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Assessing Temperature Variations in Punjab, Pakistan Using Mann Kendall Trend Analysis and Inverse Distance Weighting (IDW) for Spatial Interpolation

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Abstract

This study is an effort to identify the temperature inconsistency in Punjab, Pakistan, by using advanced statistical techniques on temperature records of last 20 years, from 1998 to 2017. In this research temporal and spatial temperature record of mean monthly extreme and least surface air temperature records of 14 meteorological stations in the Punjab Pakistan were inspected for progressive trends and spatial variation distributions. Linear trends are calculated with Sen's slope approximation procedure and Mann Kendall test, while the spatial distributions and regional variations across the Punjab were envisioned using spatial tendency maps and interpolation with Inverse Distance Weighting (IDW). Annual temperature rise was found to be most noticeable in the southern and south eastern parts of the Punjab.

Keywords: Temperature fluctuation. Spatial distribution, Inverse Distance Weighting (IDW)

Introduction

Temperature rise is a global issue now, although the distribution pattern has not been same across the globe. The present study is conducted in Punjab, Pakistan. Punjab is the 2nd largest province of Pakistan by area and it is situated between 31.1704° N, 72.7097° E latitude. There are 36 districts in Punjab. It is the most populous province having 110,012,442 people with the annual growth rate of 2.13% according to census of Pakistan, 2017. Lahore is the provincial capital of Punjab. Temporal analysis of temperature often shows a statistically significant successive connection. This connection is an indication to a glowing scene that the Mann–Kendall test can detect a trend even when it does not occur (Chen et al., 2013). Temperature is the main variable in climate studies due to which drives all the climatic processes. Change in temperature can change all the climatic processes. Fluctuations in temperature can be seen from year to year with changing pattern of season e.g. hot/dry season, hot/humid season etc. which affect the society (Francesco Viola et al, 2013). The study was carried out to observe geographical and temporal variations in the temperature. Changing temperature of Punjab is playing a great role in warming of the province, evaporating more water, disturbing the cultivation, promoting infections and diseases, melting more glaciers, altering the climate etc. While maximum temperature is decreasing this means the less warming (Kabo-Bah et al., 2016).

Materials and methods

This study is conducted by both statistical and spatial analysis that's why both statistical and spatial data is used (Eischeid et al., 1995). Average temperature data is collected from time period of 1998 – 2017. For this purpose 14 meteorological stations were selected. As shown in table 1. This research is about spatial & temporal statistical investigation of temperature tendency using Mann–Kendall Trend Model (MKTM), and Sen's slope estimator (SSE) in Punjab Pakistan.

Table 1. Location of 14 selected synoptic meteorological stations in Punjab

Station Name	Latitude	Longitude	Elevation (meters)
Bahawal Nagar	29˚ 20’	73˚ 51’	163
Bahawalpur	29˚ 20’	71˚ 47’	214
Bhakkar	31˚ 37’	73˚ 08’	159
Faisalabad	31˚ 26’	73˚ 078’	186
Jhelum	32˚ 56’	73˚ 44’	287
Khanpur	28˚ 39’	70˚ 41’	83
Lahore	31˚ 35’	74˚ 24’	214
Multan	30˚ 12’	71˚ 26’	122
Sialkot	32˚ 31’	74˚ 32’	255
Sargodha	32 03’	72 40’	187
D.G.Khan	30 03’	70 38’	129
Mangla	33 04’	73 38’	377
Mianwali	32˚ 55’	71˚ 55’	171
Islamabad	33˚ 68’	73˚ 04’	487

Mann-Kendall Test

Mann–Kendall nonparametric assessment was used for the temporal temperature trend analysis. The magnitude of the major trend has been estimated in view of the Calculation. Trend analysis of temperature of the selected 14 synoptic places was executed by means of the Mann Kendall (MK) test to monitor inference of the perceived trends. Mann-Kendall trend analysis test is commonly used for the study of different types of time series trends in climatology. One of the main benefits of the test is that, statistics need not to adapt certain dissemination pattern. Other benefit of this test is its minute compassion to rapid disruptions because of non-equal interval series (Gocic et al., 2013)

Sen’s Slope

Theil-Sen’s slope evaluates from all probable groupings of facts joins within the full data set (Ahmad et al., 2015) A progressive rate specifies an “ascending trend” while a negative rate specifies a “descending trend”. Existence of a linear trend in a time series depicts the true.

Spatial pattern of tendencies

To visualize the spatial pattern of distributions of trends, their extents were incorporated by the inverse distance weighted (IDW) method (Abolverdi et al., 2014) Assurance points of the temporal trend analysis and slopes of the trend have been spatially interpolated by using inverse distance weighted (IDW) interpolation technique that results in a raster surface. Mann Kendal trend analysis has validated investigation of the general trends that disturb the climate of the Punjab, to detect likely spatial outlines. Spatial analysis methods are used in order to validate the existence of a spatial array in temperature tendencies (Ren-Ping et al., 2016). Spatial zoning of the region was done using inverse distance weight (IDW) interpolation method by ArcGIS software.

Results and Discussion

According to the historic temperature record from (1960-2014) of 24 districts of Punjab by Pakistan Meteorological Department (PMD), the regular extreme and least temperature rise 0.960C and 0.930C correspondingly. The positive τ value indicate increasing trend while negative trend indicates decreasing trend (Irannezhad, 2015). The results obtained from Mann-Kendall test shows negative (decreasing) trend for mean maximum temperature data for some stations and show posi-

tive (increasing) trend for mean minimum temperature data for few stations (Soltani et al., 2015). Rest of stations shows no trend. Following is the detail of results obtained from the trend analysis for each meteorological station which is selected for this study.

Average Monthly Minimum Temperature (Tmin) trend

In Bahawal Nagar, Mann-Kendall trend analysis shows positive increasing trend for average minimum in December. Magnitude is calculated with Sen's slope is 0.558˚C per year. In Bahawalpur there is positive significant trend for the month of November for minimum temperature. The tau value is 0.406 and the magnitude of trend is 0.06˚C/ year. also point out increasing trend in Bahawal Nagar.

Trend analysis shows no trend observed month wise in Bhakkar, Islamabad and Dera Ghazi Khan Stations. According to Mann Kendal trend analysis for Faisalabad station, there is negative trend in the month of April. The magnitude of trend is -0.118˚C per year. There is decreasing trend for Jhelum in month of April, May and July with the magnitude of -0.071˚C, -0.113 ˚C and 0.056 ˚C per year in average minimum temperature. In Khanpur station, the analysis show increasing trend for March and October. For Lahore, the analysis shows negative decreasing trend for the month of April, August and November.

The magnitude of Mann Kendal analysis trend is -0.107, -0.1 and -0.097 respectively. In Mangla station, for average minimum temperature, there is also negative trend in April, August and November and the magnitude of trend is -0.107, -0.1 and -0.097 respectively. In Multan there is positive trend for March, September and November for average minimum temperature. November and December has negative trend in Mianwali station with the magnitude of -0.093 and -0.098 respectively. Results of the analysis show negative decreasing trend for the month of March and April in Sargodha station. The magnitude of analysis is -0.532 and -0.422 per year respectively. For average minimum temperature monthly trends in Sialkot station July and September shows positive increasing trends. This means that average minimum temperature is increasing making these months warmer. The magnitudes of increase in these months are 0.026 ˚C and 0.075˚C per year. The result reveals that there is significant positive trend in March for Khanpur and Multan stations (Boi P., Fiori M., Canu S., 2011).

Multan and Khanpur are present in the southern part of Punjab and are considered as warmest cities of Punjab. Jhelum is the only city which shows negative decreasing trend for average minimum temperature. The magnitude of decreasing trend is -0.045 per year. This may be due to its location on the northern part of Punjab and because of elevation. Jhelum station shows negative trend which shows that there is decreasing trend in minimum temperature. Result shows other station indicates no trend in many stations especially Sialkot and Bahawalpur.

Spatial Distribution of Monthly Mean minimum Temperature (Tmin):

Figure 1 shows monthly mean minimum temperature for each month of past 20 years. In January, mean monthly minimum temperature is about 3.1 to 6˚C in whole Punjab except for Islamabad, Lahore and Bahawal Nagar. Islamabad station has less than 3 ˚C monthly mean minimum temperatures while Lahore and Bahawal Nagar has 6.1 to 9 ˚C. In February, the three stations on eastern side (Lahore, Bahawal Nagar and Bahawalpur) and one in the center of Punjab (Sargodha) have 9. ˚C to 12 ˚C monthly mean minimum temperature. Islamabad station has least consistent mean lowest temperature which ranges from 3.1 ˚C to 6 ˚C. Rest of Punjab has 6.1 ˚C to 9 ˚C minimum temperature.

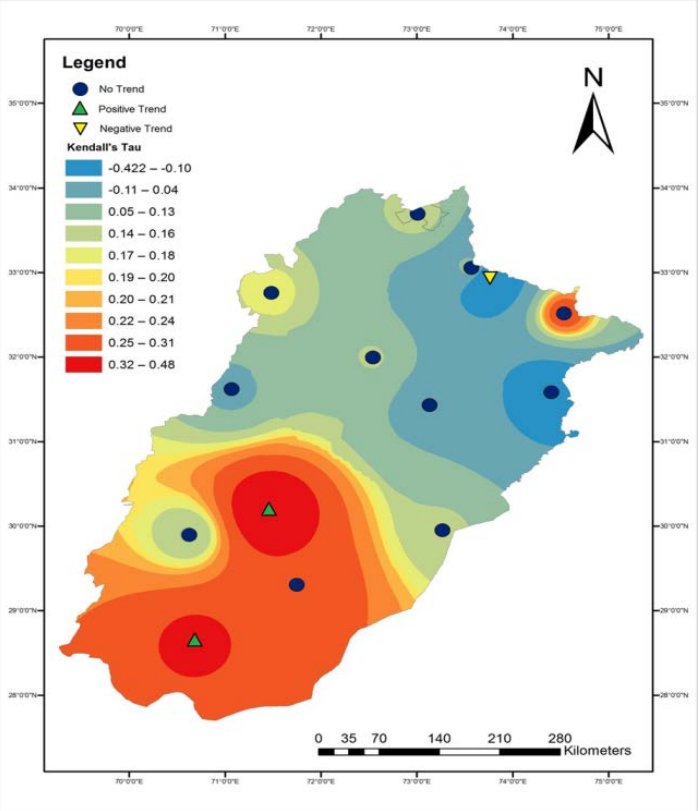

Figure 1. Spatial pattern of Kendall's tau and Mann-Kendall trend analysis for average minimum temperature in Punjab

Spatial Distribution of Monthly Mean minimum Temperature (Tmin):

Figure 2 shows monthly mean minimum temperature for each month of past 20 years. In January, the monthly mean minimum temperature is about 3.1 to 6˚C in whole Punjab except for Islamabad, Lahore and Bahawal Nagar. Islamabad station has less than 3 ˚C monthly mean minimum temperatures while Lahore and Bahawal Nagar has 6.1 to 9 ˚C. In February, the three stations on eastern side (Lahore, Bahawal Nagar and Bahawalpur) and one in the centre of Punjab (Sargodha) have 9.1 ˚C to 12 ˚C monthly mean minimum temperature. Islamabad station has least monthly mean minimum temperature which ranges from 3.1 ˚C to 6 ˚C. Rest of Punjab has 6.1 ˚C to 9 ˚C minimum temperature. The minimum temperature increases in March and the average lowest recorded temperature is 12.1 ˚C to 15 ˚C except for Islamabad, Lahore and Bahawalpur. Lahore has highest mean minimum temperature in March while in Islamabad station has 9.1 to 12 ˚C and Bahawalpur stations has 6.1 to 9 ˚C a nd its surrounding area contain 9.1 to 12 ˚C mean minimum temperature. Highest minimum temperature in April is in Lahore station with 21.1 ˚C to 24 ˚C. Whereas the lowest average lowest temperature is recorded in Bahawalpur station with 6.1 to 9 ˚C and increases outwards the station. Islamabad main station area has 12.1 to 15 ˚C minimum temperature but increases to 15.1 to 18 ˚C including Mangla station. Rest of stations has 18.1 to 21 ˚C mean minimum temperature.

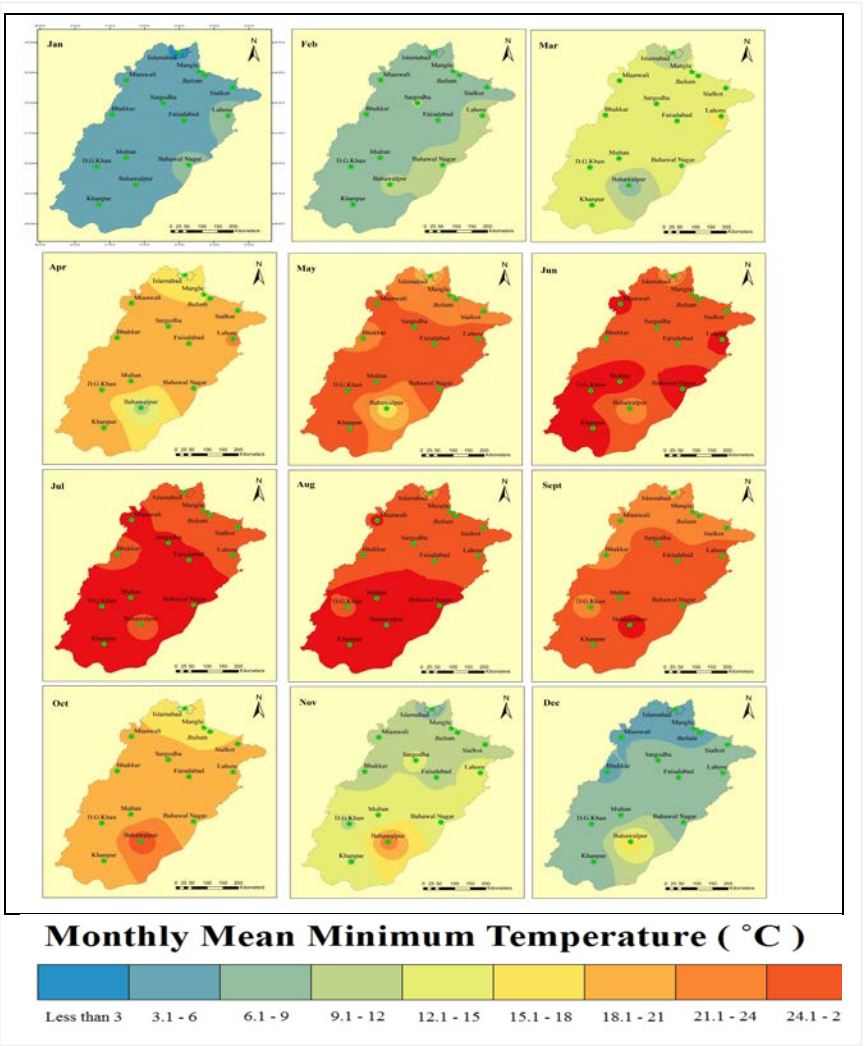

Figure 2. Spatial distribution of Monthly Mean Minimum Temperature (˚C)

Figure 3 Spatial distribution of Monthly Mean Minimum Temperature (˚C) Summer season starts with the increase in mean lowest temperature in the whole Punjab. Figure no. 3 shows that the most of the part has 21.1 to 27 ˚C mean minimum temperature. Lahore, Mianwali, Multan, D.G.khan, Bahawal Nagar and Khanpur are recorded with maximum minimum temperature of 27.1 to 30 ˚C. While Bahawalpur and Islamabad has lowest mean minimum temperature (21.1 ˚C to 24 ˚C) recorded in June. Rest of stations has 24.1 to 27 ˚C mean minimum temperature. According to the map, the northern part of Punjab and Bhakkar and Bahwalpur stations shows 24.1 ˚C to 27 ˚C mean minimum temperature while rest of stations shows 27.1 to 30 ˚C mean minimum temperature.

In August, half of Punjab (northern side & including D.G.Khan station) shows 24.1 ˚C to 27 ˚C mean minimum temperature while half of Punjab (southern side & including Mianwali) shows 27.1 to 30 ˚C mean minimum temperature. Bahawalpur station has lowest mean minimum temperature of 15.1 to 18 ˚C and increases in September, the temperature begins to decrease and the minimum temperature also decreases. North and north western stations and one station from south west have 21.1 ˚C to 24 ˚C average lowest temperature. Remaining area of Punjab has 24.1 ˚C to 27 ˚C average minimum temperature in September except for Bahawalpur which has highest mean mini-

mum temperature and decreases outwards while Islamabad has 12.1 ˚C to 15 ˚C minimum temperature (lowest in October) and increases outwards to 15.1 ˚C to 17 ˚C including Mangla and Jhelum stations. Remaining stations has 18.1 ˚C to 21 ˚C. In November, there is mixed results. Most of the part in north-west has 9.1 to 12 ˚C mean minimum temperature. While a large part in south-east has 12.1 to 15 ˚C mean minimum temperature. Lowest minimum temperature is recorded in Islamabad station and highest minimum temperature is recorded in Bahawalpur station. Bahawalpur station has 15.1 ˚C to 18 ˚C of minimum temperature and decreases as move away from stations. North-western stations have 3.1 to 6 ˚C mean minimum temperature. Remaining stations have 6.1 to 9 ˚C minimum temperature.

Average Monthly Maximum Temperature (Tmax) trend:

Figure 3 shows mostly decreasing trend in most of months for maximum temperature Tmax. Multan has negative trend in November for average maximum temperature. In Mangla station, there is negative trend for April and December for average maximum temperature. The magnitude of trend is -0.238 and -0.108 respectively. In Khanpur station there is decreasing trend for June and November with the magnitude of -0.085 ˚C and -0.089˚C per year respectively. April is the month which show decreasing trend for average maximum temperature for Jhelum. The analysis has shown in table no. figure 4 shows negative tendency in mean extreme temperature in Islamabad with -0.076˚C each year magnitude as calculated by Sen's slope.

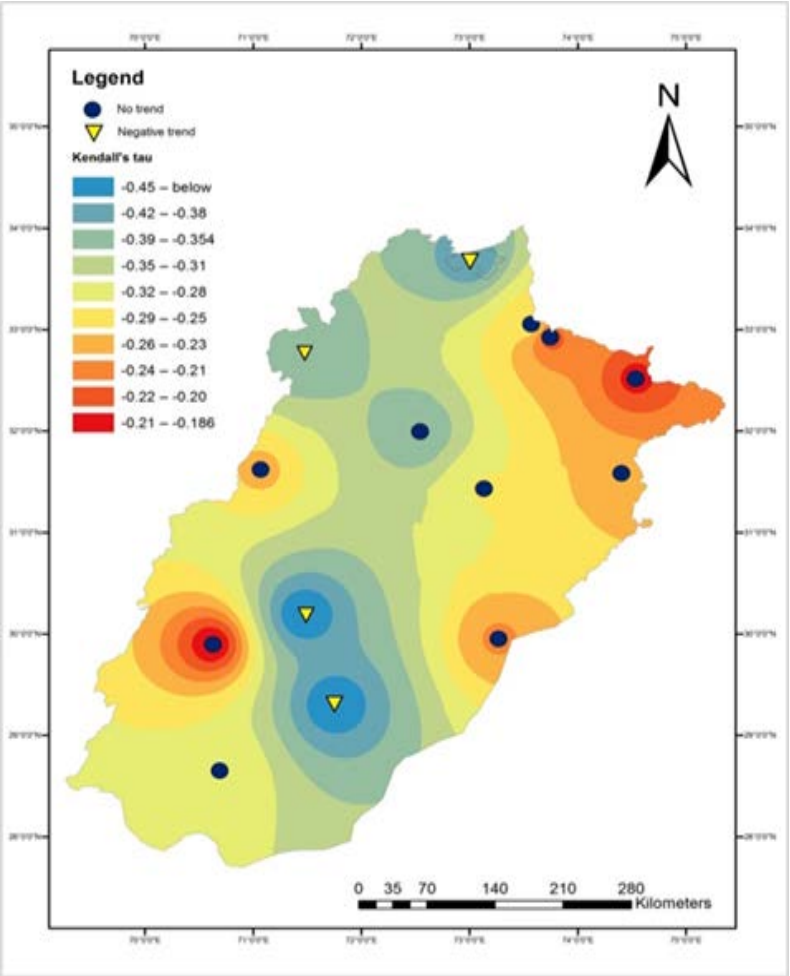

Figure 3. Spatial distribution of Mann-Kendall trend in Punjab for average maximum temperature

In Bhakkar, average maximum monthly temperature shows negative trend in July and November. The tau values are -0.153 and -0.406 respectively with the magnitude of 0.363 and -0.092 per year. Bahawalpur The analysis shows negative trend for maximum temperature with -0.07 magnitude value. June, November and December have negative tau values -0.409, -0.411 and -0.394 respectively. D.G.Khan shows negative trend in November for average maximum temperature. The magnitude of trend is - 0.106 per year.

Average maximum temperature (Tmax) trend for each selected station is used in this study. The regular extreme temperature tendency analysis displays negative decreasing drift for four stations. These four stations are Bahawalpur, Islamabad, Multan and Mianwali. Bahawalpur station is the south-east district and most of the part is covered with Thar Desert. So the overall temperature in this region is high. The magnitude of trend calculated by Sen's slope is -0.07˚C, -0.076˚C, -0.07˚C and -0.061˚C per year respectively. This means that average maximum temperature is decreasing in these areas. The strongest trend is found in Islamabad and Mianwali station. All other stations show no trend for average maximum temperature.

The temperature gets hotter in March. Islamabad and Sialkot stations have less maximum temperature (24.1 to 27.0˚C) in March than rest of Punjab. Rest of Punjab have maximum temperature ranging from 27.1 to 30.0˚C while Khanpur and its surroundings have highest maximum temperature of 30.1 to 33˚C. In April the average maximum temperature rises. Islamabad station has 30.1 to 33.0˚C maximum temperature. The rest of Punjab's temperature splits into two parts. In the northern Punjab the average maximum temperature ranges from 33.1 to 36.0˚C and in southern part the average maximum temperature is 36.1 to 39.0˚C. With the month of May, summer starts and the maximum temperature increases. The average maximum temperature in the northern most part of Punjab which includes Islamabad, Mangla Sialkot stations ranges from 36.1 to 39.0 ˚C except for Jhelum.

The average temperature in rest of Punjab ranges from 39.1 to 42.0 ˚C including Jhelum but excluding Bahawal Nagar and Khanpur stations. Bahawal Nagar and Khanpur experienced extreme maximum temperature in May also.June is the hottest month in Punjab. The average maximum temperature ranges from 42.1 to 45.0 ˚C except for some stations. There is less temperature in Sargodha, Lahore, Sialkot and Islamabad which ranges from 39.1 to 42.0 ˚C. July is considered as the ending month of summer season with dropping of temperature. Islamabad, Sialkot and Lahore stations have minimum average maximum temperature in July and Khanpur, Bahwalpur and Bahawal Nagar have highest average maximum temperature in July, ranges from 33.1 to 36.0 ˚C and 39.1 to 42.0˚C respectively. In rest of the Punjab average maximum temperature ranges from 36.1 to 39.0 ˚.

Autumn season starts with the start of August. Large part of Punjab's average maximum temperature ranges 36.1 to 39.0 ˚C while upper part of Punjab which includes Lahore, Sargodha, Sialkot, Jhelum and Islamabad has less temperature ranges from 33.1 to 36.0 ˚C. During the month of September, the half of Punjab's average maximum temperature ranges from 33.1 to 36.0 ˚C and half ranges from 36.1 to 39.0 ˚C. The temperature drops in month of October. Northern parts of Punjab and Bhakkar station have average maximum temperature of 30.1 to 33.0 ˚C while rest have high temperature ranges from 33.1 to 36.0

Winter starts in November so the temperature drops to 30 ˚C and less. The average maximum temperature in Islamabad, Sargodha and Sialkot ranges from 24.1 to 27.0 ˚C while the whole Punjab have 27.1 to 30.0 ˚C average maximum temperature in the month of November. In December, the whole Punjab's average maximum temperature ranges from 21.1 to 24 ˚C except for Sialkot station which has 18.1 to 21.0 ˚C average maximum temperature.

Spatial distribution of mean monthly temperature in Punjab

Islamabad and Sialkot station shows least average monthly maximum temperature which is less than 29˚C and between 29.5 to 29.9 ˚C respectively. Bhawal nagar, Bahawalpur and Khanpur stations shows highest average monthly maximum temperature ranges from 32.9 to 33.4 ˚C. Multan and D.G.Khan are less hot and Bhakkar station temperature ranges from 31.7 to 32.0 ˚C. Mianwali and Faisalabad has moderate temperature while Mangla, Lahore and Sargodha stations have less average monthly maximum temperature ranges from 30.5 to 30.7 ˚C. Jhelum shows slightly more temperature than Mangla.

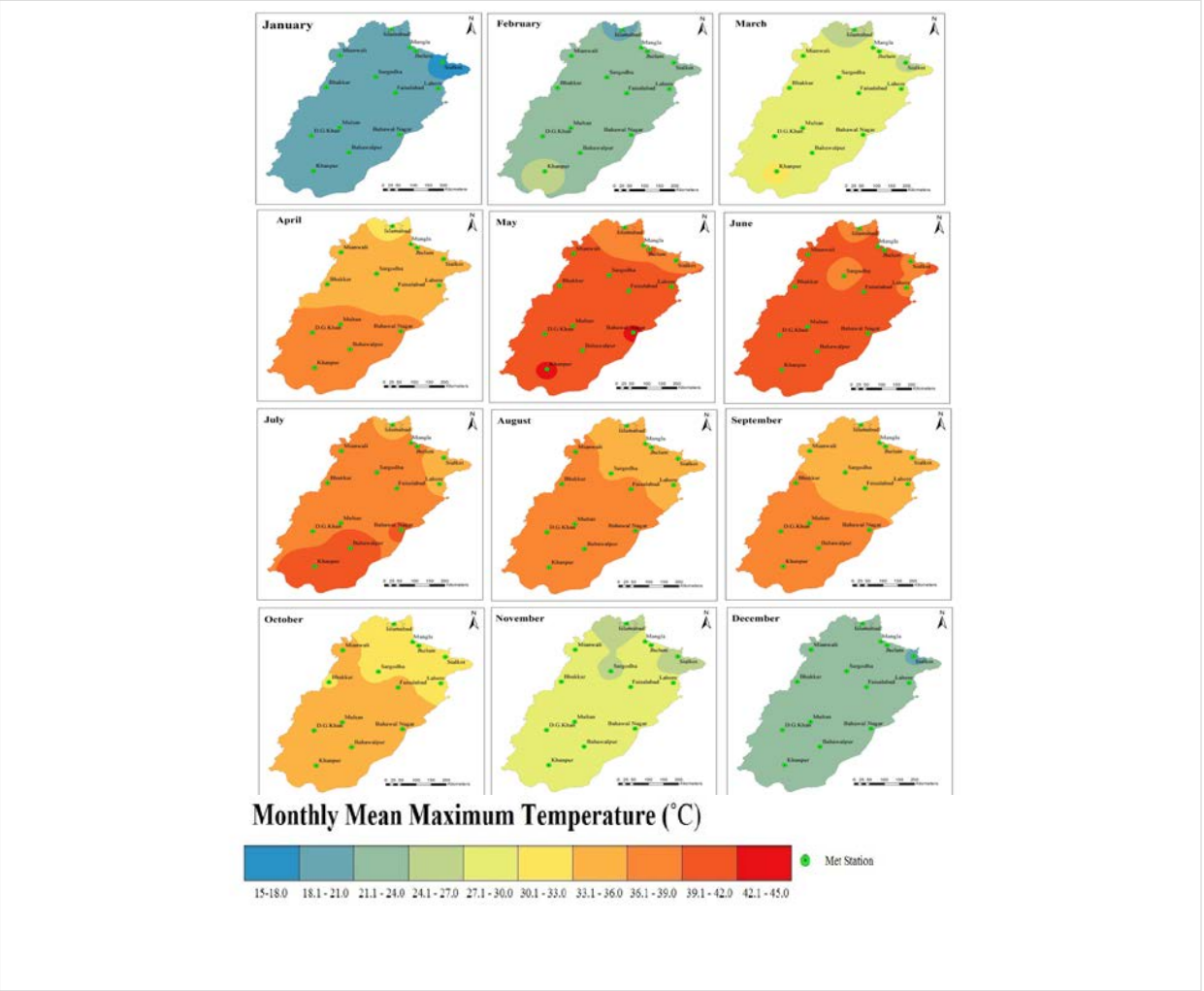

Figure 4. Spatial distribution of Monthly Mean Maximum Temperature (˚C)

Spatial distribution of average minimum temperature in each station selected in Punjab is shown in figure no.5. Islamabad station and its surrounding areas show lowest mean minimum temperature which is 14.1 to 14.7 ˚C. Lahore, Bahawal Nagar and Multan stations have highest mean minimum temperature which is 18.8 ˚C to 19.3 ˚C. Sialkot, Jhelum and Bhakkar stations has 17.1 to 17.6 ˚C minimum temperature. Faisalabad, D.G.Khan, Mianwali and surrounding areas of Sargodha has 17.7 ˚C to 18.1 ˚C minimum temperature. Mangla station has 15.9 to 16.4 ˚C minimum temperature.

According to the statistical analysis and temperature catalogues represent inclusive heating up in the whole Punjab (Kousari MR et al., 2013). The regularity of tremendously cold days and nights has shrunk and occurrence of the exceptionally hot days and nights has augmented throughout the investigation time period. This indicates that the nature of the spatial distribution of diurnal temperature extremes has transformed with their past average values.

Conclusion

The analysis of diurnal minimum and maximum temperatures records of 14 selected synoptic stations of Punjab, was performed to identify long-term trends and fluctuations in chronological and spatial dissemination patterns in the last two decades in Punjab. The minor change in climate can have major impacts. Following are some of the impacts and consequences due to temperature variability.

- The selected stations used in this study are major cities of Punjab and are densely populated. So the urbanization in these cities is increasing as the population increases. Increase in urban area and decrease in green area can be the cause of warming in Punjab.
- The increasing trend in minimum temperature is due to rapid urbanization due to population increase and the decrease in the green areas and deforestation.
- Mann Kendal trend analysis exposes pretty composite changes in the pattern, and a substantial declining trend of the diurnal maximum and minimum temperature throughout the winters, and an growing trend throughout the summer season.
- Cyclical range of temperature displays an accumulative trend: summers are warmer than past while the winters are colder than previous records.
- The rise in minimum summer temperature is very noticeable than the rise of the extreme temperature, though the decrease of the maximum temperature in winter time is more than the reduction of the least, thus causing in a noteworthy drop of the daily air temperature in both seasons.
- Generally, analysis of temperature extremes showed a consistent pattern of warming across the selected cities of Punjab, Pakistan.
- Temperature rise in urban zones can causes a transformation in the energy equilibrium of the urban areas, under the marvel of urban heat island effect.
- In the changing climates, increased temperature in countryside will balance the cooling sensation of plants, the hot weather in Multan and Sargodha will yield profitable mango and citrus.
- Continuously increasing temperatures can affect inner quality of fruits. A rise in the number of hot days can affect more crop water requirements in the region.
- Existence of heat waves will rise another challenge to meet the greater crop water necessity
- It is very important to study the special effects of these raised temperatures for sustainable development in future.

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