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Research Article

Temporal Variations in Minimum, Maximum and Mean Temperature Trends of Lahore-Pakistan during 1950-2018

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Abstract: The present study analyses the pattern of temporal variations in minimum, maximum, and annual mean temperature trends of Lahore (Pakistan) using the in-situ data collected from the Pakistan Metrological Department (PMD) during the period from 1950 to 2018. Sixty eight-year records of maximum, minimum and mean temperatures were extracted from two meteorological stations, the Shadman (PBO) station located within the urban region and the City's Airport (APT) station situated in a rural environment. Annual average trends of minimum, maximum, and mean temperatures were analyzed, and their statistical significance was calculated by applying the linear regression method to determine the Spatio-temporal variability in temperature trends. The results reflect that the minimum air temperature at both the station increased more than the maximum temperature. It was also identified that the minimum temperature increased more in the urban station as compared to the rural station. Furthermore, no significant difference was observed in the maximum temperature at both stations. The urban population growth of Lahore had a greater effect on the minimum temperature as compared to the maximum temperature. The findings indicate that the UHI effect increases with the increase of both the temperature and the urban warming rate. The outcomes of research are considerably emphasizing that an increase in minimum temperature observed at urban and rural stations significantly influenced the annual mean temperature of Lahore. Taking these findings into consideration, the policymakers, town planners and the government can formulate several distinctive methodologies and policies to mitigate the impact of urbanization on rising air temperature in Lahore, Pakistan.

Keywords: Minimum, Maximum, Mean Temperature, Trends, Temporal Variation, Lahore.

1. INTRODUCTION

Air temperature is one of the most significant component of forecasting weather and climate. So the analysis of its behavior is significant for the comprehension of climate changeability which can vary temporally and spatially at local to global scales. The International Panel on Climate Change (IPCC) has recognized that the global trends of temperature on a global scale show a warming of 0.85°C (0.65–1.06°C) during the period from 1880–2012. The average temperature from 2003 to 2012 is 0.78°C higher than that from 1850 to 1900 [1]. If air temperature continues to increase at the present rate, projections for 2050 specify that the global temperature will increase 2 to 4°C [2]. Climate change generally has a strong impact on human life, agricultural resources, the availability of water and human behavior and its significant effect can be seen particularly on those areas where economic activities are mostly dependent on agriculture [3]. Several studies [4-6], have pointed out the significance and direction of spatial and temporal trends of temperature from local to global scales. They highlight that the general warming trend is on the rise as far as the global mean temperature is concerned [3].

In recent years, several scholars have studied the influence of urbanization on temperature [7-13]. By comparing meteorological data of cities and nearby countryside, the analysis exhibited that urbanization had a significant effect on the temperature [2]. According to the fourth assessment

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report by IPCC, it was determined that the increase in mean temperature since the mid-twentieth century is very likely due to the increase in human activities (such as urbanization) and GHGs emissions in cities [14]. The annual mean temperature increases in cities is higher than in the countryside. Many comparative studies on observational data from urban and rural areas show that urbanization had an important effect on temperature [15] and revealed an increase in mean temperature in an urban area with the growth of the urban population [16]. After examining the Historical Climate data (1219 Station) of American, Karl et al [17] noted that the urbanization influence on temperature was 0.06°C approximately from1901–1984, and Kukla et al [18] after analysis North America, observed that the urbanization effect on temperature was 0.12°C/10a approximately. Meanwhile, local temperature is a key climate element to measure environmental changes carried out by urbanization and industrialization [19]. All over the world, the major cities of the developing world are undergoing climate change due to rapid urbanization and industrialization, particularly Beijing [20], Delhi [21] and Shanghai [22], resultantly they are increasingly becoming unsafe for life.

Some of the world's major cities such as Sao Paolo, Brazil experienced an increase in temperature by 2°C since 1993 [23]. During the past 29 years, the yearly mean temperature of Seoul, South Korea rose by 1.5°C [24], and China's capital, Beijing, also suffered rising temperature trends, as reported by Song et al [25], found that the average rate of temperature increase in an urban area is 0.43°C/10a and in peripheral is 0.21°C/10a. Duhan et al [11], evaluated the change in temperature with the impact of urbanization for a period from 1901 to 2001 in Madhya Pradesh. The study concluded that temperature observed an increasing trend, winters experienced warming more than summers and temperature rose high during the urbanization period.

Furthermore, GHGs emissions [26], and the change in land use have a significant influence on temperature. With the use of numerical experiments and simulations for long term temperature data, several scholars consider that large scale land-use change will affect regional and even global climate [27-30]. Kalnay and Cai [31] recommended that the decrease in the diurnal temperature was owing to land-use change due to urban expansion. Sertel et al [32], determined that the average temperature of Turkey increased due to urbanization as a result of simulation by the WRF regional climate model. Sajjad et al [33], investigated temperature change in Karachi for the period from 1947-2005. The results indicated that Karachi was more prone to the MMxT than MMiT where the temperature rose. Sajjad et al [34], examined the effect of urbanization on the temperature in Lahore from 1950 to 2007. The Findings have suggested a significant increasing trend in MMiT which was 2.51°C, while MMxT was found constant. On basis of the mean minimum and maximum temperature, the mean annual temperature of Lahore increased by 0.89°C. On the other hand, Ghous et al [35], observed a slight change in temperature with an average rate of increasing 0.021°C/year. The conclusions of the study disclosed that human activities and land-use change have a significant influence on the temperature of Lahore. The rising temperature trends in urban areas are generally higher than of those in rural areas, because of urban expansion and related changes in land use primarily impact on the minimum temperature of cities and micro-climate [36]. Therefore, the analysis of microclimate and the local temperature is a key factor to measure climate changes in increasing urban areas and metropolitans because of rapid urbanization, industrial and commercial activities. As the significance of temperature is the key element for climate changes, the regional temperature in increasingly developing urban areas of Pakistan has drawn a great deal of interest and attention. The objective of the present study is to describe the significant features of temporal and spatial (trend and change point) temperature changeability of Lahore, over the period from 1950–2018, to precisely signify climate change diversities.

1.1 Study Area

The study area, Lahore, (Figure 1) is the administrative capital of the Punjab, Pakistan, and the second-largest metropolitan city of Pakistan after Karachi in terms of Population. It lies between Rechna and Bari Doab and is situated on the bank of the river Ravi. It extends between 74°-10' to 74°-39'east longitude, and 31°-15' to 31°-42' north latitude [37], with an average altitude of about

217 m above sea-level by a flat topographical characteristic and fertile alluvial plains and covers an area of 1772 km2. In 1951, the city has a population of 1.12 million [37] which increased to 11 million in 2017 and the whole Lahore has been declared as an urban area [38].

The city of Lahore touches extremes climatic conditions during both winter and summer season. According to the Koppen Classification System, Lahore is situated in an area experiencing a semi-arid type of climate with mild winters and rainy and hot summers. The summer starts from April to September, where warmest months are May and June, during these months the temperature ranges between 27.4°C and 40.4°C (Figure 2). The winter persists from November to March, where coldest months as December and January, during these months temperatures sometimes reaches to the freezing point [37]. Most of the rainfall is received during the monsoon seasons especially the months of July and August, while during the rest of the year, the city remains almost dry.

2. MATERIAL AND METHODS

The temperature data for sixty eight-years from 1950 to 2018 has been used for this analysis to find out the possible variations in temperature of Lahore, because within this period Lahore has experienced massive land-use changes and urbanization activities which are the prime causes of temperature increase is urban areas [26]. The monthly maximum, minimum and mean temperature of two weather stations of Lahore ware collected from Pakistan Meteorological Department (PMD), Jail Road Lahore Office and mean minimum, maximum and mean annual temperature series are prepared. There are two meteorological stations in Lahore-Shadman (PBO) and the city Airport (APT). The distance between these two weather stations is about 10 kilometers. Details about the two ground weather stations are given in Table 1, and the location of these weather stations are shown in Figure 1. One meteorological station is located within the urban area (Shadman (PBO)) having impervious surfaces and the second (Airport (APT)) is situated

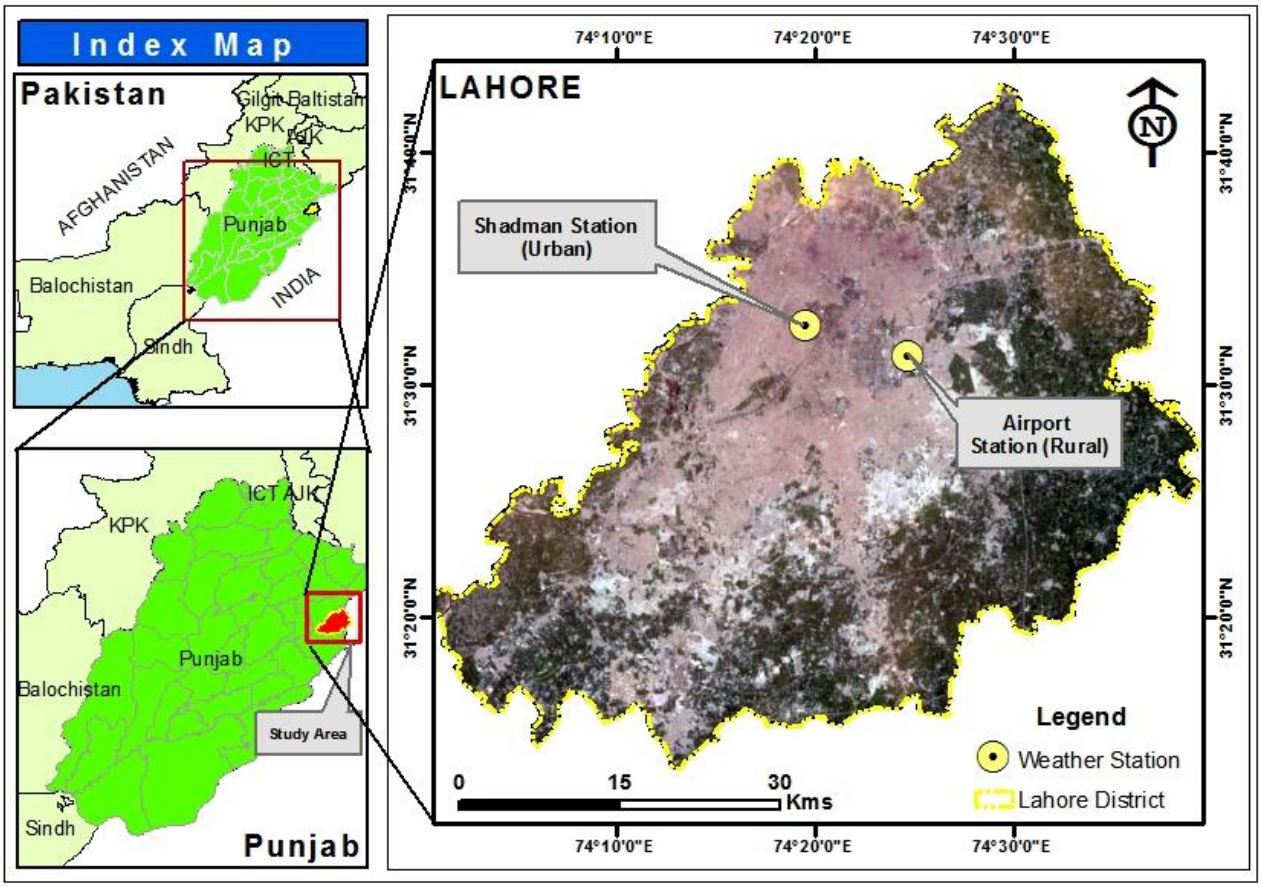

Fig 1. The geographical location of weather stations and study area (Lahore) map.

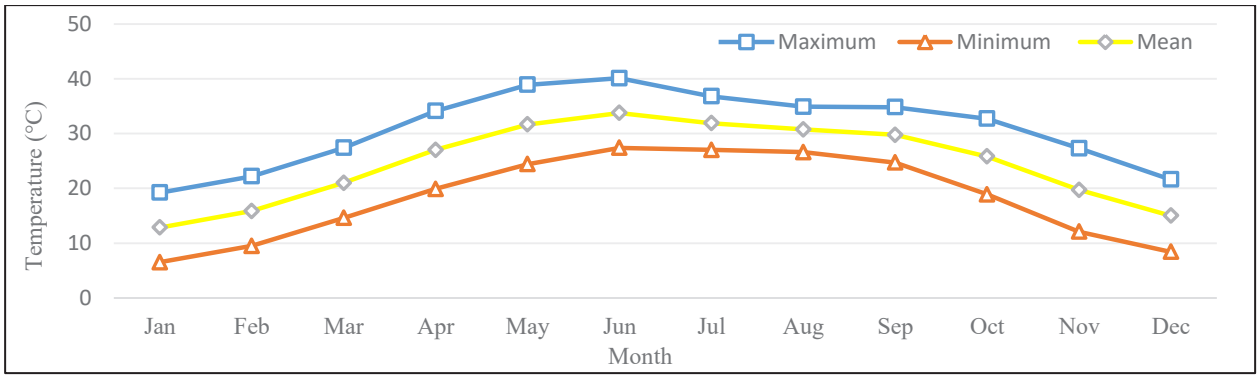

Fig 2. Monthly minimum, maximum, and mean temperature of Lahore (1950-2018)

in a rural environment as shown in Figure 1. The observational data from Shadman (PBO) is used to represent the climate conditions of the urban area of Lahore, while city Airport (APT) weather station is intended to represent the weather conditions of the rural environment, outside the city. In this study, the monthly mean temperature data from Shadman (PBO) for the period 1950-2018 and from Airport (APT) for the period from 1953-2018 were collected and used to calculate the annual mean temperatures. The temperature data of these two stations were collected in centigrade scale.

The time series of minimum, maximum and mean annual temperatures of Lahore from 1950 to 2018 were observed by applying the linear regression method to find out a significant change in temperature trends for the past 68 years. The behavior of temperature is analyzed in the whole study period from 1950 to 2018. Trend evaluates have generally used fundamental statistical procedures for perceiving climate changes on a local to global level [39]. The time-series data was then compiled subsequently and scatter plots were utilized to investigate temperature trends through SPSS to choose the type of test, i.e. Mann Kendal, spearman of linear data to study time series of mean minimum, mean maximum and annual mean temperature. In the examination of quantitative measurement of minimum, maximum and annual mean temperature, along with its numerous parameters, were used as a dependent variable, and time series on annual temperature was utilized as an independent variable. By using this method, the temporal changes in minimum, maximum and mean annual temperature of Lahore studied by Mann Kendal rank statistic to approve the significance of the observed trends. The analysis was done by using the formula given by [40] as

$$Y = \alpha + \beta x + \mu$$

Where, Y stands for temperature (minimum, maximum, annual mean), X stands for the time series, and μ= random error term. $\alpha + \beta x$ is a relationship between Y dependent and independent X and how much bring change in one unit change of the dependent variable in the independent variable.

3. RESULTS AND DISCUSSION

3.1. Temporal Variation of Temperature in Urban Area

Figure 3 shows the temporal variation of the annual mean temperature of Lahore from 1950 to 2018. The variations and change in the annual mean temperature of Lahore by exploring linear

Table 1. Geographic information on weather stations site properties

Station Name	Nature	Temperature (°C)	Latitude (°N)	Longitude (°E)
Shadman (PBO)	Urban Area	1950 - 2018	31°32'34.08"N	74°19'29.16"E
Airport (APT)	Rural Area	1953 - 2018	31°31'13.75"N	74°24'37.93"E

trends have been shown in Figure 3 significant results. The annual mean temperature from 1950 to 2018, the value of r which shows the coefficient of determination having 0.512 which indicates that 51% relationship of the temperature in the data is explained by the fit line and the remaining 49% difference is because of unexplained effect. The trend line of annual mean temperature indicates an increase in temperature. However, this increasing trend has a significant positive effect. Annual mean temperature shows an increasing trend during the last seven decades with 1953, 1988, 1999, 2002, 2004, 2016, 2017, 2018 as the warmest years have the temperature 25.3°C, 25.4°C, 25.5°C, 25.6°C, 25.6°C, 25.6°C, 25.7°C, 26°C respectively. The warmest years of the study period from 1950–2018 were typically observed during the last decade as shown in Figure 3.

The observed changes in temperature trends were positive, which had clear increasing trends in annual mean temperature of Lahore over the last 68 years. The temperature trends of the city exhibit fluctuation in different years. The temperature change throughout the analysis is not constant. After 1998, the increase in the annual mean temperature of Lahore is due to the increase in mean minimum temperature. The progress in urbanization is the basic reason to increase the mean minimum temperature in Lahore. The findings of the present study explain that the increase of temperature in Lahore has likewise been the fundamental wellspring of progress in climatic conditions. The change and increasing trend of annual mean temperatures from 1950 to 1997 are less while after 1998 it had been increasing faster particularly at the urban station (Shadman (PBO)). The present study also examined the warmest year 2018 with 26°C which is the hottest year of history.

The findings of the study also show that the mean minimum temperature is higher in an urban area as compared to the countryside. On the other hand, the increase in mean minimum temperature also brings an increase and changes the annual mean temperature of an urban area which affects the population. The increase in minimum temperature caused by development and urbanization since 1980. It is observed that the increase in mean minimum temperature at the urban station (Shadman (PBO)) is due to the growth of settlement and urban population.

The findings of the study also observed that the increase in mean minimum temperature at the urban station is higher as compared to the mean maximum temperature. The results also show that the rising trend of mean minimum temperature influenced the annual mean temperature of Lahore at the urban station (Shadman (PBO)) as compared to the rural station (Airport (APT). In the analyzed parameters of temperature, the mean minimum temperature changing pattern is regular and steady throughout the study span. During 1950-2018, an increase is observed up to 1.38°C in the mean minimum temperature of Lahore. A maximum change in the mean minimum temperature during 1988-2018 is observed. The post-1980s is significant for the massive sprawl in Lahore. For the time span from the 1980s to date, the climate of Lahore has also been badly affected by the growth of the urban population, and urban expansion in terms of

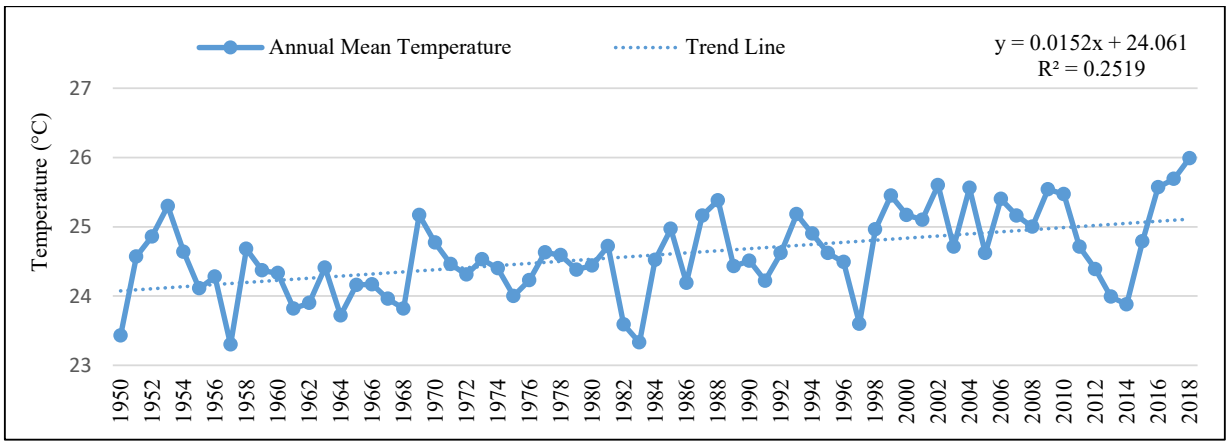

Fig 3. The annual mean temperature trend line of Lahore (Shadman (PBO)) from 1950-2018

increasing urban built-up area is affecting minimum temperature more than the maximum temperature at the urban station. Figure 4 shows that the mean minimum temperature of Lahore increasing at a faster rate after 1997 is the main reason behind this increase in urbanization and urban population growth during this period.

Figure 5 shows that there is not any critical increase in mean maximum temperature. Therefore, the annual mean temperature of Lahore is not affected by the mean maximum temperature of Lahore. The analysis of the meteorological data shows that there is no huge change in the mean maximum temperature of Lahore during the study period from 1950-2018 at an urban station. The trend line shown in figure 5 shows that the mean maximum temperature increases in urban area from 1951 to 1988, particularly the year includes 1952, 1953, 1969, 1981, 1985, 1987, and 1998 which was prominent to be the warmest year with 32.47°C, 32.51°C, 32.18°C, 31.77°C, 31.65°C, 31.9°C, 31.9°C respectively. The periods from 1955-1957, 1966-1968, 1970-1973, 1974-1976, 1982-1983, 1994-1997, 1999-2015, the trend line of the mean maximum temperature of urban station reflects a decreasing trend with temperature from 30.96°C-29.71°C,30.98°C-30.31°C,31.34°C-30.62°C,31.15°C-30.27°C,30°C-29.67°C, 30.91°C-28.6°C, 31.17°C-29.82°C respectively. The findings of the study confirm that the period from 1999-2015 the mean maximum temperature at the urban station shows a decreasing trend while the mean maximum temperature at rural stations indicates an increasing trend.

The mean maximum temperature shows less significance in the change trends. During the study period from 1950-2015, a decreasing trend is observed in the mean maximum temperature is 0.47°C. The increase in mean maximum temperature has affected the annual mean temperature of Lahore. The annual mean temperature increase for the last 68 years has been observed to be 1.7°C with an

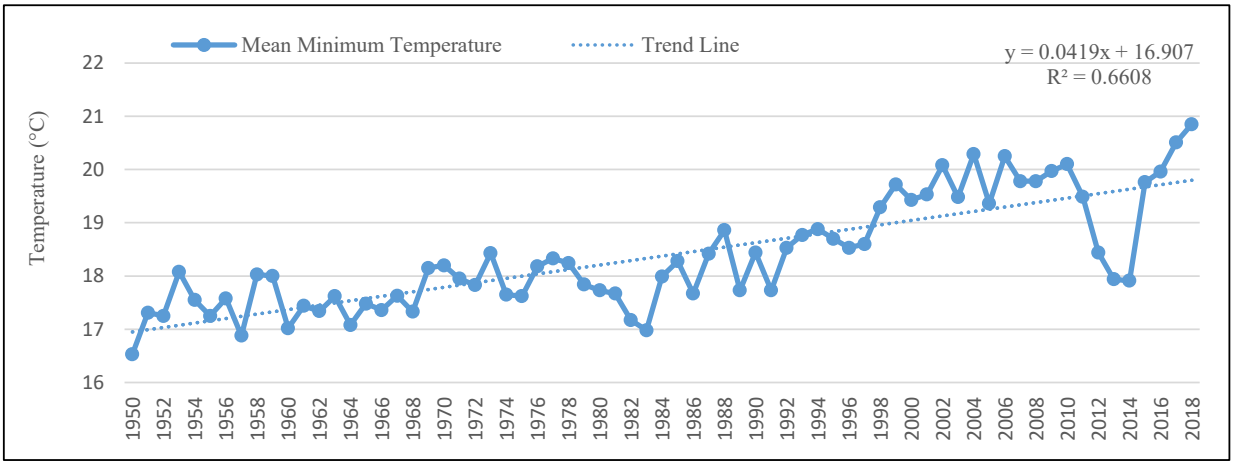

Fig 4. Mean minimum temperature trend line of Lahore (Shadman (PBO)) from 1950-2018.

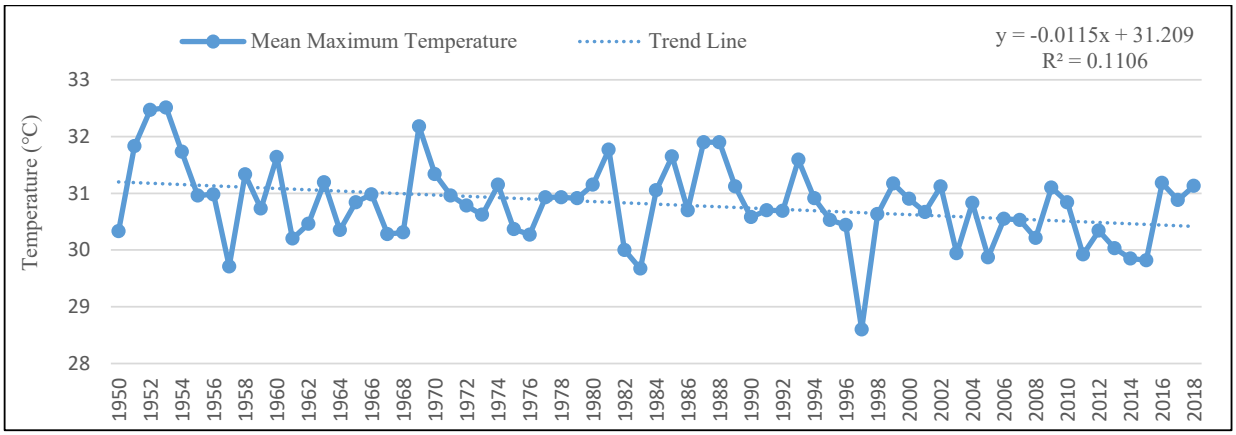

Fig 5. Mean maximum temperature trend line of Lahore (Shadman (PBO)) from 1950-2018.

average annual increase of 0.026°C.

3.2 The temperature of Urban and Rural Areas

It is observed from the analysis during the study period from 1950 to 2018, the average temperature of Shadman (PBO) and Airport (APT) was 24.59°C and 24.04°C, respectively, with an annual mean temperature difference of 0.55 between the two stations. The annual mean temperature of urban stations increased slightly from 1950 to 2018 and the annual mean temperature of rural stations increased slightly from 1953 to 2015 and then decreased slightly as shown in Figure 5. The annual mean temperature of PBO increased faster than that of APT, causing the urban population and urbanization. The temporal variations of urban-rural differences in the mean temperature fluctuated during the period from 1950 to 2018.

The annual mean temperature of the rural station (airport (APT)) reveals the significant negative impact on the rural environment. It is observed from the analysis that the trend line of the mean temperature of the rural station had an increasing trend caused by settlement growth in a rural area. The warmest mean temperature years in the rural station (airport (APT)) were 1953, 1969, 1994, 1999, 2001, 2002, 2004, 2010, 2011, 2015, 2016 and 2017 with temperature 25.08°C, 24.45°C, 24.67°C, 24.77°C, 24.69°C, 24.94°C, 24.71°C, 25.1°C, 24.95°C, 25.45°C, 24.85°C and 24.63 respectively. Figure 6 shows that the trend line of the annual mean temperature of the rural station (airport (APT)) shows the decreasing pattern as compare to the urban station (Shadman (PBO)). Figure 6 also highlights the effects of urbanization on the mean annual temperature trends of both stations. An analogous proportion is observed in the increase of temperature trends at the urban station, owing to the population growth throughout the study period. The increase in population growth keeps intensifying the minimum temperature which affects the mean annual temperature of both stations. By 1951, the Lahore population was recorded to be 1.13 million, which increased to about 11 million in 2017.

Figure 7 shows that the trend line of mean minimum temperature increases at a rural station (Airport (APT)) that affects the annual mean temperature of Lahore at the rural station (Airport (APT)) lower rate as compared to the urban station (Shadman (PBO)) mean minimum temperature. Figure 7 also indicates that the study period from 1953-1966 experienced almost the same trend in minimum temperature at both the stations, but afterward, the period from 1967-1994, the trends seem to differ in minimum temperature in the urban station as compared to the rural station. The year 1995 onwards, the minimum temperature of Lahore started increasing at a rapid pace as the city was the center of massive urban development and anthropogenic activities. During the study periods from 1960-1973, 1975-1980, 1986-1990, 1998-2002, and 2014-2018, the mean minimum temperature increased from 16.86°C-17.91°C,16.7°C-17.6°C,16.73°C-17.87°C, 17.22°C-18.32°C, and 17.06°C-18.03°C. Figure 7 reveals that the mean minimum temperature at an urban station increases faster rate as compared to the rural station due to the urban population growth and urban development.

Figure 8 reflects the analysis and variability of the mean maximum temperature of both the stations (urban and rural). The graph of mean maximum temperature trends in the urban areas shows a tendency to increase, especially the year 1998 which was declared to be the warmest in history. Before 1996, the difference in the annual mean maximum temperatures of both the stations (rural and urban) was higher as compared to the trend of increasing temperature till 1998, an urban station in particular. The period after 1998-2015, the mean maximum temperature of the urban station shows a decreasing trend while the mean maximum temperature of the rural station shows an increasing trend.

The analysis revealed that the change in mean maximum leads towards the growth and development in a rural area. The trend line shown in figure 8 shows that the highest mean maximum temperature years at the rural station are 1953, 1958, 1960, 1969, 1970, 1999, 2000, 2002, 2004, 2009, 2010, 2015, 2016, and 2017 with 31.65°C, 31.08°C, 31.38°C, 31.27°C, 31.3°C, 31.12°C, 31.01°C, 31.56°C, 31.53°C, 31.27°C, 31.56°C, 31.31°C, 31.25°C and 31.08°C respectively. The trend line shown in Figure 8 also shows that the mean maximum temperature at rural station increasing after 1997 to 2015. But at the urban station mean maximum temperature trend line

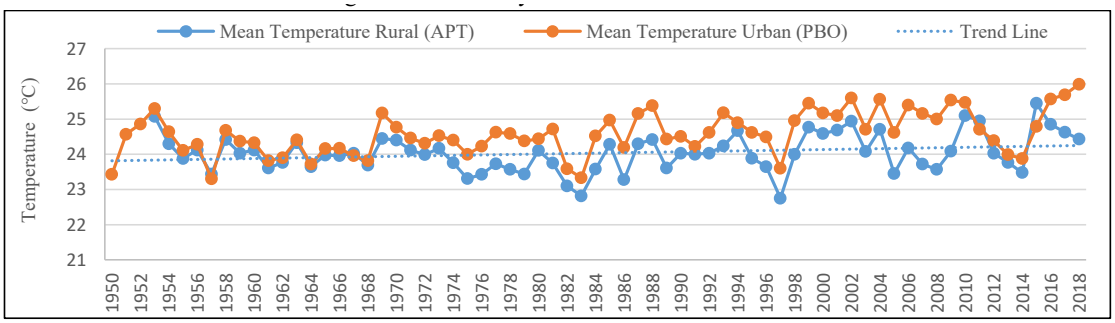

Fig 6. Trend lines of the mean temperature of Shadman (PBO) and Airport (APT) stations

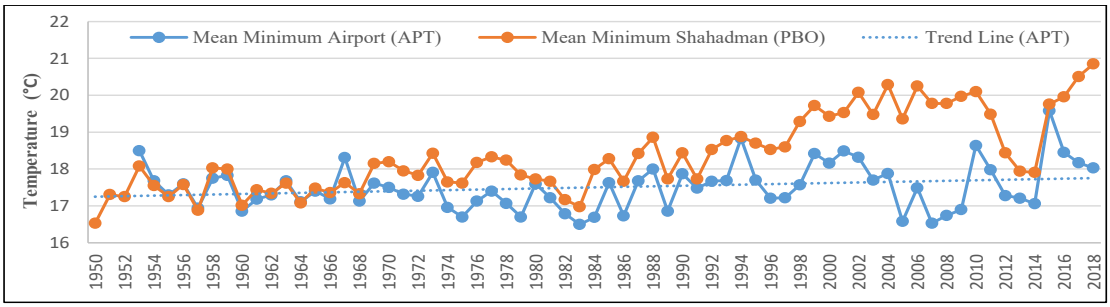

Fig 7. Trend lines of the mean minimum temperature of Airport (APT) and Shadman (PBO) stations

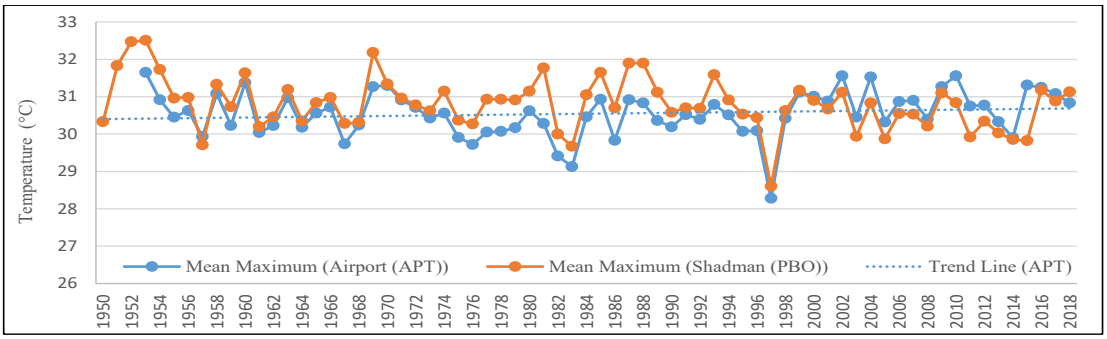

Fig 8. Trend lines of the mean maximum temperature of Airport (APT) and Shadman (PBO) stations

shows a decreasing trend from 1999 to 2015. Figure 8 also reflects that the periods from 1953 to 1957 and 1969 to 1975 the mean maximum temperature at the rural station shows a decreasing trend ranged from 31.65°C to 29.93°C and 31.27°C to 29.72°C respectively, while the periods from 1976 to 1993 and 1997 to 2016, the mean maximum temperature at rural station reflects temperature increase from 29.90°C to 31.09°C and 28.53°C to 31.39°C respectively.

3.3 Urban Development and Temperature Change

As the cultural, political, commercial, and educational hub of Pakistan, Lahore has attracted a large influx of population. Urbanization and development of Lahore generally began in the 1980s. The urbanization process is mostly reflected in the increase of urban population, expansion of the built-up area, the establishment of industries, the increase of the nonagricultural population, and the reduction of agricultural land around the city. By 1951, the Lahore resident population recorded was 1.13 million, which increased to 11 million inhabitants in 2017 as shown in Figure 9 [37-38, 41]. The population density of Lahore has also increased by this alarming growth from 641 to 6300 persons/km^2 from 1951 to 2017 respectively [38]. The urban built-up area of Lahore has grown to 643.51 km^2 in 2018, from 66 km^2 in 1951 as shown in Figure 9 [42].

Urbanization and development have caused an increase of impervious surfaces, industrial activities, energy consumption, domestic heating,

GHGs, and exhaust of automobile emissions as well as a decrease of urban green spaces and water surface it has been revealed that urban development is modifying the thermal condition of Lahore in a variety of ways, thus affecting the local temperature. The emission of CO_2 in particular, and greenhouse gases in general, contribute towards urban warming in Lahore. The significant variations in temperature trends of Lahore show an increase in annual mean temperature during various years as shown in Figure 10. When we compared the change curves between urban area and temperature, we observed that their change trends (Figure 10) were almost the same in the whole time series of the study. It means that there is a close relationship between temperature change and urban built-up area.

Figure 11 a and b reflects the growth of the urban built area, population, and its correlation with mean temperature change. As the green spaces and vegetation cover is converted into urban built-up, it has a greater impact on minimum temperature than the maximum temperature of Lahore. It also describes that urbanization in terms of growth of urban population and increasing built-up area is affecting minimum temperature than maximum temperature. The relationship between urban built-up area and annual mean temperature, revealed by Pearson correlation is 0.87 which shows a positive correlation. Figure 11(a) highlights the value of R^2 which is 0.933 also indicating a positive correlation between the built-up area and the mean temperature of Lahore. Figure 11(b) shows the positive correlation between population and annual mean temperature, Pearson correlation coefficient, which is 0.83, and R^2 is 0.68.

The installation of industrial units has ever been increasing since 1980-2018, but a massive increase can be noted after 2005 as shown in Figure 12. This increasing number of heavy industries and factory units also contributed to a considerable increase in the mean temperature of Lahore. The ever-increasing number of registered vehicles is one of the major factors responsible for changing the urban climate of Lahore. The increase in the number of registered vehicles is shown in Figure 13. These factories and vehicles are causing harmful effects on the urban environment, by constant emission of toxic gases like carbon mono oxide, carbon dioxide, unburned gases, and smoke in the air and caused smog (smoke + fog) formation which is in turn cause of an increase of mean minimum temperature of Lahore.

In order to further support and strengthening the argument about the contribution of increasing registered number of factories and vehicles to cause a modification of climate and rise of temperature in Lahore, correlation analysis has been done between the number of registered factories, vehicles, and temperature. The result obtained by Pearson correlation is 0.95. A positive correlation between mean temperature and several factories at a significant level of 95%, R^2 is obtained to be 0.910, indicating the positive correlation between mean temperature and registered factories of Lahore, while the correlation between the increasing number of registered vehicles and mean temperature of Lahore also shows a positive correlation and Pearson correlation value to be 0.92, indicating a positive correlation between the mean temperature and increasing number of vehicles per year and R^2 is found to be 0.86 (Fig. 14).

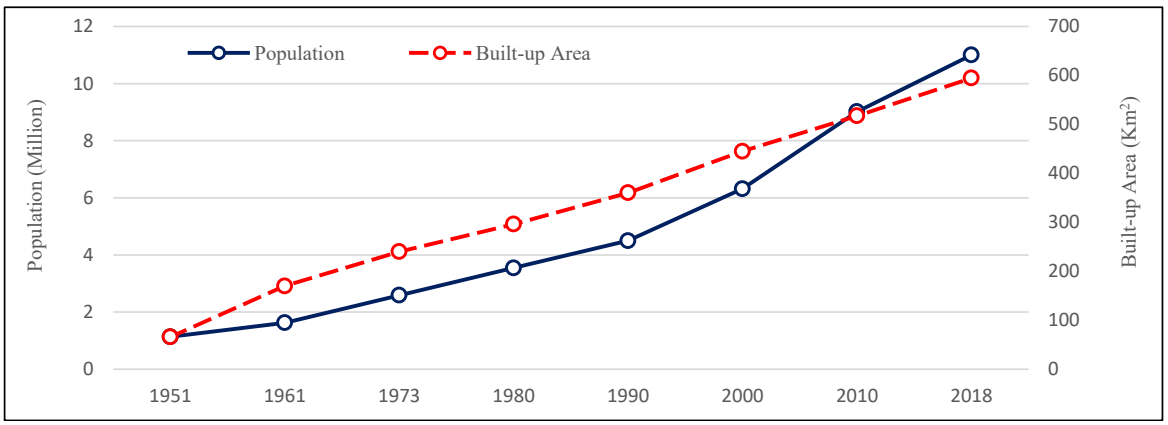

Fig 9. Growth of population and built-up area change from 1951 to 2018.

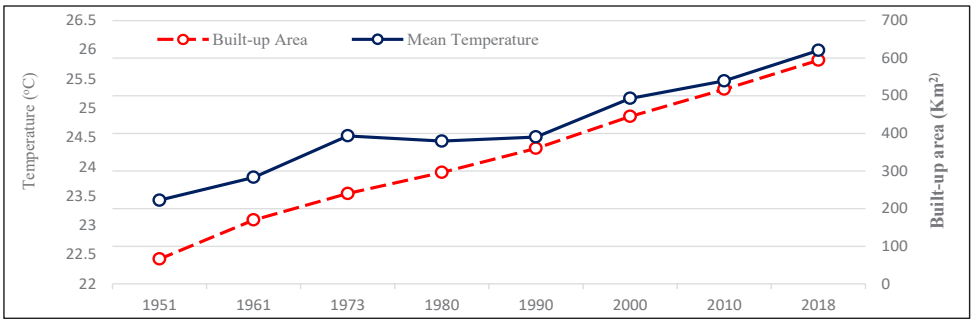

Fig 10. Change of urban built-up and mean temperature of Lahore from 1951 to 2018.

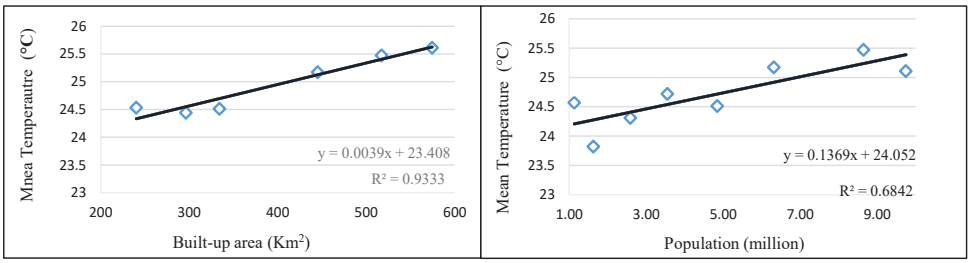

Fig 11. Correlation between built-up area (a), population (b), and annual mean temperature of Lahore.

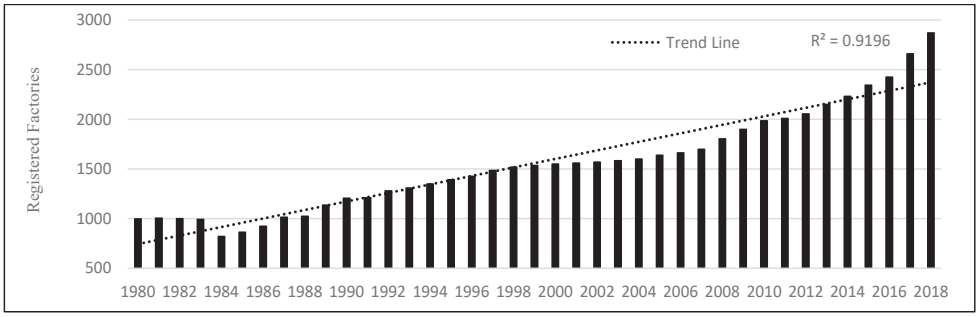

Fig 12. A number of registered factories of Lahore from 1980 to 2018.

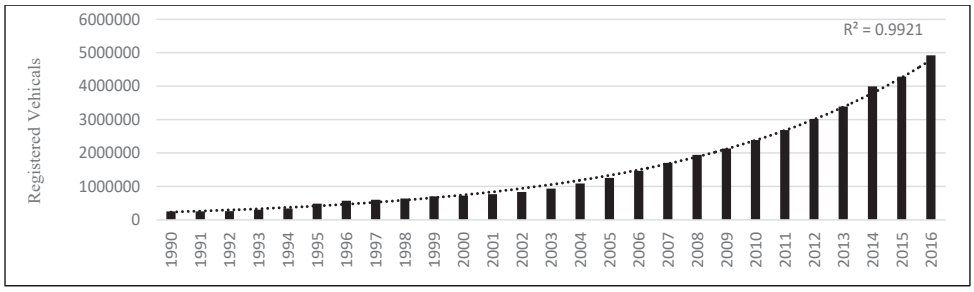

Fig 13. Growth of registered vehicles of Lahore from 1990 to 2018.

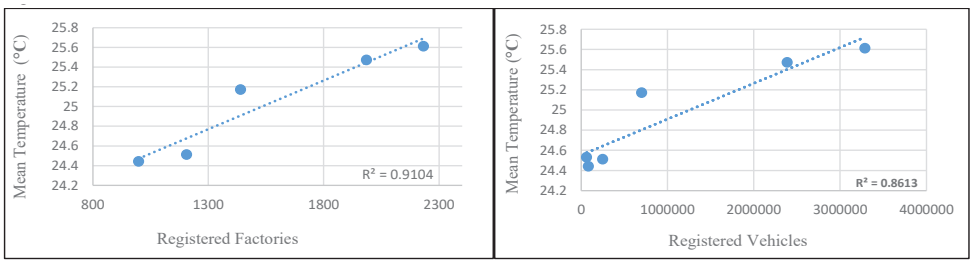

Fig 14. Relationship between MAT and Registered Factories and Vehicles in Lahore.

5. CONCLUSIONS

It is concluded that the change in minimum temperature during the study period is higher as compared to a maximum temperature, this is due to the impact of urbanization. It is observed that the increase in minimum temperature at the urban station is due to the growth of the urban population which increased momentously during the study period. It has been noted that the minimum temperature increased which affected the mean annual temperature of Lahore. According to the findings of the study, it is observed that the massive increase in urban growth resulted in an increased emission of GHGs, particularly CO_2, carbon monoxide, and sulfur dioxide, forming smog over the city in the shape of the suspended-particle laden layer of thick cloud. Lahore is the fourth worst city for smog among the ten worst cities in the world. One of the factors contributing to smog in cities is alternate energy resource in the industries; coal, wood, and other pollution producing fuels. Moreover, the traffic jams in the city also enhance the emission of carbon monoxide in the city, creating a thick layer of smog. The cloud of smog traps the emitted and reflected radiation from the surface of the Earth and produces the greenhouse effect. This effect is a major cause of an increase in the minimum temperature of the city and decreasing the maximum temperature over time. It also affects the mean annual temperature of Lahore. As the green spaces are converted into the impervious surfaces, the minimum temperature is affected more than the maximum temperature by the conversion of natural land into the urban structure. This study observed the impact of urbanization on minimum temperature which is a lot more extensive than study on maximum temperature. Future research can be worked out by utilizing Landsat satellite imagery to study the impact of urban expansion on land surface temperature and the effects of the urban heat island of Lahore. Nevertheless, the effect of UHI in Lahore still needs further research attention, considering the energy consumption and growth of the population.

7. REFERENCES

1. IPCC. Climate change 2013: the physical science basis. In *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Stocker TF,Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds). Cambridge University Press: Cambridge, UK and New York, NY, 1535 (2013).
2. Y. Wang, W. Ji, X. Yu, X. Xu, D. Jiang, Z. Wang, and D. Zhuang. The impact of urbanization on the annual average temperature of the past 60 years in Beijing. *Advances in Meteorology* 2014:1-10 (2014).
3. A.R. Ghasemi. Changes and trends in maximum, minimum and mean temperature series in Iran. *Atmospheric Science Letters* 16(3): 366-372 (2015).
4. S. Brown, J. Caesar, and C.A. Ferro. Global changes in extreme daily temperature since 1950. *Journal of Geophysical Research: Atmospheres* 113:1-11 (2008).
5. D.J. Karoly, and P.A. Stott. Anthropogenic warming of central England temperature. *Atmospheric Science Letters* 7(4): 81-85 (2006).
6. R.S. Vose, D.R. Easterling, and B. Gleason. Maximum and minimum temperature trends for the globe: An update through 2004. *Geophysical Research Letters* 32(23): 1-4 (2005).
7. J.P. Montávez, A. Rodríguez, and J.I. Jiménez. A study of the urban heat island of Granada. *International Journal of Climatology* 20(8): 899-911 (2000).
8. J. Hansen, R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, and T. Karl. A closer look at United States and global surface temperature change. *Journal of Geophysical Research: Atmospheres* 106(D20): 23947-23963 (2001).
9. T.B. Zhao, and C.B. Fu. Applicability evaluation of surface air temperature from several reanalysis datasets in China. *Plateau Meteorology* 3: 1-8 (2009).
10. M.K. Kim, and S. Kim. Quantitative estimates of warming by urbanization in South Korea over the past 55 years (1954–2008). *Atmospheric Environment* 45(32): 5778-5783 (2011).
11. D. Duhan, A. Pandey, K.P.S. Gahalaut, and R.P. Pandey. Spatial and temporal variability in maximum, minimum and mean air temperatures at Madhya Pradesh in central India. *Comptes Rendus Geoscience* 345(1): 3-21 (2013).
12. P. Sonali, and D.N. Kumar. Review of trend detection methods and their application to detect temperature changes in India. *Journal of Hydrology* 476: 212-227 (2013).
13. M. Punia, S. Nain, A. Kumar, B.P. Singh, A. Prakash,

K. Kumar, and V. Jain. Analysis of temperature variability over north-west part of India for the period 1970–2000. *Natural Hazards* 75(1): 935-952 (2015).

14. R.V. Cruz, H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li, and N.H. Ninh. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. ML Parry, OF Canziani, JP Palutikof PJ Vander Linden, CE Hanson (eds). *Cambridge University Press, Cambridge, UK,* 469–506 (2007).
15. U. Chung, J. Choi, and J.I. Yun. Urbanization effect on the observed change in mean monthly temperatures between 1951-1980 and 1971-2000 in Korea. *Climatic Change* 66(1-2): 127-136 (2004).
16. A. Dhorde, A. Dhorde, and A.S. Gadgil. Long-term temperature trends at four largest cities of India during the twentieth century. *Journal of Indian Geophysics Union* 13(2): 85-97 (2009).
17. T.R. Karl, H.F. Diaz, and G. Kukla. Urbanization: Its detection and effect in the United States climate record. *Journal of Climate* 1(11): 1099-1123 (1988).
18. G. Kukla, J. Gavin, and T. Karl. Urban warming. *Journal of Climate and Applied Meteorology* 25(9): 1265-1270 (1986).
19. A. Gadgil, and A. Dhorde. Temperature trends in twentieth century at Pune, India. *Atmospheric Environment* 39(35): 6550-6556 (2005).
20. W. Liu, C. Ji, J. Zhong, X. Jiang, and Z. Zheng. Temporal characteristics of the Beijing urban heat island. *Theoretical and Applied Climatology* 87(1-4): 213-221 (2007).
21. M. Mohan, Y. Kikegawa, B. Gurjar, S. Bhati, and N.R. Kolli. Assessment of urban heat island effect for different land use–land cover from micrometeorological measurements and remote sensing data for megacity Delhi. *Theoretical and Applied Climatology* 112(3-4): 647-658 (2013).
22. L. Chen, R. Jiang, and W.N. Xiang. Surface heat island in Shanghai and its relationship with urban development from 1989 to 2013. *Advances in Meteorology* 2016: 1-15 (2016).
23. E.D. Freitas, C.M. Rozoff, W.R. Cotton, and P.L.S. Dias. Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil. *Boundary-layer Meteorology* 122(1): 43-65 (2007).
24. Y.S. Chung, M.B. Yoon, and H.S. Kim. On climate variations and changes observed in South Korea. *Climatic Change* 66(1-2): 151-161 (2004).
25. Y. Song, W. Dong, S. Zhang, D. Zhang, S. Wang, and B. Hu. Study on characteristics of climate element in Beijing. *Arid Meteorology* 21(3): 63-68 (2003).
26. IPCC. Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis. Summary for Policymakers,* Cambridge University Press, Cambridge, UK (2007).
27. X. Yang, Y. Zhang, L. Liu, W. Zhang, M. Ding, and Z. Wang. Sensitivity of surface air temperature change to land use/cover types in China. *Science in China Series D: Earth Sciences* 52(8): 1207-1215 (2009).
28. Z.F. Zheng, Y. Zheng, and Q.C. Li. Effect of urbanization on the temperature of Beijing metropolis in recent 30 years. *Chinese Journal of Eco-Agriculture* 15(4): 26-29 (2007).
29. W. Su, C. Gu, and G. Yang. Assessing the impact of land use/land cover on urban heat island pattern in Nanjing City, China. *Journal of Urban Planning and Development* 136(4): 365-372 (2010).
30. M. Wang, X. Yan, J. Liu, and X. Zhang. The contribution of urbanization to recent extreme heat events and a potential mitigation strategy in the Beijing–Tianjin–Hebei metropolitan area. *Theoretical and Applied Climatology* 114(3-4): 407-416 (2013).
31. E. Kalnay, and M. Cai. Impact of urbanization and land-use change on climate. *Nature* 423(6939): 528-535 (2003).
32. E. Sertel, C. Ormeci, and A. Robock. Modelling land cover change impact on the summer climate of the Marmara Region, Turkey. *International Journal of Global Warming* 3(1-2): 194-202 (2011).
33. S.H. Sajjad, B. Hussain, M.A. Khan, A. Raza, B. Zaman, and I. Ahmed. On rising temperature trends of Karachi in Pakistan. *Climatic Change* 96(4): 539-54 (2009a).
34. S.H. Sajjad, S.A. Shirazi, M.A. Khan, and A. Raza. Urbanization effects on temperature trends of Lahore during 1950-2007. *International Journal of Climate Change Strategies and Management* 1(3): 274-281 (2009b).
35. M. Ghous, K. Khalida, A. Basit, and J. Hassan. Temporal analysis of urbanization and resulting local weather change: a case study of Lahore, Punjab, Pakistan. *Science International* 27(2): 1281-1287 (2015).
36. K.R. Kumar, and L. Hingane. Long-term variations of surface air temperature at major industrial cities

of India. Cl*imatic Change* 13(3): 287-307 (1988).

37. GoP. *District Census Report of Lahore 1998*. Islamabad: Population Census Organization, Statistics Division. Govt. of Pakistan, (2000).
38. GoP. *Provisional Summery of Census 2017.* Islamabad: Population Census Organization, Bureau of Statistics. Govt. of Pakistan, (2017).
39. M. Domroes, and A. El-Tantawi. Recent temporal and spatial temperature changes in Egypt. *International Journal of Climatology* 25:51–63 (2005).
40. G.A. Seber, and A.J. Lee. *Linear regression analysis John Wiley & Sons,* (2012).
41. M. Nasar-u-Minallah. Spatial and Temporal Change Assessment in Land Surface Temperature of Lahore using GIS and Remote Sensing Techniques. *Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences* 55 (3): 67–75 (2018).
42. M. Nasar-u-Minallah. *Assessing The Impact of Urban Expansion on Land Surface Temperature in Lahore using Remote Sensing Techniques*. Unpublished PhD Thesis, Department of Geography, University of the Punjab, Lahore, Pakistan, (2017).