

## Analysis of Temperature and Precipitation Trends Observed at Some Selected Districts of Punjab, Pakistan

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**Abstract:** Present study examines the trends of extreme daily temperature and rainfall indices in some selected meteorological stations/districts of the Punjab. Due to paucity of data only six weather stations were selected from the whole Punjab, having data of 33 years for temperature and precipitation on daily basis. A set of 14 indices (recommended by climate ET) were used to calculate the trends over a period of 32 years (1985–2017) by using RClimDex (1.0) software package. These results showed that the number of tropical nights (TR20) and warm nights (TN90p) has been increasing in selected weather stations/districts and number for cool nights (TN10p) has been falling. Other temperature related indices trends such as, summer days, warm days, warm spell duration indicator (WSDI) and cool spell duration (CSDI) shows a mix pattern. The precipitation indices like SDII, RX1day, R10mm and PRCPTOT showed an increasing trend in some selected stations. Most of the trends were not significant at level of 0.05 % while maximum day temperature increase has been observed at five out of six selected stations. Similarly, an average increase in precipitation in the vicinity of 3 mm per decade has been noted. The annual total rainfall and number of heavy rainfall days has also increased by 18 mm and 8.4 mm respectively during each decade. The analysis identified and highlighted a slight change which was not temporally and spatially rational. However, there is need to more and adequate yearly data of different weather stations across the Punjab to identify the ongoing apparent and impeccable changes in climate of the Punjab province.

**Keywords:** RClimDex, climate change, climate indices, climate trends, Punjab.

### Introduction

At present, climate change is one of the major problems threatening mankind. Climate changes can be well defined as negative change occurring on earth surface. These changes may be due to the natural processes of earth or anthropogenic activities. The existing and continuous climate change cannot be considered as a normal change (Nicholls, 1996; Maida, 2011). The second report of Intergovernmental Panel on Climate Change (IPCC, 2013) revealed that the climate change as a key problem i.e. the less information of daily climate extremes, variability and climate trends (IPCC, 2012; Nicholls, 1996). Folland *et al.*, (2001) indicated that higher amount of precipitation and temperature has shown the significant change in the mean values of some regions (Moberg and Jones, 2005; Rio, 2013). Many climate events have become more common and intense in recent years, leading to a rise in heat wave, heavy rainfall and scarcity of vegetation cover. Similarly heat wave is a long term and warmer phenomenon while a maximum probable precipitation and consequent flooding are getting more common in the world. Developing countries are much vulnerable to extreme weather and climatic variability episodes which lead to extensive economic loss (IPCC, 2001 and 2008, 2012). Nevertheless, such types of extreme weather conditions have adverse impact on ecosystem and hamper the efficiency of the natural resources (Jones,

2003). At macro scale, studies showed that climate is turning more humid as a consequence of annual increase in amount of precipitation (Hartmann, 2013; Donat, 2013; IPCC, 2014).

Folland (2001) stated that the global average surface temperature has increased since long (Khattak, 2011 and 2015). The unavailability of daily database for temperature and rainfall and further absence of homogeneity in periods for analyses made it more challenging and complex to compare and comprehend the outcomes of extensive studies from many areas of the world (Donat, 2013; Akhtar, 2008). The Punjab-Pakistan lies in that region along with other countries facing the harsh climate change impact due to their diverse geographical location and climatic features (Folwer, 2006). The aim of this study is to investigate the frequencies, causes and possible consequences of climate variability and to evaluate risk assessment of extreme weather events in Punjab-Pakistan. Both on micro and macro scale, the land surface temperature can alter or modify the weather and seasonal patterns of rainfall and temperature distribution over the plains of the Punjab (Chaudhary, 2009). The global temperature has risen up to 0.89 °C during 1901-2012 (IPCC, 2013). Such high scale warming affects the wind and sea water circulation patterns which directly or indirectly have an effect on local climatic conditions and consequently changing the pattern and characteristics of precipitation and temperature.

Present study shows the new statistics and data of climate change trends that were calculated by using the different indices and daily based data of precipitation and temperature of six selected stations of the Punjab. This analysis is imperative for Punjab province as any variation in climate can affect the environment as well as daily life of the population.

**Materials and Methods**

In this study, due to non-availability of 30 years daily base data of temperature and precipitation of all meteorological stations of Punjab, only six stations located in various districts have been selected with such data available for 32 years (Fig.1). The latitudes, longitudes and elevations of these stations are given (Table 1). A set of 15 climate indices were selected that are recommended by the Expert Team for Climate Change Detection Monitoring and Indices (Table 2).

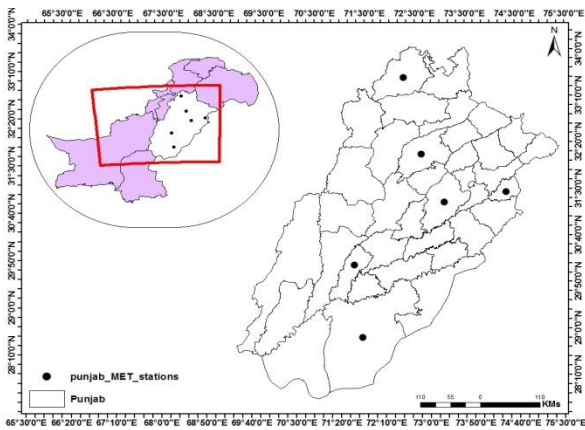


Fig. 1 Locations of meteorological stations in selected districts of Punjab

Table 1. Characteristics of selected stations/districts of Punjab.

Station/districts	Latitude	Longitude	Elevation (m.s.l)
Sargodha	32° 3′	72° 40′	187
Sialkot	32° 31′	74° 32′	255.1
Faisalabad	31° 26′	73° 8′	185.6
Lahore	31° 33′	74° 20′	214
Multan	30° 12′	71° 26′	122
Bahawalpur	29° 20′	71° 47′	110

Source: Pakistan Meteorological Department

RClmDex (1.0) software was used which have been developed by the Canadian Meteorological Service Employees (Zhang and Yang, 2004) to calculate these extreme indices for the period from 1985 to 2017 for six selected districts of the Punjab. Data Quality Control (QC) is a precondition for measuring the climatic indices. The Quality Control (QC) of RClmDex software executes the following result process:

1) It changes all missing values to -99.9

2) Changes all irrational values to NA (not available). For example, if daily maximum temperature is less than daily minimum temperature.

Moreover, Quality Control (QC) also detects outliers in daily minimum and maximum temperature (Zhang and Yang, 2005). After entering the station data, Quality Control (QC) in RClmDex indicated that no extreme deviation was found in diurnal temperature and rainfall data of the selected weather observations. The annual trends of selected measures were calculated in RClmDex through locally weighted linear regression (dashed line) and linear least square method. Further, Kendall’s tau slope estimator values were used in GIS 10.5 to show the trends, which shall be significant if p value is less than 0.05 at the level of 95% confidence. While 90 % level of confidence if  $0.05 < p \text{ value} \leq 0.10$ , 75 % level of confidence if  $0.10$  is less then p value and p value is less than or equal to 0.25 and If p value is zero. It showed a failure to reject the null hypothesis at 95% level of confidence. The trends of DTR of selected districts have been given in Figure 2.

Table 2. List of the selected climate indices for temperature and precipitation.

ID	Indicator Name	Definitions	Units
TR20	Tropical nights	Annual count when TN(daily minimum) $>20^{\circ}\text{C}$	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	$^{\circ}\text{C}$
TNx	Max Tmin	Monthly maximum value of daily minimum temp	$^{\circ}\text{C}$
TN10p	Cool nights	Percentage of days when $\text{TN} < 10\text{th percentile}$	Days
TX10p	Cool days	Percentage of days when $\text{TX} < 10\text{th percentile}$	Days
TN90p	Warm nights	Percentage of days when $\text{TN} > 90\text{th percentile}$	Days
TX90p	Warm days	Percentage of days when $\text{TX} > 90\text{th percentile}$	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when $\text{TX} > 90\text{th percentile}$	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when $\text{TN} < 10\text{th percentile}$	Days
R10	Number of heavy precipitation days	Annual count of days when $\text{PRCP} \geq 10\text{mm}$	Days
SU25	Summer days	Annual count when $\text{TX}(\text{daily maximum}) > 25^{\circ}\text{C}$	Days
PRCP TOT	Annual total wet-day precipitation	Annual total PRCP in wet days ( $\text{RR} \geq 1\text{mm}$ )	Mm
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as $\text{PRCP} \geq 1.0\text{mm}$ ) in the year	mm/day
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	$^{\circ}\text{C}$

Source: Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI)

These plotted trends show that diurnal temperature range (DTR) have been decreased from 3.4 to 7.5°C in 33 years. Two trends are statistically significant at 5 % level.

slope estimated trend shows the average increase of 2 to 3 (0.221 % days) per decade.

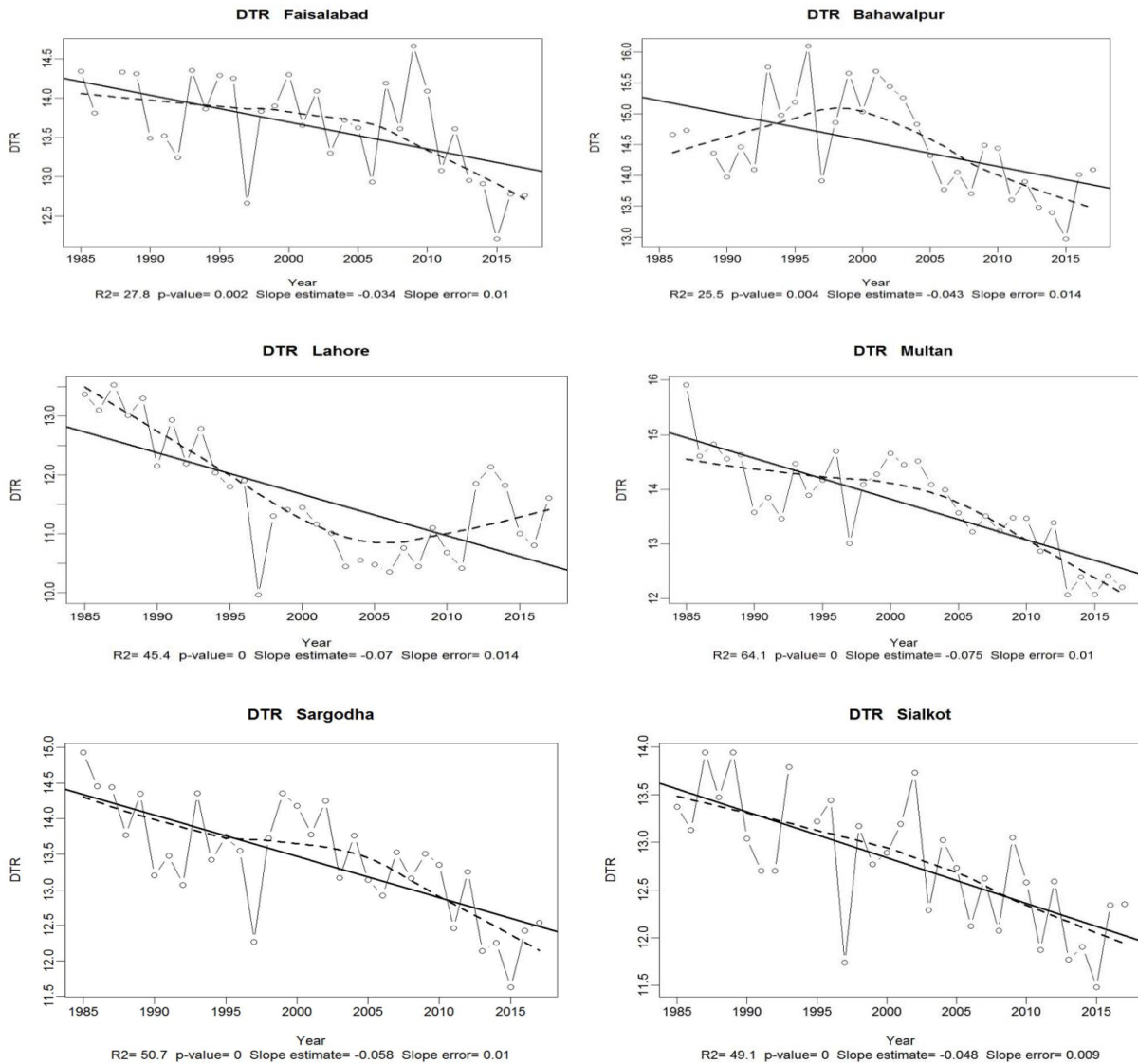


Fig. 2. Trends of DTR in selected stations from 1985 to 2017.

### Results and Discussion

Red sign shows decreasing trend of extreme climate indices and blue sign in the maps reveals an increasing trend of selected indices. Figure 3 shows the trend of summer days in selected stations of the Punjab. Three stations show a rising trend in summer days. Sialkot, Faisalabad and Sargodha show a positive trend with 0.273, 0.228 and 0.162 % days over every year when the maximum temperature was higher than 25°C and other three stations portray a negative trend. There is a decreasing trend in summer days for Lahore, Multan and Bahawalpur with -0.268, -0.204 and -0.054 % days over a year. Five out of six station's trends between 0.05 to 0.1 % are statistically significant. Kendall's tau

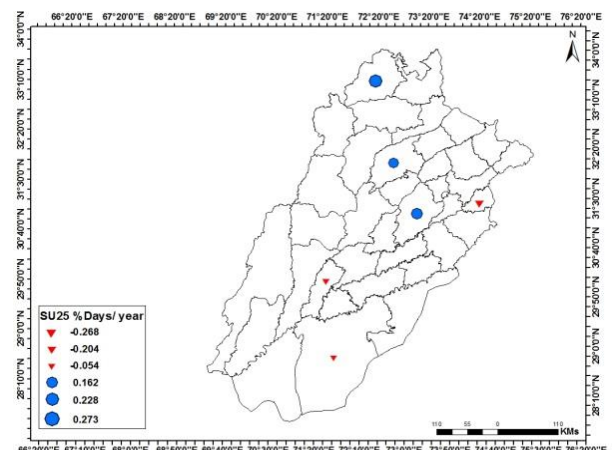


Fig. 3 Trends of summer days in selected stations.



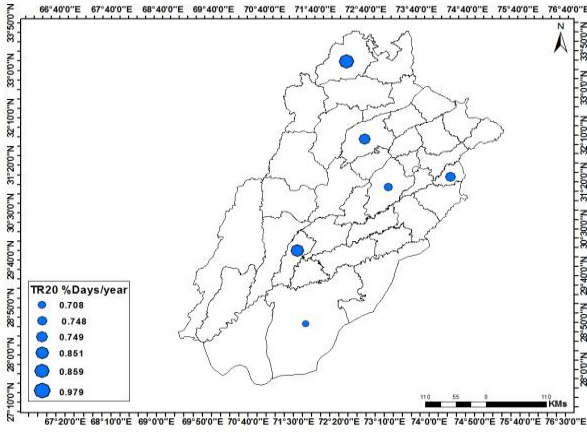


Fig. 4 Trends of tropical nights in selected stations

Figure 4 shows the trend of tropical nights in stations of interest. All stations show the positive trend. Tropical nights have been increasing in almost whole Punjab. Sialkot shows higher positive trend of about 0.979 % days per year and Bahawalpur shows the lower increasing trend i.e., about 0.708 % days per year. Trends of all stations are 0.05 % significant. These outcomes indicate that the annual number of days are increasing when the minimum air temperature was higher than 20°C. Slope estimated trend shows an average increase of 7 to 9 days per decade.

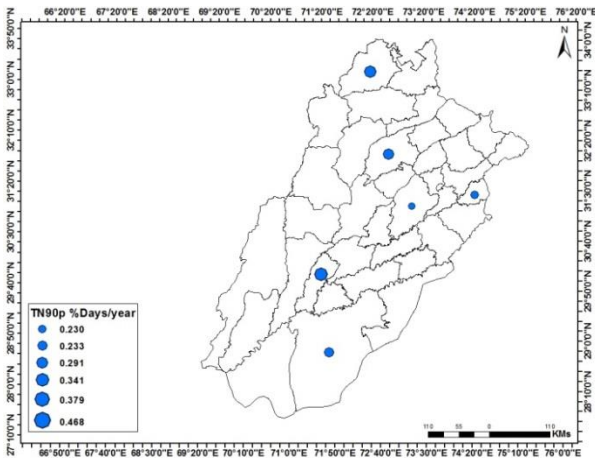


Fig. 5 Trends of warm nights.

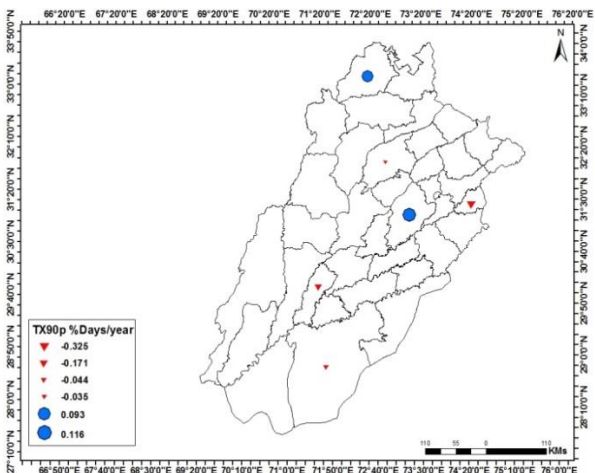


Fig. 6 Trends of warm days.

Trends of all stations are positive and statistically significant at 5% to 10%. Warm nights has been increasing in all stations of Punjab (Fig. 5). The range of rise is between 0.230 to 0.468 days per year. Multan shows the higher increasing trend of about 4.6 days per decade and Faisalabad with a less rising trend of 2.3 days over a decade.

Trends for warm days have been decreasing in four out of six stations of Punjab (Fig.6). Maximum decrease is observed in Lahore with -0.326 % days per year. Only two stations of Sialkot and Faisalabad showed a rising trend with 0.093 and 0.116 % days per year. Tau's slope estimated value show a decrease of 1 to 3 days in Lahore, Sargodha, Multan and Bahawalpur per decade and 1 to 2 day increase in remaining two stations. Only one station (Faisalabad) has shown a positive trend of 0.05 % (statistically significant). While three stations (Lahore, Multan and Bahawalpur) show a 0.05 % significance with negative trend.

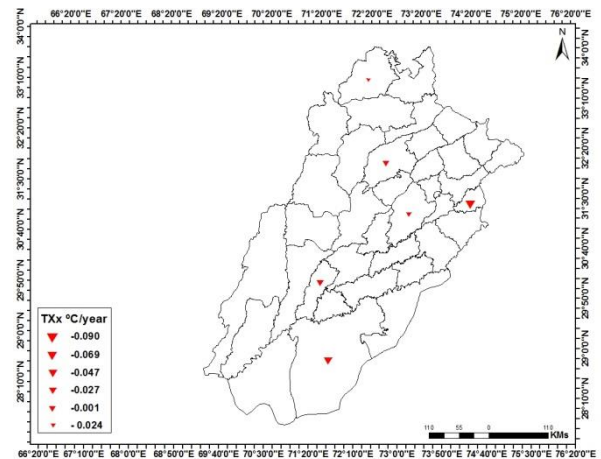


Fig. 7 Trend of maximum of maximum temperature.

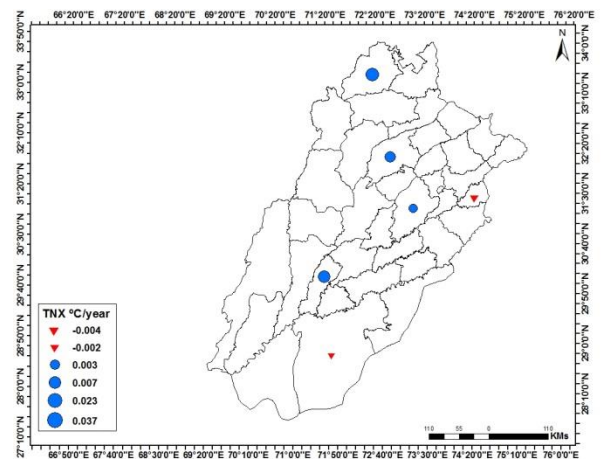


Fig. 8 Trend of maximum of minimum temperature.

Kendall Tau's slope estimated value shows the falling trend in all selected stations of Punjab (Fig.7). Monthly maximum value of daily maximum temperature has been decreasing. A higher decreasing trend is shown in Lahore with -0.090 % °C per year and a lower negative trend is shown in Faisalabad with -0.024 % °C per year. Three stations (Lahore, Bahawalpur and Multan)

are statistically significant at 0.05 % or 5% and other three (Sialkot, Sargodha and Faisalabad) are statistically significant at 10 % or 0.1 %.

Monthly maxima of minimum temperature have been increasing in four out of six stations of Punjab (Fig. 8). Sialkot shows a higher increasing trend with 0.037 % °C per year. Lahore and Bahawalpur have shown a negative trend with -0.004 to -0.002 % °C per year. Tau's slope estimated value show a 0.03 to 0.3 °C increase per decade in four stations and -0.04 to -0.02 °C decrease per decade.

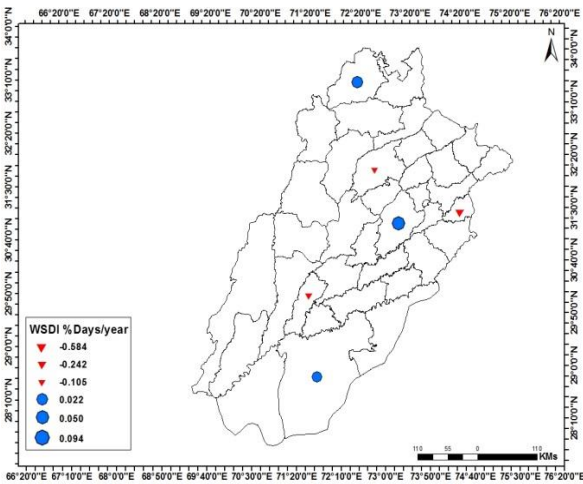


Fig. 9 Trend of warm spell duration indicator.

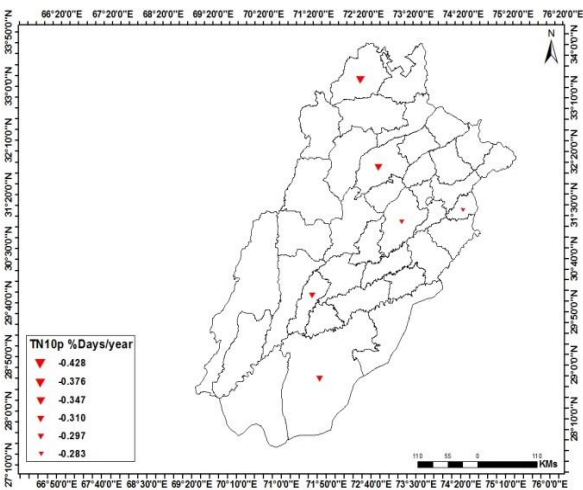


Fig. 10 Trend of cool nights in selected stations.

Warm spell duration index (Fig.9) indicates the number of annual days with a minimum of 6 sequential days on which maximum temperature is higher than the 90th percentile. Three stations of Lahore, Multan and Sargodha have shown negative trend with -0.584, -0.242 and -0.106 % days per year. Tau's slope estimated value show an average fall of 3.2 days per decade. Other three stations of Faisalabad, Sialkot and Bahawalpur have shown a rising trend with the range of 0.022 to 0.094 % days each year, and the average increasing value of slope estimate is 1 day per decade. All stations are significant at 0.05 to 0.1 % level.

Cool nights have been decreasing at all selected stations (Fig.10). The higher decreasing value is found for Sialkot with -0.428 % days per year and lower decreasing value is found for Lahore with -0.283 % days per year. Tau's slope estimated decreasing value for Sialkot is four days per decade and three days per decade for Sargodha, Multan, Bahawalpur and two days per decade for Faisalabad and Lahore respectively. All trends are statistically significant at 0.05 to 0.1 %.

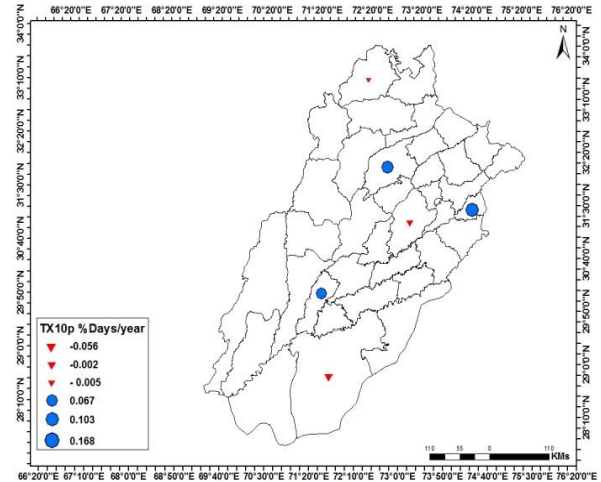


Fig. 11 Trend cool days in selected stations.

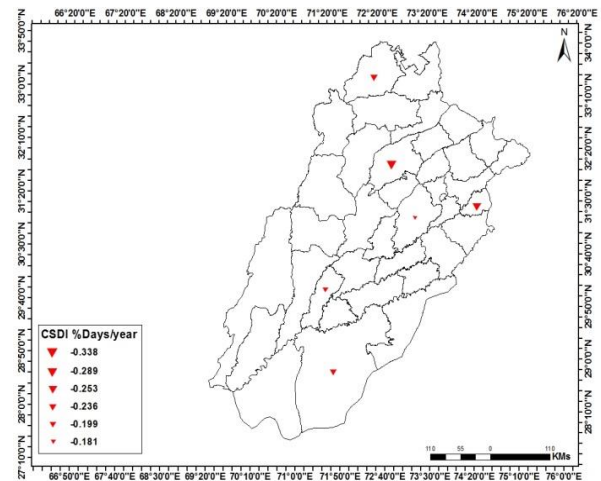


Fig. 12 Trend of cold spell duration index.

Trend for cool days have been increasing in three cities of Punjab (Fig. 11). Lahore has shown a higher increasing trend with 0.168 % days per year while Sargodha and Multan have shown a rising trend with 0.103 and 0.067 % days per year. Estimated increase in value is 2 days per decade. While other three stations of Bahawalpur, Faisalabad and Sialkot have shown a decreasing trend with -0.056, -0.002 and -0.005 % days per year. Only two stations of Lahore and Sargodha have statistically significant positive values at 0.05% and Multan is significant at 0.1 %. Bahawalpur, Faisalabad and Sialkot are negatively significant at 0.05 to 0.01 % level.

The trend of cold spell duration index (CSDI) has been decreasing in all selected stations (Fig.12). All stations have shown a negative trend, meaning the number of days with a minimum 6 sequential days annually, when minimum temperature is lower than the 10th percentile. The higher decreasing value is found at Sargodha with  $-0.338\%$  days per year and lower decreasing value is found at Faisalabad with  $-0.181\%$  days per year. The slope estimated values show a decreasing trend for Sargodha, Lahore, Sialkot, Bahawalpur, Multan and Faisalabad as four days, three days, three days, two days, two days and one day respectively. All trends are statistical significant at 0.05 to 0.1 %.

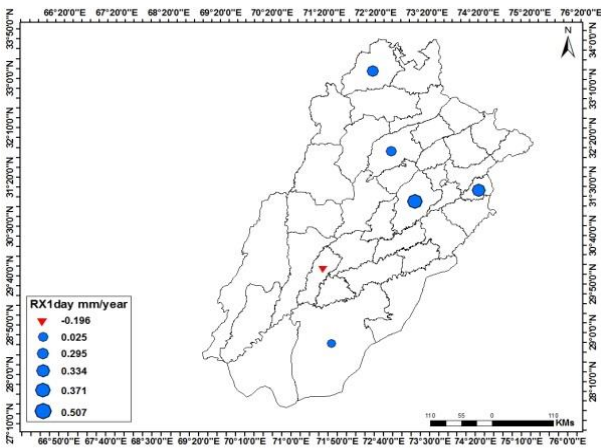


Fig. 13 Trend of maximum 1-day precipitation.

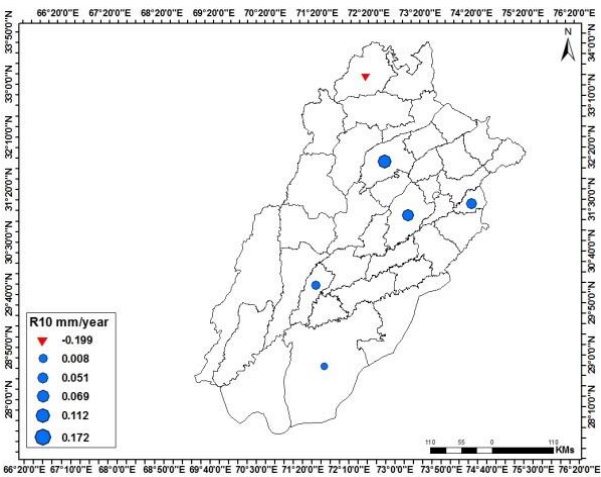


Fig. 14 Trend of heavy precipitation days.

Maximum 1-day precipitation is shown in Figure 13. All stations have positive trend except one station. RX1day has been increasing in five out of six stations. Higher value is found for Faisalabad with  $0.507\%$  mm per year, Lahore with  $0.371\%$  mm per year, Sialkot with  $0.334\%$  mm per year, Sargodha with  $0.295\%$  mm per year and  $0.025\%$  mm per year but negative value is found for Multan with  $-0.196\%$  mm per year. Tau's slope estimates a rising value of 5 mm in Faisalabad, 3 mm in Lahore, 3 mm in Sialkot, 2 mm in Sargodha per decade and slope estimates a decreasing value for

Multan i.e 1 mm for every decade. Two trends are statistically significant at level of 5 to 10 %.

Figure 14 shows a heavy precipitation day index that has been increasing in five stations except one station. Higher value is found at Sargodha with  $0.172\%$  mm per year, Faisalabad  $0.112\%$  mm, Lahore  $0.069\%$  mm, Multan  $0.051\%$  mm respectively. While a lower value is found in Bahawalpur with  $0.008\%$  mm per decade. Slope estimates have shown the average increasing value of 2 mm per decade in Sargodha, 1.1 mm in Faisalabad and 0.6 mm and 0.5 mm per decade in Lahore and Multan respectively. Sialkot shows a negative trend, R10 has been decreasing with a value of 1.9 mm per decade. Five stations are statistically significant at 5 to 10 % level.

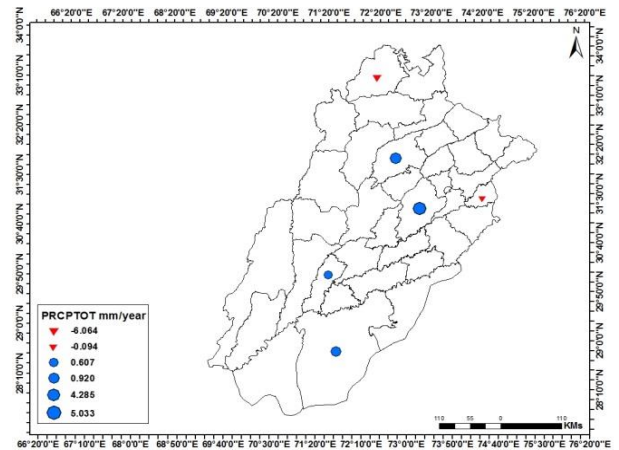


Fig. 15 Trend of annual total precipitation amount.

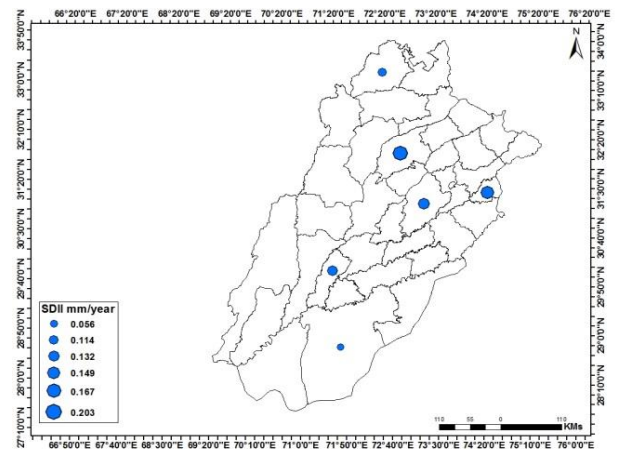


Fig. 16 Simple daily intensity index.

The average increasing amount is about 50.3 mm per decade in Faisalabad, 42.8 mm in Sargodha, 9.2 mm in Bahawalpur and 6.0 mm in Multan per decade (Fig. 15). Lahore and Sialkot have decreasing value of PRCPTOT that are about 0.09 mm and 6.0 mm per year respectively. The trend of three stations is significant at 0.05 to 0.1 % level.

The value of simple daily intensity (SDII) has been increasing trend in all stations. The value increased in the range of 0.2 mm to 0.05 mm per year (Fig.16). The



higher value is found at Sargodha (2 mm) per decade. SDII of Lahore, Faisalabad, and Multan are increased by 1.6 mm, 1.4 mm, 1.3 mm and for Sialkot, Bahawalpur increased by 1.1 mm and 0.5 mm per decade respectively. All trends are statistically significant at 0.05 to 0.1 % level.

## Conclusion

The results show that number of tropical nights have a rising trend in all stations, increased about 7 to 9 days per decade. Summer spell has increased in three station with 2 to 3 days per decade. Warm days are increasing and cool nights are decreasing in all selected stations of Punjab. Average increase is about 3.2 days per decade and average fall is about 3.4 days per decade respectively. It shows the symmetry but warm days and cool days show mixed pattern, as two stations are showing increasing trend and average rise in value is 2 days. Only three stations show a falling trend and average decrease of about 1 day per decade. That's why warm spell indicator index also shows a mixed trend pattern but cool spell indicator index has shown falling trend in all stations.

There is a maximum one-day increase in temperature at five out of six selected stations, while an average increase in precipitation is about 3 mm per decade. The annual total rainfall and number of heavy rainfall days has also increased with 18 mm and 8.4 mm respectively for each decade. The trend of SDII shows that simple daily intensity is increasing in most of selected districts/stations. Most of the trends are 10% statistically significant and these analyses confirmed a mixed pattern of climate change in Punjab during the last few decades.

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