ANALYSIS OF SEASONAL AND ANNUAL TEMPERATURE AT LOCAL SCALE: A CASE STUDY OF LAHORE

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ABSTRACT: This study is an effort to conduct an analysis of annual and seasonal temperature trends of the most rapidly urbanizing city- the Lahore, Pakistan. Therefore, this study examined the climate induced fluctuations, primarily, mean minimum and mean maximum temperature. The data were collected from Pakistan Meteorological Department (MPD), Lahore, from 1980 to 2018 (38 years) and temperature tendency was evaluated by employing the statistical techniques. The results of mean minimum temperature were indicating the upward tendencies with slight or major positive change for the whole duration ranging from 0.0207 to 0.293 °C per year. The change rate of mean maximum annual temperature was 0.693 which was showing positive change of data, while the upward trend range around 30 to 31°C in the study span. Annual and seasonal values of mean maximum temperature were showing the increasing trend of temperature, except winter, which was having a slight negative trend. The results were evident signified the climate change effects; and these adverse impacts can be mitigated with Nature Based Solutions as adaptive measures. Nature Based Solutions with green and blue can lower the temperature and alleviate climate change consequences. So, this study can be helpful for future research and urban projects for the sustainability of the environment especially, "Ravi River front Urban Project" by Govt. of the Punjab.

Keywords: Spatio-temporal, Urbanization rate, Climate change, Tendency, Adaptive measures, Nature Based Solutions.

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INTRODUCTION

Global temperature is getting warmer since 1906, while average surface temperature has increased by more than 0.9ºC, and the same has been observed in the polar areas of the world. Subsequently, glaciers and icebergs are also melting, and precipitation patterns are changing through the globe. This has made animals to shift their habitat because of ever-increasing heat waves (Horan, 2019). The phenomenon of ongoing global warming is the consequence of anthropogenic activities that occurred from the mid of 20th century, which are increasing at an extraordinary rate (Stocker *et al*., 2013).

Temperature variation has been affected by the climate, which has an important and long-lasting change in the global climatic condition. The change in the climate is observed because of many happenings across the globe. However, the most important is the massive overuse of carbon dioxide (CO2), chlorofluorocarbons (CFC's), methane and other harmful gases. Such gasses are also known as Green House Gasses (GHGs) that play an important role in creating a dense layer around our atmosphere, allowing the ultraviolet radiation (UV rays) released from the sun to penetrate the earth's surface. Thus, preventing the radiation re-emitted from the Earth's surface from escaping back into the space. This results in a general increase in the temperature of Earth. This phenomenon is referred as the Greenhouse Gas Effect (GHGs) and it is a natural process, but humans have played a vital role in increasing this effect in many folds. Therefore, the temperature of the earth is increasing, causing global warming and climate change. Global warming is a slow increase in the earth's temperature when an enormous amount of heat energy is confined inside the earth's surface and not emitted into space (Mobeen *et al*., 2017). Moreover, the Inter-annual summer climate irregularity in Europe and other areas of mid-latitude is because of the Greenhouse gas concentrations. These areas are having regular heatwaves and constant increasing variability in the summer temperatures(Seneviratne *et al*., 2018).

Along with other activities, urbanization is the most important factor which has remarkably influenced the climate structure (Bright *et al.*, 2017). Urban centers have a higher temperature than neighboring rural areas owing to the absorption of radiative properties and heat of the impermeable surface (Estoque *et al*., 2017). This change of temperature occurs due to the urban growth, which transforms the cropland and natural vegetation into built-up areas having asphalt, concrete and metal surfaces with zero evapotranspiration capacity (Shen *et al*., 2016). Urban growth increases the built-up area and

impermeable surface, which generate urban heat islands phenomena and escalate the temperature of urban areas (Chun and Guldmann, 2014). Dash and Mallick (2017) investigated the association between urbanization and temperature increase in an empirical study, during the period from 1990 to 2012. They found the positive relationship between urbanizing process and increase of average temperature across the Middle Eastern region. Similarly, Sertel *et al*., (2011) concluded that the urbanization had amplified the average temperature of Turkey, for this conclusion they employed the simulation results with the Weather Research Forecasting (WRF) regional climate model. Greenhouse gases emission is directly associated with the increase of urbanizing development (Aung *et al*., 2017).

Asia is the most vulnerable continent in terms of climate change as it is the hotbed for population increase and unplanned urbanization. It is measured that in Asia, figures of cold days and nights have decreased and warm days and nights have increased along with an increase in heatwave events in numerous parts of Asia since mid of 20th century (Crowley and Nakamura, 2018). Climate change is predominantly affected by the entire store of GHGs in the atmosphere, not by the annual release of GHGs. The developed, countries are accountable for about 75% of the overall stock of GHGs (Pachauri *et al*., 2014). Pakistan is one of the most vulnerable Asian country which is exposed to the climate change as its economy is highly dependent on agriculture and forestry, which are conditional to climate. Moreover, its population is living in deltas, which are under threat of flooding. In Pakistan, the annual mean surface temperature is continuously increasing since the start of the 20th century (Asif, 2013). Climate change in Pakistan is significant as South Asian countries are more vulnerable to it. In these countries, the dense population and increasing number of individuals living in an area have led to an escalation in removing the vegetative cover. Large areas have been cleared up for infrastructure, housing schemes, industries, factories and roads for transportations. These clearings are inversely proportional to the area covered with vegetation. The more land is cleared up, and lesser would be the area left for growing vegetation.

Lahore is the second largest city of Pakistan and it has been facing major challenges in climatic change issues. Excessive urbanization of Lahore has deteriorated its climate. The temperature of Lahore is indicating the continuous rising trend, which was nonstop and consistent after the 1980s. Mean Annual Temperature (MAT) has increased up to 0.89 °C from 1950 to 2007. More and more people are shifting to Lahore for employment, better health and educational facilities. Subsequently, to meet the necessities of residents, large areas covered with vegetation are cut down to convert into housing schemes, infrastructures, industrial zones and roads for transportation. Vehicles have also been used largely, which instigates the excessive combustion of fossil fuels, i.e. petroleum products like kerosene, gasoline, diesel and natural gas etc. producing the accelerated amount of carbon-containing gases in the atmosphere and increasing temperature (Sajjad *et al*., 2009; Shirazi and Kazmi, 2016; Abbas and Mayo, 2020a).

Consequently, a populated city like Lahore is facing harsh weather conditions as the number of summer days has prolonged and become hotter and drier. In contrast, winters are cold and dry with little or no rainfall. Moreover, for the past few years, Lahore is dealing with smog, produced from excessive amounts of air pollutants and dust particles. As a result, it affects the lungs, causing asthma, bronchial infections and causes irritation in eyes and hence human health is affected (Abbas, 2013; Abbas *et al*., 2018).

It is important to note that the world's urban population is almost 55%, and it is expected that it will upsurge about 68% in 2050 and 90% urbanization will take place in Asia and Africa (Nations, 2018). Pakistan is facing a great climate change confrontation and the fastest urbanization process and It has been recognized as the most urbanized country (with 3% urbanization rate) among developing countries of the world (Kugelman, 2013, Chaudhry, 2017). In 1970, according to World Urbanization Prospectus Report, Lahore city did not exist in the list of most populated cities whereas, in 2018, it was on 26th number and will jump to 18th position by 2030. Since, Lahore is considered to be at the second position in comparison with other cities as per the rate of urbanization (Malik *et al*,.2010).

Expanding urbanization and hovering temperature of Lahore are linked with each other. Therefore, the present study has been conducted to evaluate the temporal trends of temperature at local scale level of Lahore city, which is one of the fast growing mega polis of the country in the wake of rapid and unplanned urbanization. It is believed that due anthropogenic activities the temperature of Lahore is raising.

MATERIALS AND METHODS

The study area, Lahore is the provincial capital of Punjab and second largest city of Pakistan. Lahore Development Authority (LDA) has given it the name of Lahore Metropolitan Area LMA (NESPAK, 2004). Geographical coordinates of Lahore are 31° 15′-31° 45′ North and 74° 01 ′-74°39′ East. It is situated on the flat alluvial plain, on the left bank of River Ravi. Lahore covers approximately 1772 sq. Km and has an elevation of 217m above mean sea level (GOP, 2002). The Sheikhupura District bounds Lahore on northern and western sides, Kasur is on the southern side, and Wagha

Boarder surrounds the eastern boundary. The climate of Lahore is hot semi-arid. Summers are always long and excessively hot beginning from April and last till September. The temperature of Lahore is extreme in May, June and July. It can rise to 40-48 °C. Maximum temperature 48.3 °C was recorded on 30th May 1944 and again on 10th June 2007, which was 48 °C. Monsoon season takes place from late in June and remains till mid-September. December and January are the coldest months. Lahore had experienced the lowest temperature -1.1°C on 13th January 1967. On 13th August 2008, maximum rainfall of 24 hours was 221 millimeters (8.7in.). The population of Lahore is approximately 12,642,423, according to the, UN, World urbanization prospects (DESA, 2018).

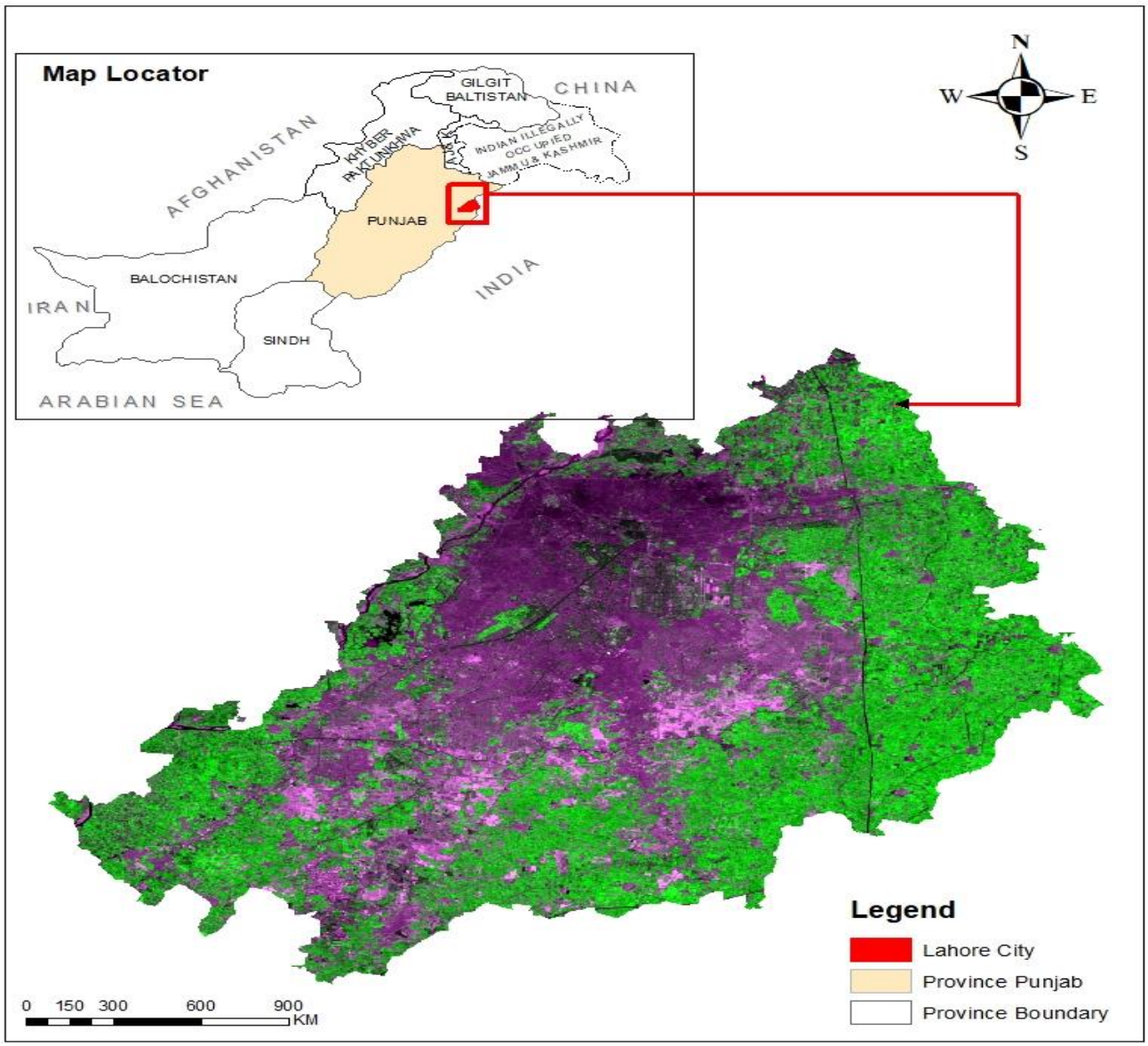

Figure 1. Location of the Study Area, Lahore

In this research work, data were collected from the Pakistan Meteorological Department (PMD Lahore, to investigate the temporal variability trend of temperature. The study period was from 1980 to 2018. Data were included seasonal, minimum and maximum average annual temperature. Statistical test trends give the essential perception of quantitative conclusions to the researcher for the procedures.

The statistical techniques have applied to investigating the seasonal-to-Inter annual temperature variability in Lahore. For the empirical investigations, quantitative estimation of minimum and maximum, simple linear regression and descriptive statistics is used.

In spite of the mean and standard deviation, the coefficient of variation has been also measured which is known as a relative standard deviation, a standardized measure of dispersion of a probability or frequency distribution. Coefficient of the variation is described as the ratio of the standard deviation to the mean. For the linear regression analysis, temperature applied as the dependent variable. The time duration applied as an independent factor in years (Time unit). Beta value is used to observe the rate of change of climate parameters (Abbas et al., 2016). The empirical investigation is performed by applying the linear regression in many studies (Wilks, 2011; Abbas *et al*., 2018, 2020b). Wilks, (2011) explained the linear regression statistically.

$Y = a + bx + e$ …… (i)

where,

Y = dependent variable as a finding of temperature of Lahore a) Minimum b) Maximum. X = Time duration of the year. The a+bx = association 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 = variation in the average value of independent factor, however the X value rises

e = calculates the error randomly between duration

Y = dependent or Predict and e is the errors. The vertical distance between data points and lines called errors or residue.

Ei = yi – y (xi)……..(ii)

This is the separated residuals for each data pair. For the analytical expression, The least square intercept a and slope b is a straightforward exercise in order to minimize the sum of squared residuals. The slope value of the regression indicates the changes in the time series (Jolliffe and Stephenson, 2012).

RESULTS AND DISCUSSION

The mean, maximum and mean minimum temperature values of meteorological data were analyzed seasonally and annually to investigate the impact of climate change on temperature fluctuations due to haphazard effects of urbanization.

In table1, Min indicates the minimum, Max ; maximum, SD; Standard deviation and CV ; coefficient of variation. Variability of vicissitudes has been observed in the mean annual temperatures from 1980-2018. The highest value of maximum average temperature (Tmax) around 32°C was observed during 1986 and1987 while lowest Tmax of 28.5°C was observed during 1997. The value of β as 0.693 was showing the slight positive change of data while upward trend, ranging around 30°C from 1980 to 31°C until 2018 was presented in this study. No major ups and downs were observed in the summer season where linear presentation with a minute change and β of only 0.005 was observed with a range of Tmax as 35.5°C in 1980 and 35°C in 2018. In Spring, though a significant temperature increase from 1980 to 2018 was observed, as Tmax was around 32 °C, its average was shown to be 35 °C in subsequent years. In winter, slight negative change in -0.053 β value was observed with a drop of around 1°C from 1980 to 2018 and that was depicted in the picture below.

Minimum average temperature (Tmin) was observed either using year wise data or seasonal data clearly showing the shift of Tmin to the higher side of temperature from 1980 to 2018. All the trends were on the upward tendencies with slight or major positive change.

Likewise, Asian Development Bank has explained in a report that the annual average temperature of Pakistan has been increased about 0.5℃, in last 50 years. The annual amount of heat wave days has increased approximately quintuple in past 30 years. In that report, it was estimated that Pakistan's mean temperature will escalate near 3 °C to 5 °C per year, around the turn of the century.

Lahore is the populated city of Punjab and it has been facing major challenges regarding increase in temperature. Increasing trend of urbanization has deteriorated its infrastructure and leads towards the major issue of climate change. Mean Annual Temperature (MAT) has increased up to 0.99 °C from 1980 to 2018. Successively, to meet the necessities of residents, large greenspaces areas converted with housing schemes, infrastructures, industrial zones and roads for transportation. Vehicles have also been used largely, which instigates the excessive combustion of fossil fuels which producing the accelerated amount of carbon-containing gases in the atmosphere and increasing temperature (Sajjad *et al*., 2009; Shirazi and Kazmi, 2016; Abbas and Mayo, 2020a). Additionaly, Lahore is also dealing with smog, produced from large amount of dust particles. As a result, it affects the lungs, causing asthma, bronchial infections and causes irritation in eyes and hence human health is affected (Abbas, 2013; Abbas *et al*., 2018).

Table 1: Annual and seasonal trends of temperature over Lahore, Pakistan.

Year	Minnimum	Maximum	Mean	SD	CV%
1980	23	47	35.25	7.8175	0.221774
1981	23	45	34.67	7.6555	0.220831
1982	23.5	44	34.15	7.1568	0.209568
1983	23.2	44.3	34.21	7.2096	0.210757
1984	22.9	46.1	35.15	7.5436	0.214613
1985	25	44.1	36.31	6.4868	0.17866
1986	22	46.4	34.78	7.6391	0.219674
1987	25	46	36.41	7.5044	0.206116
1988	25.2	47.4	36.03	7.6071	0.211161
1989	22.6	45.2	35.28	7.4631	0.211519
1990	25.7	44	34.91	6.7448	0.193213
1991	26.5	44.5	35.66	6.3948	0.179336
1992	24.4	45.7	35.03	7.0461	0.201126
1993	25.5	46.8	36.63	7.1176	0.194337
1994	24.2	46.4	35.13	7.5487	0.214858
1995	24.7	47.1	34.93	7.5123	0.215048
1996	23.2	44.9	34.76	6.7904	0.195361
1997	23.7	43.2	33.94	6.9384	0.20442
1998	21.7	45.6	35.20	7.3243	0.208077
1999	21.5	44	35.24	7.4296	0.210819
2000	24	43.8	34.91	6.7652	0.193799
2001	26	46	35.25	6.3725	0.180779
2002	24.1	45	35.38	7.0973	0.200629
2003	23	45.4	34.48	7.0884	0.20561
2004	23.2	45	35.20	6.7517	0.19181
2005	20.7	45.2	33.65	7.5774	0.225183
2006	23.4	44	34.65	6.9826	0.201519
2007	24.6	47	35.19	7.1387	0.202852
2008	21	42.9	34.77	6.3073	0.181419
2009	22.7	44.3	35.46	7.245	0.204324
2010	24	46	35.22	7.2012	0.204484
2011	22	44.2	34.56	7.1484	0.206849
2012	21.5	46	35.02	8.1708	0.23334
2013	23.2	46.5	34.18	7.4948	0.219254
2014	24.2	46	34.82	7.5491	0.216824
2015	22.7	42.8	34.75	6.7137	0.1932
2016	23.5	45.5	35.38	7.2123	0.203834
2017	23.2	45.3	35.54	7.4318	0.209101
2018	24	44	35.51	6.6135	0.186253

Source: Pakistan Meteorological Department, Lahore

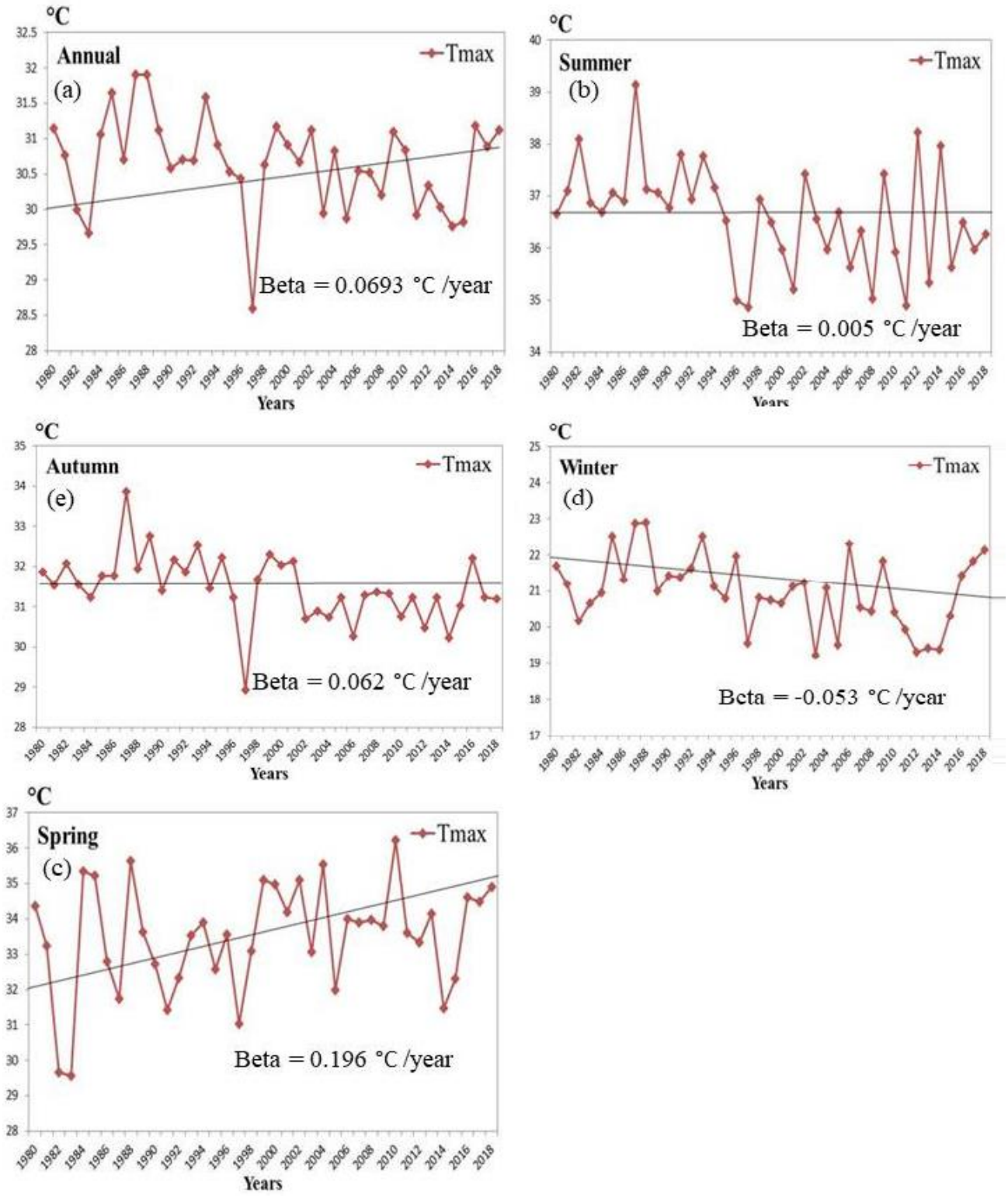

Figure 2. Annual and seasonal trends and variability of maximum temperature over the Lahore

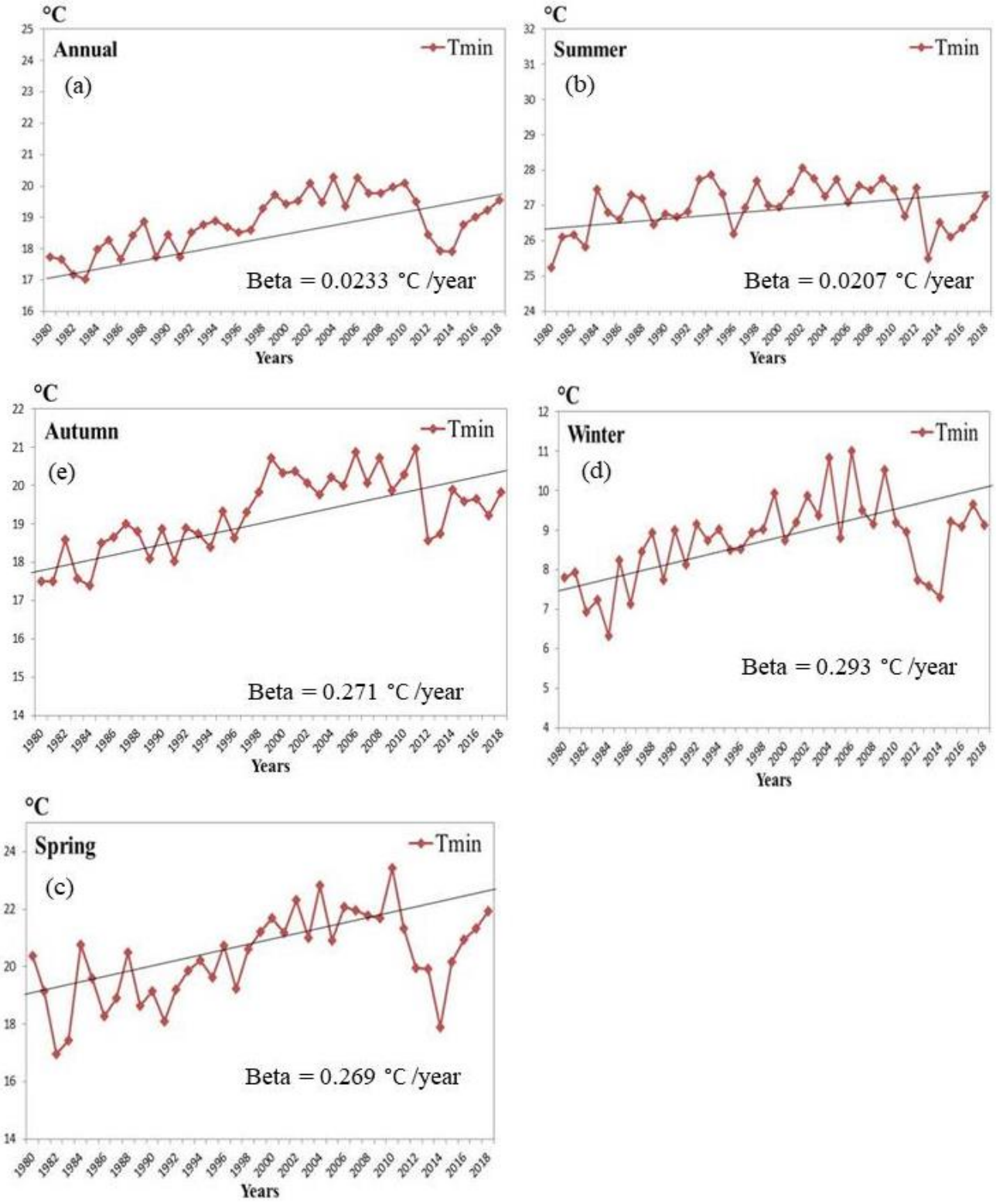

Figure 3. Annual and seasonal trends of minimum temperature over the Lahore

Conclusion: The escalating temperature had become a persisting phenomenon and that had adversely affected the micro climate of Lahore. Those adverse effects of climate change can be mitigated by

incorporating Nature Based Solution (NBS) in the form of establishing green and blue structure in the City. Similarly, a substantial addition of NBS by planting vegetation on all available spaces, like the ground, walls, rooftops, balconies and even indoor plants and by making ponds and lakes in empaty areas of the city even rainfall water that cause urban flooding can be stored. Vegetation cover and water bodies are two natural remedies that can mitigate the adverse impacts of climate change and make the local climate pleasant and comfortable.

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