); S: strong ($0.01 < p \leq 0.05$); W: weak ($0.05 < p \leq 0.10$); L: little ($0.10 < p \leq 0.50$); VL: very little ($0.50 < p \leq 1.0$) show trend significance, while black circle indicates a positive trend and silver circle indicates a negative trend.

Table 3b. Results of MK statistic (Zmk) with significance level (p-value) and trend slope for TMN at climatic stations.

Station	Static	Wi	Sp	Su	Au	An
Rawalpindi	Z_{mk}	6.56	4.59	3.26	5.14	5.81
	p-value	**<0.0001**	**<0.0001**	**0.001**	**<0.0001**	**<0.0001**
	Slope	0.053	*0.055*	0.020	0.040	*0.040*
Faisalabad	Z_{mk}	**2.01**	**3.87**	-0.28	**2.84**	**3.22**
	p-value	**0.045**	**<0.0001**	0.777	**0.004**	**0.001**
	Slope	0.015	*0.038*	-0.002	0.021	*0.018*
Lahore	Z_{mk}	6.86	4.81	1.17	5.88	6.18
	p-value	**<0.0001**	**<0.0001**	0.241	**<0.0001**	**<0.0001**
	Slope	0.068	*0.055*	*0.007*	*0.058*	*0.048*
Jhelum	Z_{mk}	3.22	3.99	1.47	4.26	5.13
	p-value	**0.001**	**<0.0001**	0.142	**<0.0001**	**<0.0001**
	Slope	0.023	*0.033*	0.005	0.029	0.022
Multan	Z_{mk}	5.40	4.23	1.45	4.63	5.89
	p-value	**<0.0001**	**<0.0001**	0.146	**<0.0001**	**<0.0001**
	Slope	0.044	0.039	0.006	*0.036*	0.032
Sargodha	Z_{mk}	5.77	6.11	3.75	6.85	7.01
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Slope	*0.053*	*0.061*	0.019	*0.062*	0.050
Sialkot	Z_{mk}	2.47	2.32	0.25	3.08	3.48
	p-value	**0.013**	**0.020**	0.806	**0.002**	**<0.0001**
	Slope	0.021	0.019	0.001	*0.024*	*0.016*
Rahim Yar Khan	Z_{mk}	-0.37	0.00	1.85	2.07	0.98
	p-value	0.714	1.000	**0.065**	**0.038**	0.329
	Slope	-0.037	0.000	0.055	0.167	0.051
D.I Khan	Z_{mk}	2.26	3.09	0.57	2.87	3.35
	p-value	**0.024**	**0.002**	0.566	**0.004**	**0.001**
	Slope	0.015	0.031	0.003	0.025	0.020

Bold values indicate significance results at 10% significance level

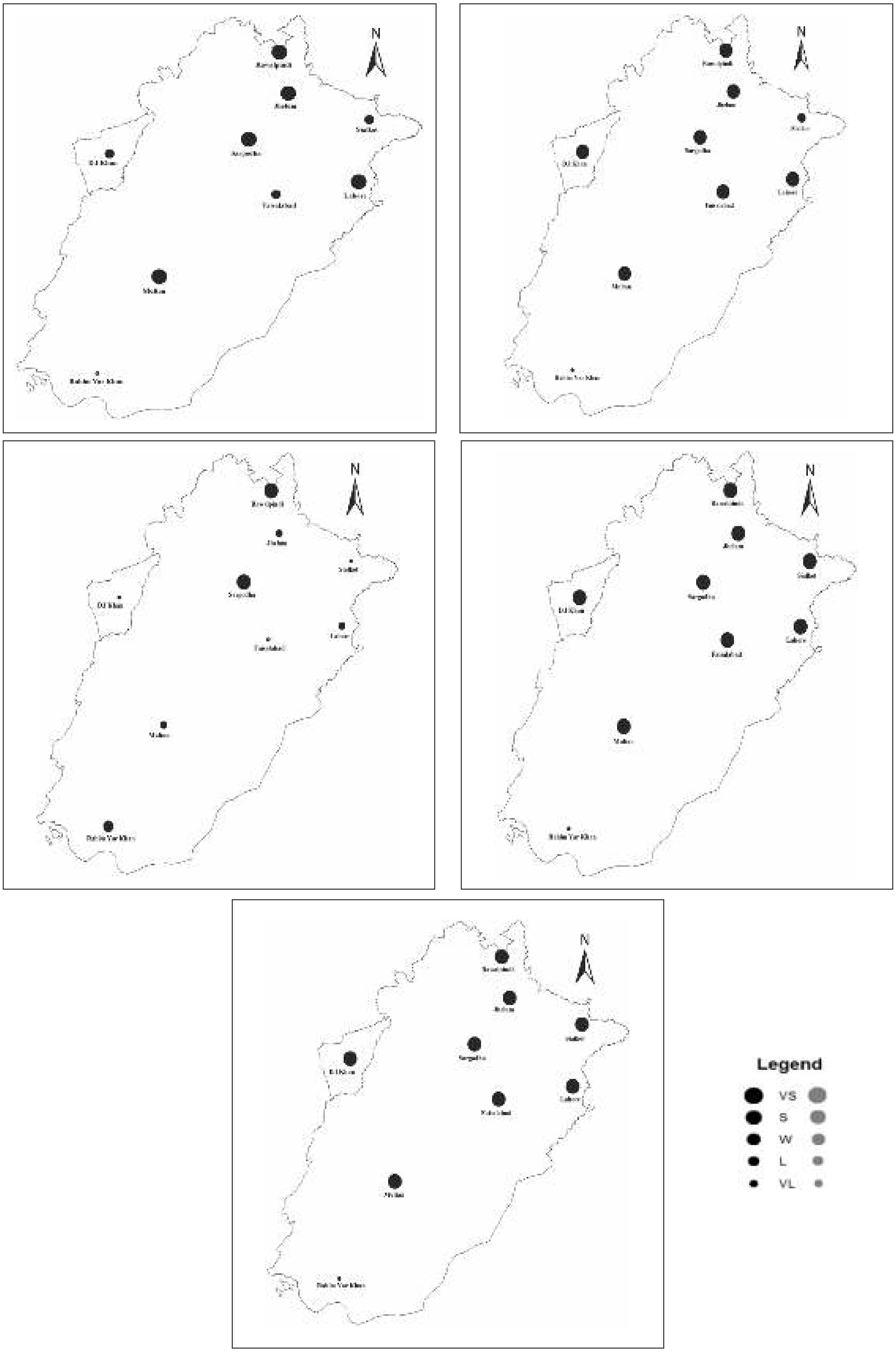


Fig. 7. Showing spatial distribution of changing trends of minimum temperature (TMN) in: (a) winter, (b) spring, (c) summer, (d) autumn, and (e) annual over the period 1961–2014.For key see figure 6.

Table 3c. Results of MK statistic (Zmk) with significance level (p-value) and trend slope for rainfall at climatic stations.

Station	Static	Wi	Sp	Su	Au	An
Rawalpindi	Z_{mk}	3.23	2.02	2.34	3.22	3.62
	p-value	**0.00**1	**0.043**	**0.020**	**0.001**	**<0.0001**
	Slope	1.701	*1.000*	4.826	2.199	*9.850*
Faisalabad	Z_{mk}	0.28	-0.07	0.71	2.56	1.60
	p-value	0.783	0.946	0.478	**0.010**	0.109
	Slope	0.052	-0.011	0.550	0.949	1.799
Lahore	Z_{mk}	-0.41	-0.38	1.25	0.95	1.60
	p-value	0.682	0.704	0.213	0.340	0.109
	Slope	-0.131	-0.100	1.696	0.494	2.747
Jhelum	Z_{mk}	0.07	-0.72	0.60	0.63	0.23
	p-value	0.941	0.469	0.546	0.526	0.817
	Slope	0.071	-0.458	0.709	0.296	0.402
Multan	Z_{mk}	1.51	0.28	-0.23	2.86	1.60
	p-value	0.130	0.777	0.817	**0.004**	0.110
	Slope	0.227	0.038	-0.124	0.280	1.223
Sargodha	Z_{mk}	0.35	-0.43	0.64	1.38	1.13
	p-value	0.726	0.671	0.521	0.167	0.260
	Slope	0.090	-0.152	0.655	0.475	1.360
Sialkot	Z_{mk}	0.48	0.22	1.37	0.28	1.60
	p-value	0.633	0.829	0.172	0.783	0.109
	Slope	0.284	0.091	2.960	0.276	3.372
Rahim Yar Khan	Z_{mk}	-0.31	2.26	0.12	1.59	1.10
	p-value	0.760	**0.024**	0.903	0.111	0.272
	Slope	-0.663	2.236	0.142	1.888	6.358
D.I Khan	Z_{mk}	0.36	-0.26	1.22	2.87	1.96
	p-value	0.720	0.794	0.224	**0.004**	**0.050**
	Slope	0.103	-0.098	0.852	0.685	1.920

Bold values indicate significance results at 10% significance level

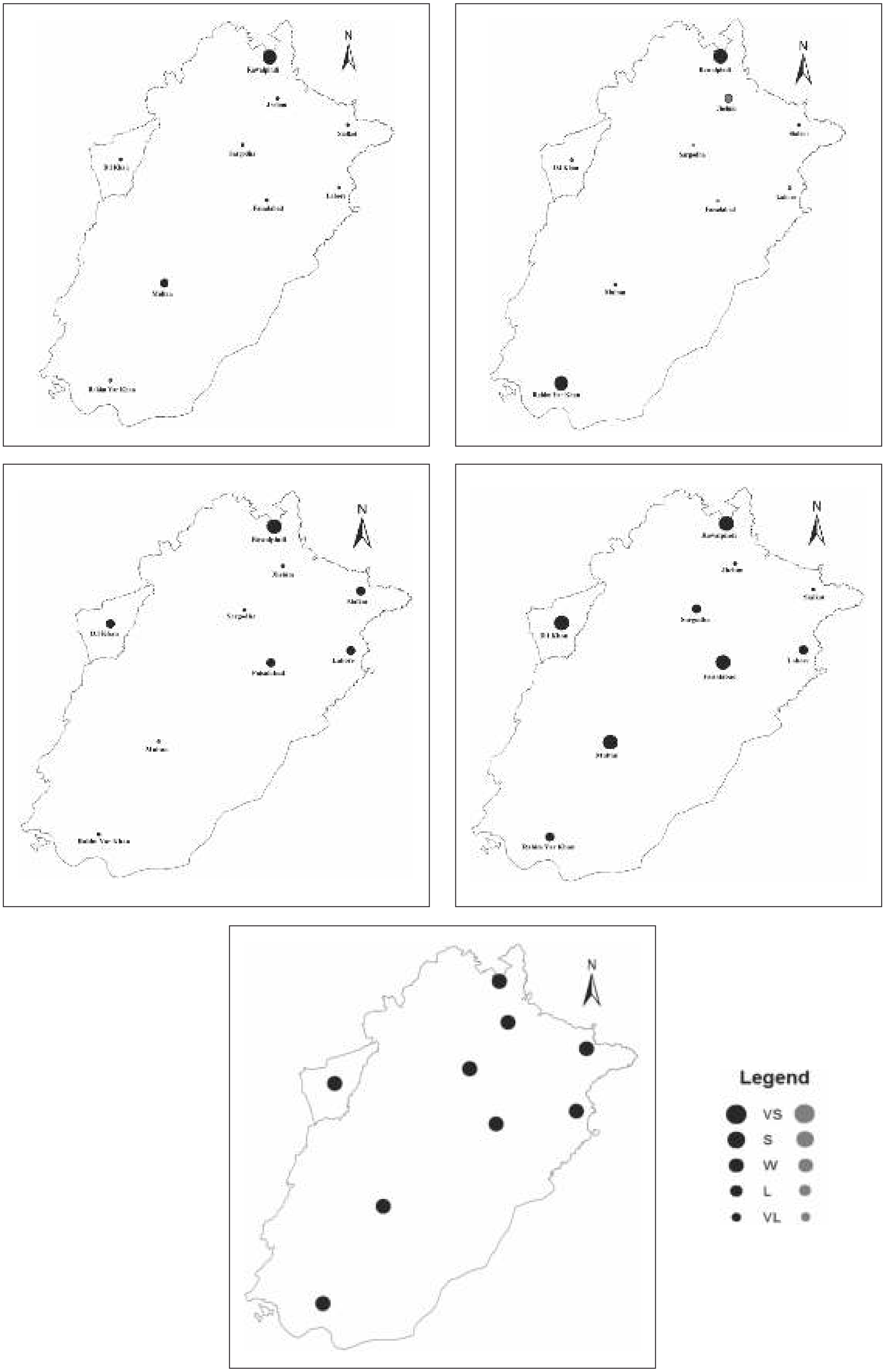


Fig. 8. Showing spatial distribution of changing trends of Rainfall in: (a) winter, (b) spring, © summer, (d) autumn, and (e) annual over the period 1961–2014. For key see figure 6.

Table 4a. Monthly results of MK statistic (Zmk) with significance level (p-value) over study area.

Month	TMX		TMN		Rainfall	
	Z_{mk}	p-value	Z_{mk}	p-value	Z_{mk}	p-value
January	-2.81	**0.005**	2.99	**0.003**	0.09	0.929
February	0.07	0.941	3.10	**0.002**	1.44	0.150
March	1.19	0.233	2.72	**0.007**	-0.08	0.935
April	1.55	0.121	1.42	0.154	0.34	0.737
May	2.28	**0.023**	3.28	**0.001**	0.31	0.760
June	-0.73	0.039	-0.14	0.887	2.57	**0.010**
July	-1.22	0.465	-0.07	0.946	0.36	0.720
August	-1.34	0.224	1.02	0.307	1.69	**0.090**
September	-1.26	0.179	2.10	**0.036**	1.95	**0.052**
October	0.46	0.207	3.08	**0.002**	1.53	0.126
November	1.03	0.649	3.92	**<0.0001**	0.58	0.565
December	-0.63	0.30	3.59	**<0.0001**	-0.72	0.47

Bold values indicates significant results at given significance level

Table 4b. Results of MK statistic (Zmk) with significance level (p-value) and trend slope over study area.

	TMX			TMN			Rainfall		
Season	Zmk	p-value	Slope (ºC /year)	Zmk	p-value	Slope (°C /year)	Zmk	p-value	Slope (mm /year)
Winter	-0.63	0.526	-0.007	5.17	**<0.0001**	0.033	1.29	0.197	0.349
Spring	2.33	**0.020**	0.028	3.17	**0.002**	0.032	0.04	0.970	0.017
Summer	-1.90	**0.058**	-0.013	0.66	0.507	0.003	1.83	**0.068**	1.790
Autumn	-1.40	0.161	-0.009	3.95	**<0.0001**	0.032	2.35	**0.019**	0.739
Annual	0.49	0.622	0.002	4.14	**<0.0001**	0.025	2.41	**0.016**	3.238

Bold values indicates significant results at given significance level

Contrary to temperature rainfall results revealed significant increasing trends in summer (1.790mm/year=0.068), autumn (0.739mm/year, p=0.019) and annual (3.23mm/year, p=0.016) i.e. autumn and annual rainfall have weak increasing trends though significant. These trends can be attributed to increasing significant trends in the months of June, August and September as shown in Table 4ab. Time series plot along trend lines in TMX, TMN and rainfall in Punjab in various months and seasons have been illustrated in Figure 9.

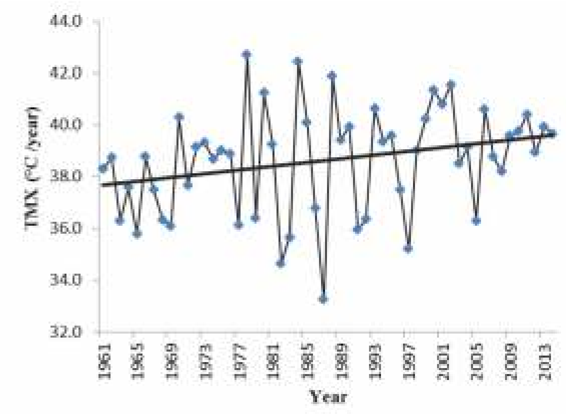


Fig. 9a. Time series plot along trend line in the month of May.

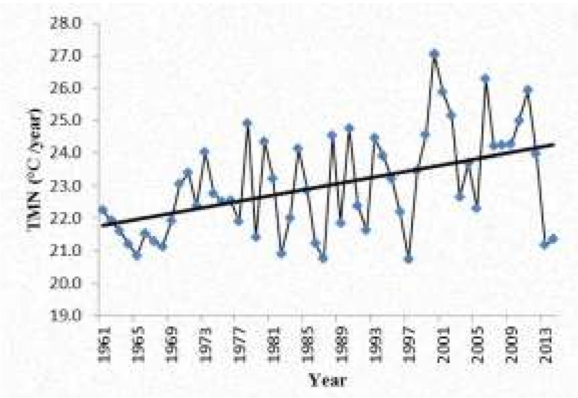


Fig. 9b. Time series plot along trend line in the month of May.

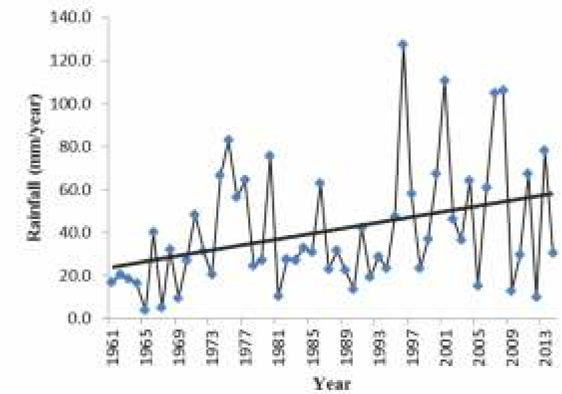


Fig. 9c. Time series plot along trend line in the month of June.

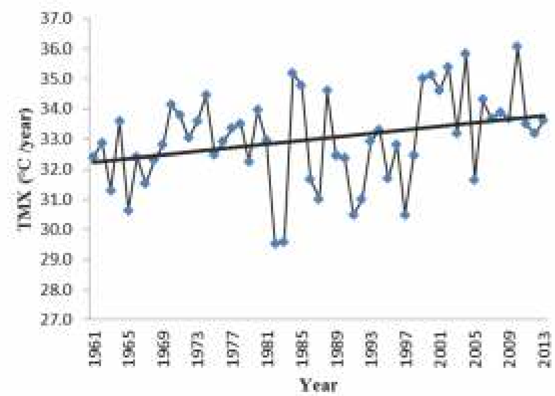


Fig. 9d. Time series plot along trend line during spring season.

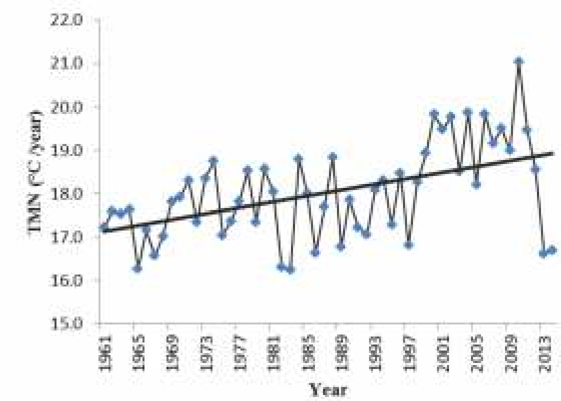


Fig. 9e. Time series plot along trend line during spring season .

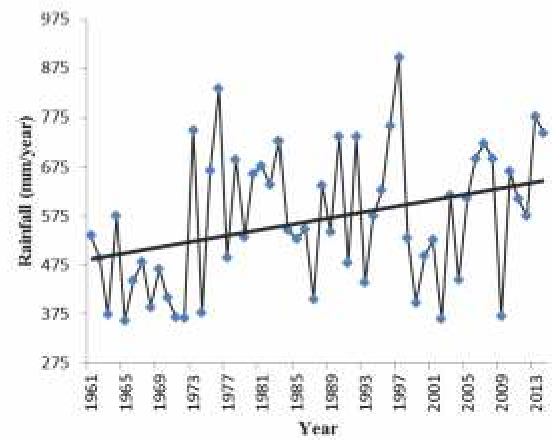


Fig. 9f. Time series plot along trend line on annual basis.

The results of this study are in agreement with the report of Rio et al. (2013) which revealed that the rate of mean annual temperature rise in Pakistan is 0.036 °C /year indicating that warming trend is being observed both at provincial and country level. Since rainfall trends in Punjab have increasing trends, this is contrary to the report of Salma et al. (2012) which revealed that precipitation has a negative trend of 1.18mm/year in Pakistan indicating that Punjab is not affected by country level decreasing rainfall trends. The finding of Yaseen et al. (2014) revealed that Annual maximum, minimum and mean temperatures have significant negative trend in all basins of Mangla watershed i.e. cooling trends. Thus it can be concluded in general that some parts of northern areas in Pakistan have cooling trends while plains in general are being suffered by global warming. A study of stream flow trends of Jhelum, Chenab and Indus River by Khattak et al. (2015) have shown an increasing trend in annual stream flow. In this study an increasing trend of annual rainfall was observed which may be considered as one of the cause of increasing trends in stream flow. Though increasing rainfall trends have been detected in Punjab which will cause sufficient ground water recharge, yet rainfall may not be seasonable and it's spatial distribution may not be uniform to meet the demands of rain fed areas (southern parts). Secondly most of the area in Punjab is irrigated by canals so increasing rainfall trends may not affect irrigation demands to a greater extent rather it may cause damage to standing crops due to high intensity. Since domestic water demands depends mostly on ground water so this sector will have plenty of available water if same increasing trends in rainfall continue in future. However increasing rainfall trends may cause water logging, floods and cause considerable damage to property and cultivated lands in Punjab.

5. Conclusions

This study identified trends in maximum, minimum and mean temperature and rainfall on seasonal and annual basis from 1961 to 2014 for nine districts of Punjab. The method used was non-parametric Mann-Kendall test in time series for all parameters. All trends in temperature and rainfall may be attributed to regional climate changes, local land use and high emission rates of carbon gases from various sources so it is strongly emphasized that water resource planners and agricultural experts must consider these changes in policy making for effective implementation. Following specific conclusions derived from this study are:

1. Maximum temperature and rainfall data have same percentage (12%) of significant results of Lag-1 correlation coefficient while minimum temperature has twice (23%) as compared to TMX and rainfall. For all parameters auto-correlation was mostly found in annual data.

2. At station level for maximum temperature, positive significant trends were observed at Rawalpindi (0.011°C /year) and Faisalabad (0.010°C /year) while negative significant trends at Lahore (-0.007 °C /year) and Sialkot (-0.015°C /year) on annual level. For minimum temperature, positive significant trends were revealed at eight stations in all seasons (except summer) and annual basis.

3. All stations have experienced increasing trends in rainfall on annual basis in which only two stations (Rawalpindi have and D.I Khan) have revealed significant values, the highest was noted in Rawalpindi at the rate of 9.85mm/year. Significant positive trends in autumn were seen only at four stations.

4. Overall, the mean maximum temperature in Punjab has shown a significant increasing trend in spring (0.028°C /year, $p=0.020$) and a decreasing trend in summer season (-0.013°C/year $p=0.058$). For minimum temperature there is significant increasing trends in winter (0.033°C /year, $p<0.0001$), spring (0.032°C/year, $p=0.002$), autumn (0.032°C/year, $p<0.0001$) and annual level (0.025°C/year, $p<0.0001$) i.e. winter and autumn were subjected to the greatest change of all.

5. The overall mean rainfall results for Punjab have shown a significant increasing trend in summer (1.790mm/year, $p=0.068$) and autumn seasons (0.739mm/year, $p=0.019$) as well as on annual basis (3.23mm/year, $p=0.016$).

Acknowledgment

Author is very thankful to the Regional Meteorological Centers of Punjab and KPK for providing long term meteorological data.

References

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D.,Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., Vazquez-Aguirre, J.L., 2006. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysics Research, 111, D05109.

Arun, M., Sananda, K., Anirban, M., 2012. Rainfall trend analysis by Mann-Kendall Test: A case study of North-Eastern part of Cuttack District, Orissa, India. International Journal of Geology, Earth and Environmental Sciences, 2 (1), 70-78.

Christopher, J.M., Jerome J., Maleski., Martin, F., Miller, 2012. Trends in precipitation and temperature in Florida, USA. Journal of Hydrology, 452-453, 259-281.

Fowler, H.J., Archer D.R., 2006. Conflicting signals of climate change in the Upper Indus Basin. Journal of Climate, 19, 4276-4293.

Frich, P., Alexandar, L.V., Delaa-Marta, P., Gleason, B., Haylock M., Klein Tank, A.M.G., Peterson, T., 2002. Observed coherent changes in climate extremes during the second half of 20th Century. Climate Research, 19, 193-212.

Hua, Chen., Shenglian, Guo., Chong-yu, Xu., Vijay, P.S., 2007.Historical temporal trends of hydro - climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. The Journal of Hydrology, 344, 171-184.

Indrani, P., Abir, Al-Tabbaa., 2009. Trends in seasonal precipitation extremes – An indicator of climate change in Kerala, India. Journal of Hydrology, 367, 62-69.

IPCC (Intergovernmental Panel on Climate Change), 2001a. Impacts, Adaptations, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, UNEP, WMO, Arendal, Norway, Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change), 2001b. Working Group I: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, UNEP, WMO, Arendal, Norway, Cambridge University Press, UK.

IPCC (Intergovernmental Panel on Climate Change), 2007. Summary for policymakers: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK.

IPCC (Intergovernmental Panel on Climate Change), 2013. The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change, Cambridge University Press, UK, 5-204, 2013.

IPCC (Intergovernmental Panel on Climate Change), 2014. Summary for policymakers: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom and New York, NY, USA, 1-32.

Keggenhoff, I., M. Elizbarashvili., A. Amiri-Farahani., L. King., 2014. Trends in daily temperature and precipitation extremes over Georgia, 1971-2010. Weather and Climate Extremes, 4, 75-85.

Kendall, M.G., 1975. Rank Correlation Methods, Charles Griffin, London, UK.

Khaliq, M.N., Ouarda, T.B.M.J., Gachon, P., Sushama, L., St-Hilaire, A., 2009. Identification of hydrologic trends in the presence of serial and cross correlations, A review of selected methods and their application to annual flow regimes of Canadian rivers. Journal of Hydrology, 368, 117-130.

Khattak, M.S, Naseem, R., Sharif, M., Mahmood, A.K., 2015. Analysis of Stream flow data for trend detection on major rivers of Indus Basin. Journal of Himalayan Earth Sciences, 48, 1, 99-111.

Khattak, M.S., Babel, M.S., Sharif, M., 2011. Hydro-meteorological trends in the upper Indus basin in Pakistan. Climate Research, 46, 103-119.

Maida, Z., Ghulam, R., 2011. Frequency of extreme temperature and precipitation events in Pakistan 1965-2009. Science International (Lahore), 23(4), 313-319

Mann, H.B., 1945. Non- Parametric tests against trend. Econometrica, 13, 245-259.

Onoz, B., Bayazit, M., 2008. The power of statistical tests for trend detection. Turkish journal of engineering and environmental sciences, 27, 247-251.

Pakistan Bureau of Statistics, 2011. Report on Agricultural census in Pakistan by Agricultural statistics directorate in PBS, under federal government of Pakistan.

Rio, S., Iqbal, M.A, Ortiz, A.C., Herrero, L., Hassan, A., Penas, A., 2013. Recent mean temperature trends in Pakistan and links with teleconnection patterns. International Journal of Climatology, 33, 277-290

Salma, S., Rehman, S., Shah, M.A., 2012. Rainfall trends in different climate zones of Pakistan. Pakistan Journal of Meteorology, 9.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63, 1379-1389.

Sonali, P., Kumar, N, D., 2013. Review of trend detection methods and their application to detect temperature changes in India. Journal of Hydrology, 476, 212-227.

Theil, H., 1950. A rank invariant method of linear and polynomial regression analysis, Part 3. Netherlands Akademie van Wettenschappen, Proceedings, 53, 1397-1412.

Thelma, A. C., Rusalina, G., Flaviana, D., Hilario., David, M., Wilson., 2014. Long-term trends and extremes in observed daily precipitation and near air surface temperature in the Philippines for the period 1951-2010. Atmospheric Research, 145-146, 12-26.

Yaseen, M., Tom, R., Ghulam, N., Rehman, H., Latif, M., 2014. Assessment of recent temperature trends in Mangla watershed. Journal of Himalayan Earth Sciences, 47, 1, 2014, 107-121.

Yue, S., Pilon, P.J., Phinney, B., Cavadias, G., 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrological Processes, 16 (9), 1807-1829.