

Urban Growth and Its Effect on Temperature Trends of Lahore City, Pakistan

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Abstract : The current study deals with the effect of urban growth and urbanization on temperature trends over Lahore city of Pakistan. This research was conducted using mean monthly temperature data for the period of 1950-2017. The urban population growth, urban expansion, the increase of vehicles and factories as well as the expansion of built up area have influenced on the change of temperature in Lahore city. The annual trends of temperatures have been analyzed, and their statistical significances are calculated by the linear regression method. It has been deduced that there is a close relation between temperature change and urban growth. The findings are as follows; the mean minimum temperature rises greater than the maximum temperature at urban station and rural station. However, the maximum temperature is not rising positively and thus significantly at both stations. The findings show the fact that mean minimum temperature increasing more quickly after the 1995 due to the increase of urban development in Lahore city in which the built up area has increased from 66 km² to 740 km² since 1950. A massive increase in the numbers of vehicles have also influenced on the change of temperature in the city. However, the mean maximum temperature at rural station of Lahore has significant effect during 1973-1997.

Key Words : temperature change, rising trends, urbanization, Lahore city

1. Introduction

Over the past many decades, our views about climate variability and change and our ability to evaluate their future impacts has improved expressively. Our comprehension of environmental change enhances ceaselessly empowering researchers to reach progressively certain inferences about its causes and effects. Since the Earth shaped in

excess of four billion years prior, its atmosphere occasionally moved from warm to cool and back again sometime. The earth's climate has been evolving continuously over last 100 to 150 years (Farooqi *et al.*, 2005). Most recent climate changes are caused by human activities, i.e. increasing population, urban area, industry and emissions of greenhouse gases (Hardy, 2003). Human prosperity, settlement and migration depend on favorable

climatic conditions. In parallel, human activities, i.e. rapid growth in population, an increase in urban area and industrialization destruct the climate rapidly. The effect of urban extension on urban smaller scale atmosphere has been watched all through the world and the metropolitan urban areas of creating nations like Beijing (Liu *et al.*, 2007), Delhi (Mohan *et al.*, 2013), Lahore (Sajjad *et al.*, 2009b; 2015) and Shanghai (Chen *et al.*, 2016), are not sheltered and are liable to the ecological change because of the quick urbanization. Some of the world's major cities such as Sao Paulo, Brazil experienced an increase of temperature of 2°C since 1993. During the past 29 years, the yearly mean temperature of Seoul, South Korea rose by 1.5°C and China's capital of Beijing also suffered from rising temperature patterns as reported by Sajjad *et al.* (2009a). Other than the financial, social and mental impacts of huge urbanization on the common habitat, the procedure of urban development and its effect on temperature can be estimated quantitatively.

A number of studies have been concentrated on climatic changes in mega cities and economic hubs (Duhan *et al.*, 2013; Sonali and Kumar, 2013; Punia *et al.*, 2015). Roy and Balling (2005) examined the seasonal change in temperature, diurnal temperature range and cloud cover across India from 1931 to 2002 and find a remarkable increase in temperature over Deccan Plateau, but a decline observed in northwest Kashmir. Sajjad *et al.* (2009a) investigated temperature data of Karachi city for the period from 1947-2005. The results indicated that Karachi is more prone to the mean maximum temperature than the

mean minimum temperature. Sajjad *et al.* (2009b) explored the changing patterns of temperature in Lahore due to infiltrated procedural urbanization from 1950 to 2007. The authors observed an increasing trend in mean annual temperature and mean minimum temperature, but maximum temperature found constant. Duhan *et al.* (2013) 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 the temperature rose up high during urbanization period. Jeganathan and Andimuthu (2013) conducted a study for a time period from 1951 to 2010 and found clear positive trends with an increase of 1.3°C temperature in Chennai, India.

Urban areas depend upon a complex infrastructure system to provide human, environment and economic services (Kirshen *et al.*, 2008). Cities all over the world have been continually expanding due to the influx of people from rural to urban areas (Da Silva *et al.*, 2010). Urban warming often defined as the difference in temperature between a city and the surrounding of a rural area is called the urban heat island (Chung *et al.*, 2009). In respect of long-term warming trend, Choi *et al.* (2003) suggested, may be the causes are not local climatic changes, such as urban effect, but also some non-climatic factors, such as location of stations, instrumentation and observation time. Globally, annual urban warming rates vary between the ranges of 0.01 to 0.42°C (Choi *et al.*, 2003).

The annual temperature increase in large urban

areas is higher than the rural and marine stations (Chung *et al.*, 2004b). The urban-rural temperature difference can reach 10°C at large cities (Fujibe, 2009). Recently, regional urbanization is believed to be more influential on the regional temperature than the global warming, and urban warming has an obvious linkage to population size (Chung *et al.*, 2004a). Urban environment is playing an increasingly significant role in the climate change (Kishtawal *et al.*, 2010). Urbanization is spreading quickly, these urban developments are causing regional climate change, i.e. an urban heat island and urban air pollution (Ooka, 2007).

The temperature variation in urban areas and issue of climate changes is due to urban expansion, industrial activities and their consequences have become a matter of substantial global discus-

sion and investigation. Urban areas are influenced all around the world by environmental changes. However, the climate parameters in the environment brings changes in land use patterns and surface temperature of Lahore, Pakistan. In the urban world as metropolitan city, the Lahore city faced the threat of visible change in urban areas and increase in surface temperature. Thus the present study is carried out with aims to examine the urban effects on the temperature over the Lahore city of Pakistan.

2. Profile of case study area

The second biggest city of the Punjab province is the Lahore in Pakistan. This city located on the eastern bank of the Ravi river. The Lahore is

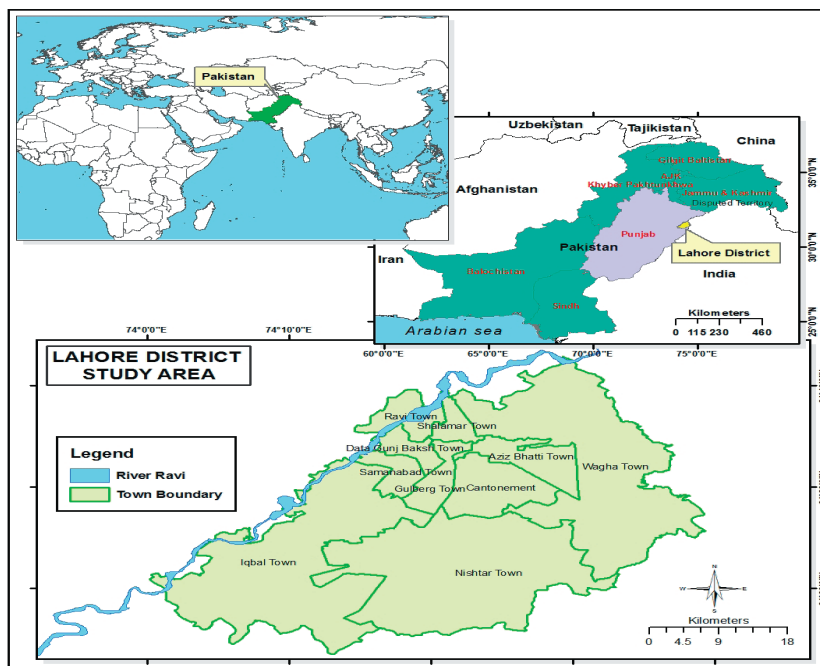


Figure 1. Location of the study area, the Lahore city, Punjab province, Pakistan.

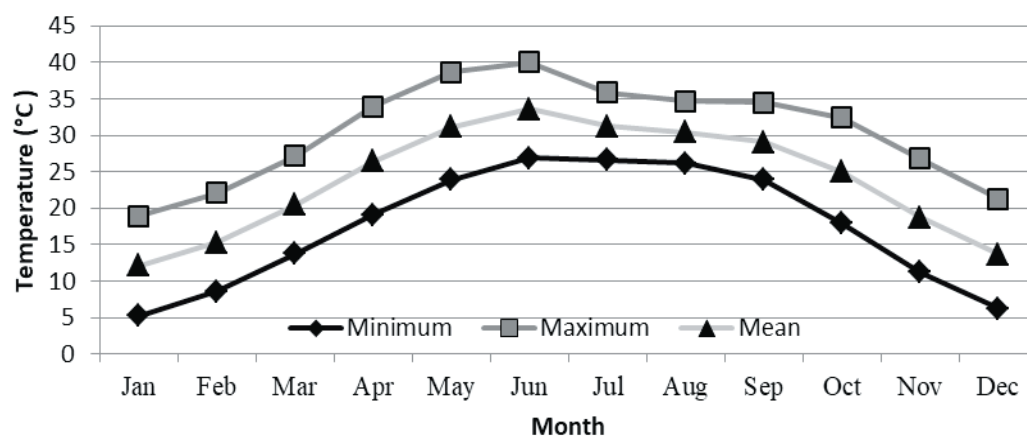


Figure 2. Mean monthly temperature (1951-2017) of Lahore (PBO).

a level of alluvial plain with sensitive gentle slope towards the southwest region. Its height above sea level varies from 700 feet in the northeast to 680 feet in the south west. Climatic features of Lahore are humid sub-tropical climate with extreme and long summer. The pronounced characteristics are mild winter, fog days (December & January), summer monsoon and dust storms. Temperatures range from a low of 10°C to a high of 42°C. The average daily maximum is 10°C in January, rising to 47°C in June - July.

Lahore is a populated city and facing massive development during the last two decades covered total land area of 1,772km² (Figure 1). According to the population of 1998, the population of Lahore was 5.1 million. In 2007, it is an estimated to 8 million population of Lahore city. Administratively, Lahore is divided into nine Towns with one Cantonment area. Iqbal Town, the largest town of Lahore, covers an area of 476.79km², while Shalimar town, the smallest town of Lahore, comprises an area of 26.88km².

In the context of the urban area station (PBO),

the highest minimum, maximum and annual temperature in the month of June was 27.70°C, 39.96°C and 33.69°C. The lowest minimum temperature was in the month of January and February 6.55°C and 7.52°C (Figure 2). The rural area highest minimum, maximum and annual temperature in the month of June was 26.89°C, 40.05°C and 33.60°C but the minimum temperature is lower than the urban area station. The highest maximum temperature in the month of June and lowest was in January. Large scale expansion and sprawling of the urban area in Lahore is started after 1980. It was forced the government to start many projects to develop the mega towns of residential, industrial zones and infrastructure for transportation. With the passage of time, the city had thousands and millions of vehicles on the roads which caused the harmful gases. Similarly, an increase in population, systematic public transport and new residence of urban areas are affecting the environment of the city.

3. Data and Methodology

The time series data of mean annual minimum temperature, mean annual maximum temperature and mean annual temperature from 1951 to 2016 are analyzed in this study by applying the linear regression method to find out significant change in temperature. Climatic data collected from Pakistan Meteorological Department (PMD). There are two weather stations in Lahore Shadman (PBO) and City Airport (APT). One weather station is situated on Shadman (PBO) Jail Road, Lahore, which is considered an urban area having impervious structures, and the second is located at City Airport (APT), which is considered to be rural vicinity having rural structures. The change in minimum, maximum and mean annual temperature in rural and urban area stations would be investigated. Statistic information is utilized for investigative the connection between the temperature and populace thickness of the examination zone. Demographic data is used for investigating the relationship between the temperature and population density of the study area. The population data for this study, mainly came from the Population Census Organization (PCO) of Pakistan.

For the empirical investigation, quantitative estimation of mean minimum, mean maximum and mean annual temperature, is used as dependent factor and time duration is utilized as an independent factor.

I. Temperature applied as the dependent variable as minimum, maximum and mean annual

II. The time duration applied as an independent factor.

Year (Time unit)

The empirical investigation is performed by applying the linear regression:

$$Y = a + bx + e$$

Where,

Y = dependent variable as a finding of temperature of Lahore

a) Minimum b) Maximum (c) Annual

X = Time duration in the year

a+bx = Relationship between dependent Y and X independent factor and how much bring change in one unit change of dependent variable in the independent variable

a = y intercept means when x= 0 and mean value of independent factor

b = The variation in the average value of independent factor, however the X value rises

E = calculates the error randomly between duration

Equation to calculate a value

$$a = (\sum y)(\sum y^2) - (\sum y)(\sum xy) / n(\sum x^2) - (\sum x^2)$$

Equation to calculate b value

$$b = n(\sum y)(\sum y^2) - (\sum y)(\sum xy) / n(\sum x^2) - (\sum x^2)$$

Where, n is the numbers of the intervals and $\sum xy$ is the product of x and y variables in regression, $\sum x^2 - (\sum x)^2$ is the difference between square of independent variable and sum of x independent variable squares.

4. Results and Discussion

1) Temperature trend of urban area

The mean temperature from the 1950-2017, the r value which indicate the coefficient of determination having value 0.512 which implies that 51% association of the temperature in the data is clarified by the fit line and the remaining 49% difference is because of unexplained effect. The trend line of mean temperature shows the increasing. However, this increasing trend has a significant positive effect. The increasing trend of mean temperature from 1951 to 1953 shows the change from 23.44°C to 25.30°C. While some other periods like 1964-1966, 1991-1993, 2005-2008 and 2015-2016 have the temperature range from 23.71°C to 24.18°C, 24.14°C to 25.18°C, 24.61°C to 25.61°C and 24.90°C -26.01°C respectively (Figure 3).

The outcomes of the moving patterns demon-

strate the higher expanding inclination in temperature at urban territory. Whereas, this change is examined higher following 2012 with 26.70°C that is the hottest year of the history. After 1995, the increase in mean temperature is due to increase in mean minimum temperature of Lahore. The urban population growth is responsible to increase in mean minimum temperature. The results of the findings explain that temperature increase in Lahore has likewise been the fundamental wellspring of progress in climatic conditions. Since from 1951 to 1997, there is less distinction in temperature while it had been increasing faster after 1999 particularly at urban station.

There isn't any critical rise in the maximum temperature. Thus, the mean temperature of Lahore isn't fundamentally influenced by the mean most extreme temperature. The most extreme maximum temperatures recorded have not encountered any huge change in the time range of

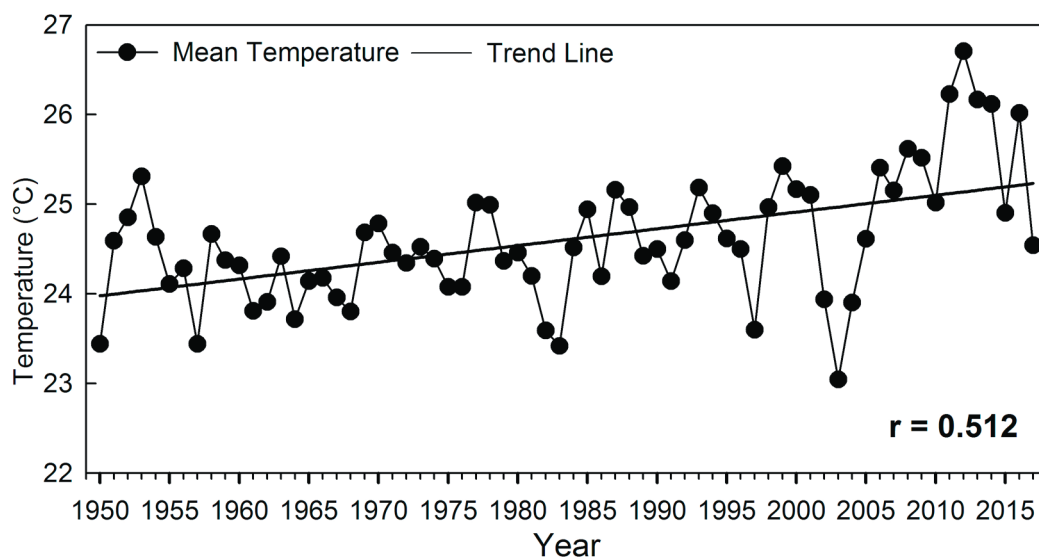


Figure 3. Trend line of mean temperature of Lahore Shadman (PBO).

67 years. The coefficient value of mean maximum temperature is 0.370 that declares the significant effect on the urban area which consist of 37% relationship of the maximum temperature is clarified by the fit line and the remaining 63% is difference in the coefficient determination. The results of most maximum temperature change drifts in the urban regions indicate the propensity of rise from 1950 to 1999, particularly the year 1953 and 1988 which was pronounced to be the hottest year with 32.51°C and 31.17°C respectively in the history (Figure 4).

It is investigated that the greatest growth measured in maximum temperature at the PBO urban station over the 1951-2017 period in summer and winter. It increased 2.94°C during these seasons and the lowest is measured during the summer where it is calculated and finds only 1.28°C during 67 years. The periods after 1970-1973, 1987-1997 and 1999-2014, the mean

maximum temperature of urban station demonstrates a decreasing trend with temperature range from 31.34°C to 30.62°C, 31.90°C to 28.60°C and 31.17°C to 29.77°C respectively. The period after 1999-2017, the mean most extreme temperature of urban station shows the decreasing pattern while the mean greatest temperature of the rural station indicates an expanding pattern.

It is noticeable from the investigation of data that the rise in minimum temperature is recorded in the urban station identified with the country station arranged at the air terminal which is an open territory. The trend shows that the minimum temperature trend in urban area is higher as compared to the rural area. However, the increase in minimum temperature brings the change the mean temperature of the urban area which effect on population. The increase in mean minimum temperature rise the urban growth and development since 1980, where built up area 296km²

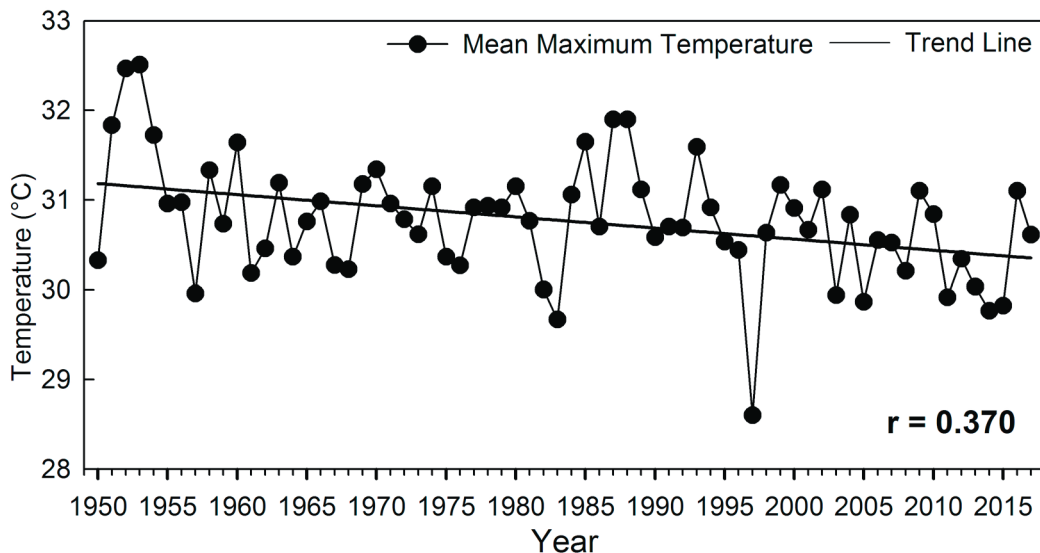


Figure 4. Trend line of mean maximum temperature of Lahore Shadman (PBO).

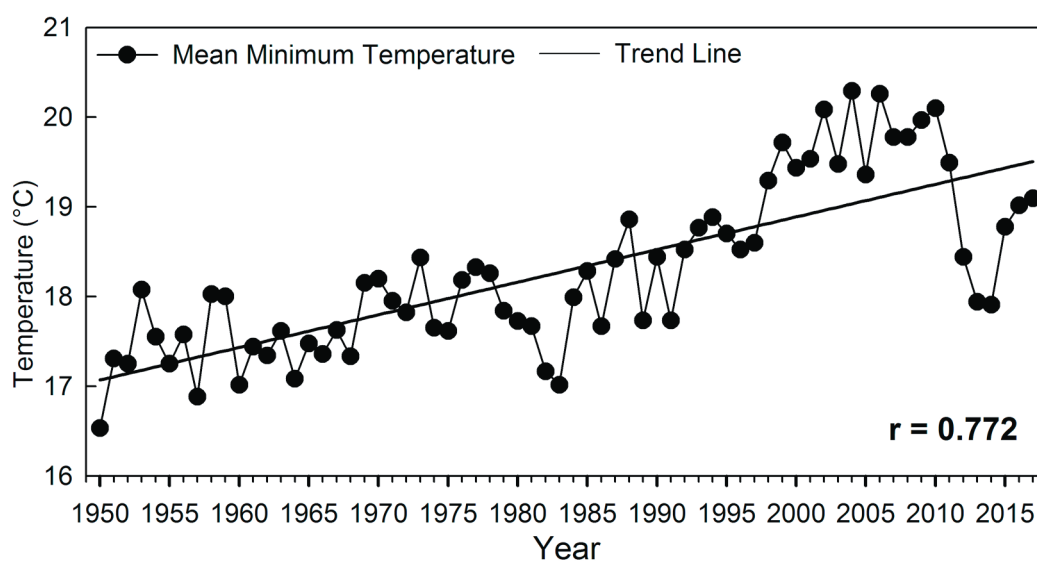


Figure 5. Trend line of mean minimum temperature of Lahore Shadman (PBO).

but in 2017 it is 740km². The r coefficient value of mean minimum temperature is 0.772 that declares the significant effect on the urban population that consist of 77% relationship of the minimum temperature is clarified by the fit line and the remaining 23% is the difference. It is seen that the expansion in minimum temperature at PBO station is due to increase of the population. The trend outcomes show that change in minimum temperature in the urban area station is higher than the maximum temperature. The results show that trend of minimum temperature rise, which influenced the mean temperature of Lahore at the Shadman (PBO) station as compared to the airport (APT) station. It has been clearly seen that the minimum temperature after the year 1995 began rising at a faster rate which increased the urbanization during this period. The period from 1950-1953 and 1995-2006, minimum temperature rise is 1.54°C and 1.55°C re-

spectively (Figure 5). The periods after 1951-1975 and 1978-2002 the mean minimum temperature of urban station demonstrates an increasing trend with temperature range from 16.53°C to 17.61°C and 18.75°C to 20.08°C respectively.

2) Temperature trend of rural area

Figure 6 shows the graph that consists of years on x axis and the mean temperature on vertical y axis. The points are firmly grouped around the best fit line and the r value (0.001) is near 0. In the context of the above results. The mean temperature of airport station (APT) shows the significant negative effect on rural area. The highest mean temperature years in the rural area are 1953, 1969, 1999, 2001 and 2004 with 25.08°C, 24.43°C, 24.78°C, 24.71°C and 24.73°C respectively. The trend line shows the decreasing pattern as compared to the urban area station. The highest mean temperature in 1953 was 25.08°C as

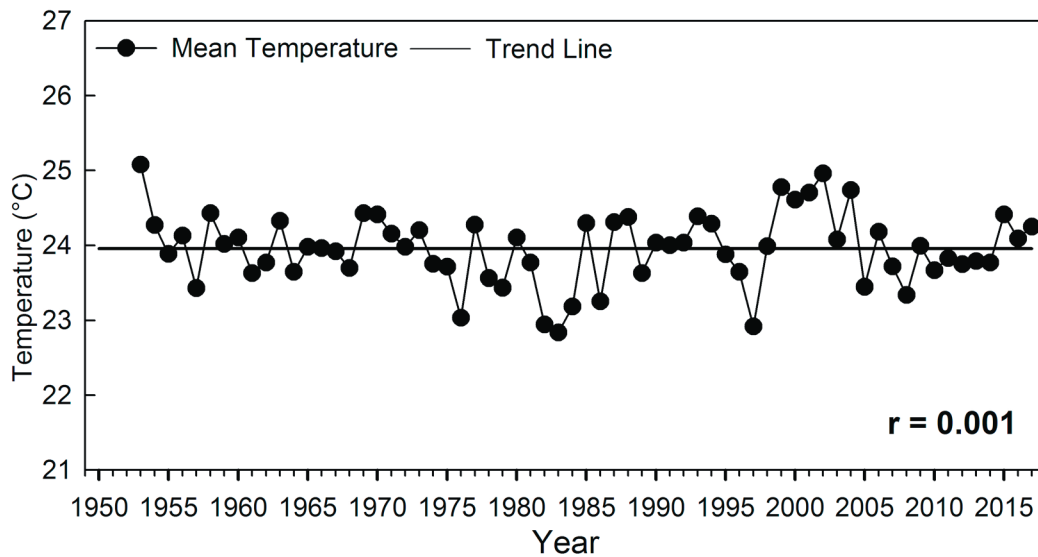


Figure 6. Trend line of mean temperature of Lahore Airport (APT).

compared to the urban area station was 25.30°C. After 1999, the minimum temperature is relay on the decrease in mean monthly temperature of airport station Lahore, particularly after 1999s. The outcomes of the investigation shows that the mean temperature decrease in airport station Lahore that has the significant effect on the growth of the rural area.

Figure 7 declares that highest maximum temperatures in rural area station from 1953-2017 have not come across to any change. The r value of mean maximum temperature is 0.028 that declares the significant effect because its r value does not exceed the 1 and it is near to 0. The outcome of change in maximum temperature leads towards the rural area growth and development. The trend shows the highest maximum temperature years like 1953, 1958, 1960, 2004, 2011 and 2016 to 31.65°C, 31.08°C, 31.30°C, 31.53°C, 31.38°C, 31.32°C respectively. The

lowest maximum temperature years were 1957, 1982, 1983 and 1986 with 29.93°C, 29.41°C, 29.15°C and 29.83 respectively. The trend of the mean maximum temperature in rural station after 1997-2015 increasing. But in the urban station trend is decreasing. The periods after 1953-1957 and 1969-1975 the mean maximum temperature of the rural station shows a decline trend with temperature range from 31.65°C to 29.93°C and 31.27°C to 29.72°C respectively. The period after 1976-1993 and 1997-2016, the mean maximum temperature of airport station shows the rise pattern with 29.90°C to 31.09°C and 28.53°C to 31.39°C respectively.

The highest increase in minimum temperature at the rural station is perceived in spring season where is measured from trend 1.53°C but in the winter season it shows the decreasing trend in the same station. The coefficient r value of mean minimum temperature in rural station is 0.262

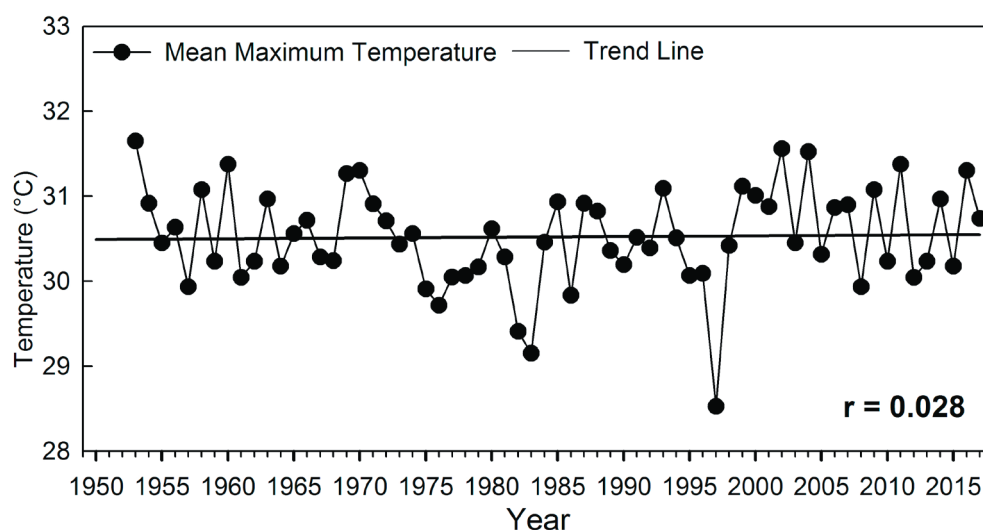


Figure 7. Trend line of mean maximum temperature of Lahore Airport (APT).

which is low as compared to urban area. So, the rural area has less effect on the growth of urbanization as compared to the urban area. The trend shows the minimum temperature increase that effect the mean temperature of Lahore airport (APT) station lower as compared to Lahore at the Shadman (PBO). It has been obviously measured from analysis that the trend of mean minimum temperature increasing after the year 1995-2016 from 17.70°C to 20.60°C with rate 2.40. The period from 1960-1973 and 1974-1994, the minimum temperature increase from 16.85°C to 17.90°C and 16.95°C to 18.07°C respectively (Figure 8). The mean minimum temperature in the urban area have r value greater than rural area. So, its brings large changes in the mean annual and mean maximum temperature. The r value 0.262 of mean minimum temperature in rural area shows the small change in the trend where as the 0.772 r value declares the large change in mean minimum temperature due to the expan-

sion of urban population.

3) Effect of urbanization

The urban population increased during the 1951-2017 from 861,279 to 9,346,079 persons (Figure 9) that effect the minimum temperature of the urban area. So, rise in the minimum temperature in urban area increase the mean annual temperature. The important change brings up in minimum temperature is seen after 1990 in which the urban population reach to 5 million as compared to 1950 have the 0.857 million.

During the period 1951-2017, the urban population had increased due to increase of the total district population. However, the built up area was also increased from 66km² to 740km². The built up area in the 1951, 1973, 1980 and 2010 was 66km², 240.14km², 296.2km² and 524km² (Figure 10). The increase in trend is due to increase in urbanization growth that affects the temperature.

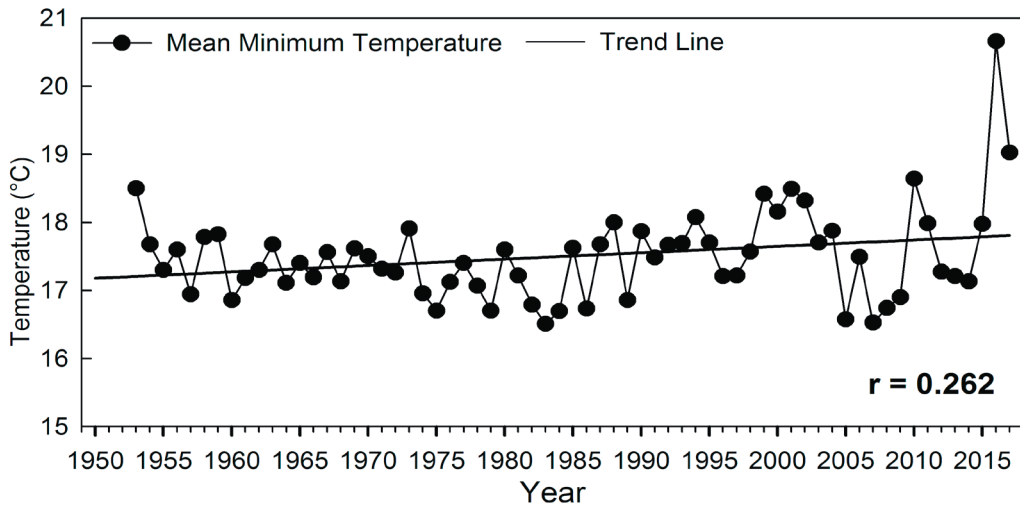


Figure 8. Trend line of mean minimum temperature of Lahore Airport (APT).

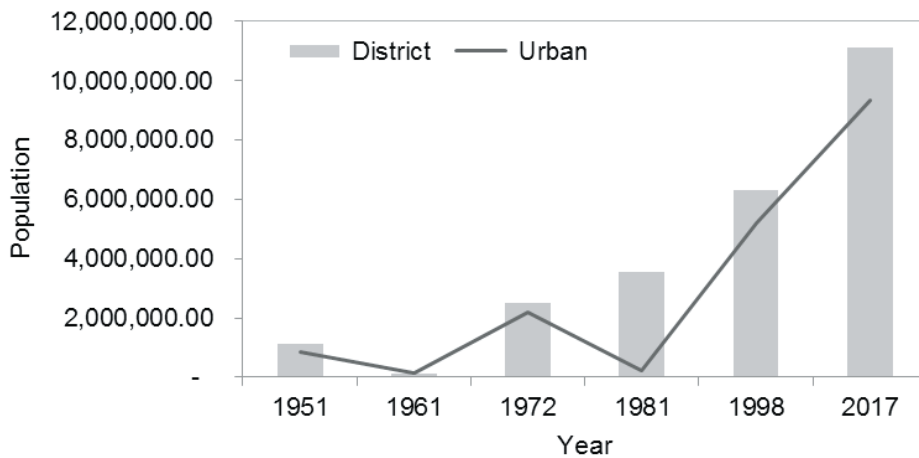


Figure 9. Urban and district population growth of Lahore from 1951 to 2017.

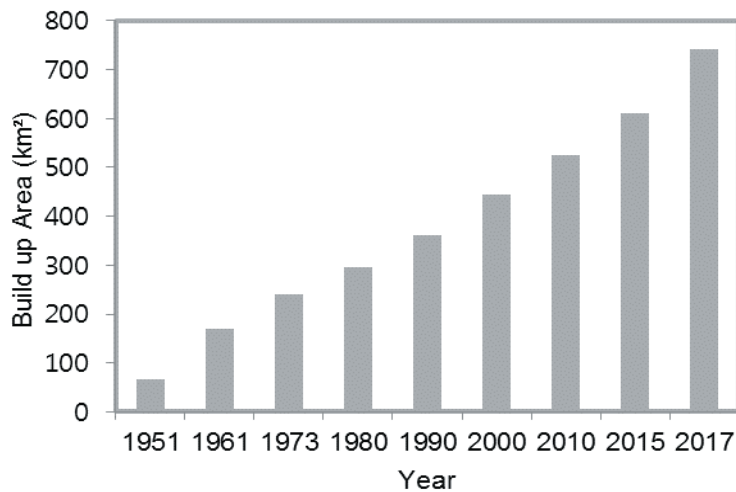


Figure 10. Built up area (km²) of Lahore from 1951 to 2017.

The numbers of the registered factories have increased since 1990-2017 but increases can be seen during 2015-2016 and 2016-2017 with numbers of factories 2,230 to 2,450 and 2,450 to 2,670. This increase in numbers of factories also contributed to increase in minimum temperature that affect the maximum and minimum temperature. The massive increase in the numbers

of factories be noted after 2007 (Figure 11). So, this trend brings variability in the maximum and minimum temperature. The massive increase in the numbers of vehicles during the periods 1992-1993, 2004-2005 and 2016-2017 with 216,458 to 342,143, 923,875 to 1,160,000 and 3,442,000 to 4,287,662 vehicles (Figure 12). The increase in the vehicles trend due to the expansion of urban

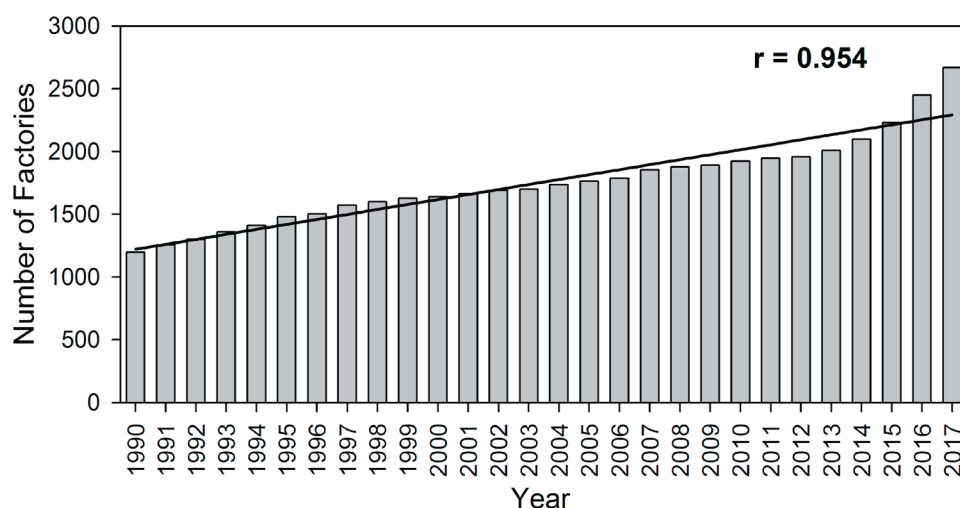


Figure 11. Trend of number of factories of Lahore from 1990 to 2017.

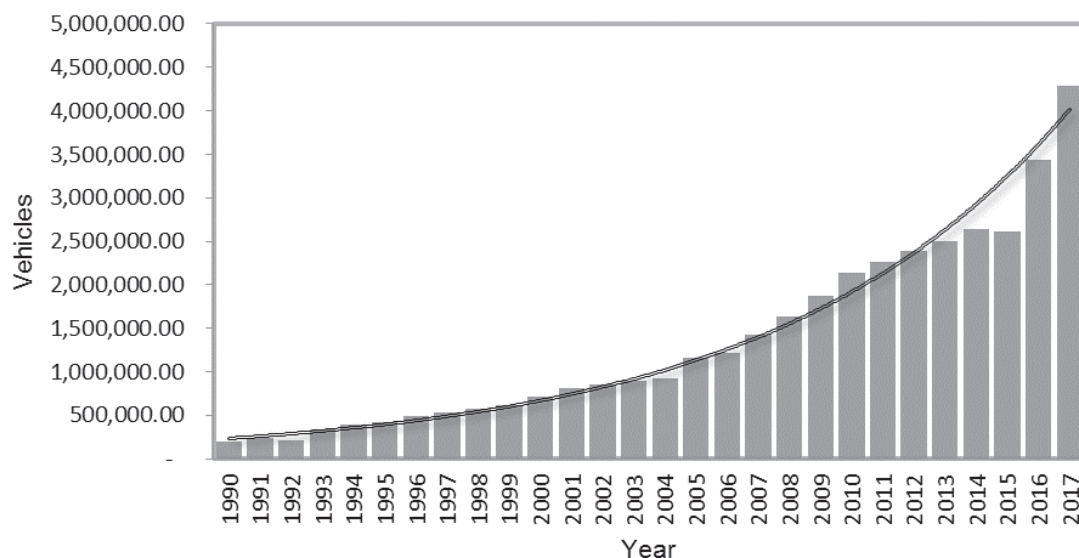


Figure 12. Trend of number of vehicles of Lahore from 1990 to 2017.

growth that effect on the climatic parameters like temperature.

5. Conclusion

Three different data time series of mean annual, mean minimum and mean maximum temperature has utilized to find the trends and climatic changes from 1951 to 2017. The trend line of mean temperature in the urban area station shows the increasing pattern as compared to the rural area station. However, this increasing trend has a significant positive effect. The increasing trend of mean temperature from 1951 to 1953 shows the change from 23.44°C to 25.30°C. The periods after 1970-1973, 1987-1997 and 1999-2014, the mean maximum temperature of urban station demonstrates a decreasing trend with temperature range from 31.34°C to 30.62°C, 31.90°C to 28.60°C and 31.17°C to 29.77°C respectively. On the other hand, over a period of 67 years, there isn't huge change in mean maximum temperature at the two stations. The pattern of mean minimum temperature increase, which affected the mean temperature of Lahore at the Shadman (PBO) station when contrasted with the airport terminal (APT) station. It has been obviously observed that the mean minimum temperature ascending at a quicker rate after the year 1995 which increased the urbanization during this period.

The highest mean minimum temperature at PBO station is due to increase of the urban population and built up area. The trend line shows that

change in minimum temperature in the urban area station is higher than the maximum temperature as compared to the airport (APT) station. However, the correlation coefficient r value of mean minimum temperature is 0.772 at urban area higher as compared to the rural area with r value 0.262. The findings show that mean minimum temperature brings the higher change in the mean temperature due to increase the population trend in urban area. Urbanization has a significant effect on the PBO station.

The recorded highest maximum temperatures in rural area station from 1953-2017 have not come across to any change. The trend shows the highest maximum temperature years like 1953, 1958, 1960, 2004, 2011 and 2016 to 31.65°C, 31.08°C, 31.30°C, 31.53°C, 31.38°C, 31.32°C respectively. The highest increase in minimum temperature at the rural station perceived in spring season where observed the increasing trend 1.53°C, but in the winter season, where it shows the decreasing trend in the same station.

This investigation also measured the impact of urbanization on mean minimum temperature was greater than on mean maximum temperature. The outcomes also demonstrates that there is no basic change in mean minimum and mean maximum temperature of Lahore at the airport climatic station. The significant change brings up in minimum temperature is seen after 1990 in which the urban population reached to 5 million as compared to 1950 have the 0.857 million. However, the built up area was also increased from 66km² to 740km².

The massive increase in the numbers of vehicles

during the periods 1992-1999 with 216,458 to 342,143 vehicles. This increase in numbers of factories also contributed to increase in minimum temperature that affects the maximum and annual temperature. The massive increase can be noted from trend after 2007.

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