THE LONG-TERM VARIABILITY IN MINIMUM AND MAXIMUM TEMPERATURE TRENDS AND HEAT ISLAND OF LAHORE CITY, PAKISTAN

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ABSTRACT: *The second largest city of Pakistan is Lahore which has population of 10 million. The purpose of this research work is to study the annual and seasonal trends of surface temperature of two stations of Lahore one located in center of the city and another one at airport of Lahore about 10 km away from the first site. The temperature data of minimum and maximum collected from Pakistan Meteorological Department (PMD) was analysed by using linear regression. The results show that at both stations minimum temperature is increasing more than maximum temperature. While maximum temperature at both station is not increasing significantly. The highest increase in minimum temperature is measured in spring season.*
Key word: *urbanization, local climate, population change, PMD, Urban Heat Island*

1. INTRODUCTION

In recent decades, human activities have significantly altered and changed the ground cover all over the world such as rapid urbanization, increasing environmental pollution and deforestation [1]. The significant change on land surface is rapid urbanization which is highly affecting the local climate in special and global climate in general. So the urban areas' effect on local climate is becoming an important issue as it cause urban heat island phenomenon in urban areas [2]. Presently, this issue is attracting significant attention [3] of researcher, planners and policy makers toward sustainable urban habitat. Many of the world cities are considered as the major anthropogenic sources of heat and pollution through different sources, utilization of energy and performance of economic activities. In addition, in most of the city centers, major part of the buildings, roads and other infrastructure is covered by asphalt and concrete material. These dry and water-proof surfaces with less albedos and higher heat absorption capacities store incoming radiation as sensible heat better than the surrounding countryside [4]. Many of the world cities are highly vulnerable to urban climate change and urban heat island (UHI) effect. A "heat island" is characteristics of whole or part of the city which is comparatively warmer than its nearby surrounding rural area. UHI varies from season to season and day to day. The urban areas' temperature can be 2–6°C higher in hot seasons [5] and can be 13°C higher in winter hotter than the surrounding countryside. The phenomenon of UHI can't be confused with global warming as it has separate mechanics of formation and effects on local scales and scientists call it the "urban heat island effect."

Various studies show the effect of local areas' effect on local temperature trends. World Meteorological Organization presented that the mean annual temperature of Sao Paolo has been increased to about 2°C [6]. Another study about mean annual mean minimum temperature of South Korea highlights that it has increased due to rapid urbanization in major part of the country. Chung *et al.* elaborated that as compare to all the cities of South Korea, the highest increase in population is seen in Seoul, whereas daily minimum temperature increased by 0.7°C higher than the nearby surrounding rural sites [7]. On other hand, strong positive correlation between UHI intensity for minimum temperature and increase in the urban population and the expansion of the yearly construction area in Beijing is measured [8]. Du et al. (2007) highlighted that UHI effect made the regional annual mean air temperature increased 0.072°C from 1961 to 2005, of which 0.047°C from 1991 to 2005, and the annual maximum air temperature increased 0.162°C, of which 0.083°C from 1991 to 2005, all these indicating that the urban expansion in the Yangtze River Delta (YRD) in China from 1991 to 2005 may be regarded as a serious climate signal [9]. The observational studies based on direct measurements of climatic variables indicate that during calm and clear nights, UHI is prominent and its intensity can exhibit diurnal and seasonal cycles e.g. [10, 11, 12].

In Pakistan, Lahore is the second largest city. It is the city of almost 8 millions of population. Most of the city is condense in respect of population and is spread over an area of 1,772 km^2. The huge population of the city has almost greater effects on its local climate. This paper describes the long term surface urban heat island (UHI) effect of Lahore. In section 2 of the paper data and methodology, in section 3 results and discussion and in section 4, conclusion is given.

2. DATA AND METHODOLOGY

2.1 Case study area

For this study, Lahore is selected as the case study area. It is located on eastern side of Punjab province with geographical coordinates of 31°32′59″N and 74°20′37″E. The area has flat surface and surrounded by fertile alluvial plains. In 1972, the city has a population of 2.17 million which has reached to 9.75 million in 2014 with an increase of 350 per cent in four decades. The demand of residential sites had been increasing with increasing urban areas' population. In 1972, land surface area covered by built-up area of Lahore city was just 103.42 km^2 which has increased to 1772.53 km^2 in 2012 with an increase of 1613 per cent with in four decades (Fig. 1). The increasing population and changing land-cover of Lahore has adverse effects on local climate. Growing demand of the buildings for residential and administrative purposes has expanded the city towards all sides and mainly toward south east of the city [13].

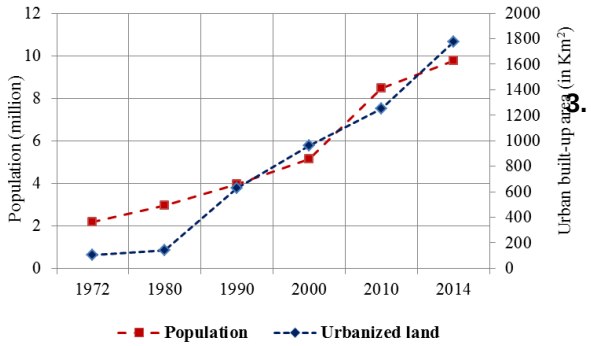

Figure 1: Populaion and urbanized surface area of Lahore since 1972 to 2014.

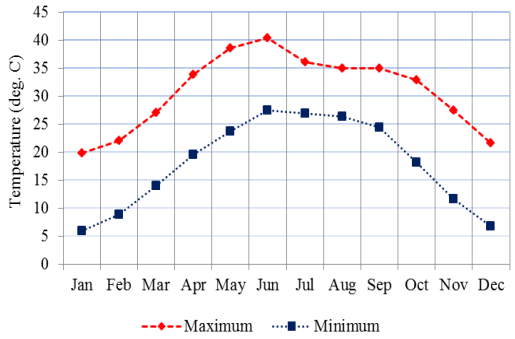

Figure 2: Monthly average minimum and maximum temperature of Lahore.

Lahore is located in area having semi-arid type of climate. In summer (June, July, August), average temperature exceeds to 40 °C and in winter it reaches to freezing point with dense fog conditions (Fig. 2). Most of the precipitation is received during monsoon season that starts in late June and ends up to September.

2.2 Data type and method of data analysis

For this study, mean average monthly data of maximum and minimum temperature data of two observatories located in Lahore was collected from Pakistan Meteorological Department of Pakistan. One observational site is located at Shadman and the other one is located at Lahore Airport. The former is highly urbanized area with urban surface structure and the later is located at airport in the periphery of Lahore city and is considered as rural station with rural type of surface structure. The distance between the two stations is about 10 kilometer. The mean monthly minimum and maximum temperatures data of these two stations for the period of 1972 to 2011 is analysed by using simple regression method in which temperature is used as dependent variable while the time period is used as an independent variable. By using this technique, the change in minimum (dT_{min}) and maximum dT_{max} temperature of Lahore in computed. The UHI is considered as nonlinear function of population that is measured as:

$$\Delta T_{u\text{-}r} = a(pop)^b \qquad (1)$$

where $\Delta T_{u\text{-}r}$ is the yearly mean temperature difference (°C) between urban station and Lahore Airport, *pop* is the urban population and *a* and *b* are the constants. For long term measurement of UHI at Lahore, we have used this formula to study how the local temperature is being affected by urban area.

3. RESULTS AND DISCUSSION

3.1 Seasonal Changes

In figure 2, seasonal changes in minimum and maximum temperature of Lahore (urban) station and Lahore (rural) station are given. The temperature for all the seasons is given in anomalies because the temperature anomalies can be compared on a month by moth or season by season basis, in a way in which absolute numbers can't. The regressed results of each season are given in Table 1 and Table 2 shows the net change in minimum and maximum temperature over 40 years. At both stations, minimum and maximum temperature had been increasing at different rate except winter temperature at Lahore airport. It is highly important to note that minimum temperature increased more at urban station than rural site located at airport. On the other hand, over period of 40 years, there is not significant change in maximum temperature at the both stations.

In Table 1, it can be seen that the highest growth observed in temperature at urban station over the studied period is measured winter and spring where it increased 3.24°C during the both seasons and the lowest is observed during summer where it is computed only 0.98°C during 40 years. On other hand, at Lahore airport, the highest increase in minimum temperature is observed in spring season where it is calculated 1.4°C while at this station minimum temperature during winter has shown decreasing trends.

Table 1: dT_{min} and dT_{max} over the period of 40 years (1972-2011) at Lahore urban station and Lahore airport station.

Period	dT_{min}/4 decades		dT_{max}/4 decades	
	Lahore (PBO)	*Lahore (AP)*	*Lahore (PBO)*	*Lahore (AP)*
Annual	2.68	0.64	-0.404	0.928
Winter	3.248	-0.064	-0.364	0.736
Spring	3.24	1.4	1.072	2.544
Summer	0.98	0.408	-1.248	-0.016
Autumn	3.184	0.824	-1.084	0.448

Table 2: Regression results of temperature of Lahore urban station and Lahore airport during 1972 to 2011.

Period	Minimum temperature		Maximum temperature	
	Lahore (PBO)	*Lahore (AP)*	*Lahore (PBO)*	*Lahore (AP)*
Annual	y = 0.067 R^2 = 0.73	y = 0.016 R^2 = 0.10	y = -0.0101 R^2 = 0.0372	y = 0.0232 R^2 = 0.18
Winter	y = 0.0812 R^2 = 0.69	y = -0.0016 R^2 = 0.0005	y = -0.0091 R^2 = 0.014	y = 0.0184 R^2 = 0.07
Spring	y = 0.081 R^2 = 0.43	y = 0.035 R^2 = 0.1189	y = 0.0268 R^2 = 0.0443	y = 0.0636 R^2 = 0.19
Summer	y = 0.0245 R^2 = 0.2121	y = 0.0102 R^2 = 0.0598	y = -0.0312 R^2 = 0.1503	y = -0.0004 R^2 = 3E-05
Autumn	y = 0.0796 R^2 = 0.6996	y = 0.0206 R^2 = 0.0814	y = -0.0271 R^2 = 0.1627	y = 0.0112 R^2 = 0.04

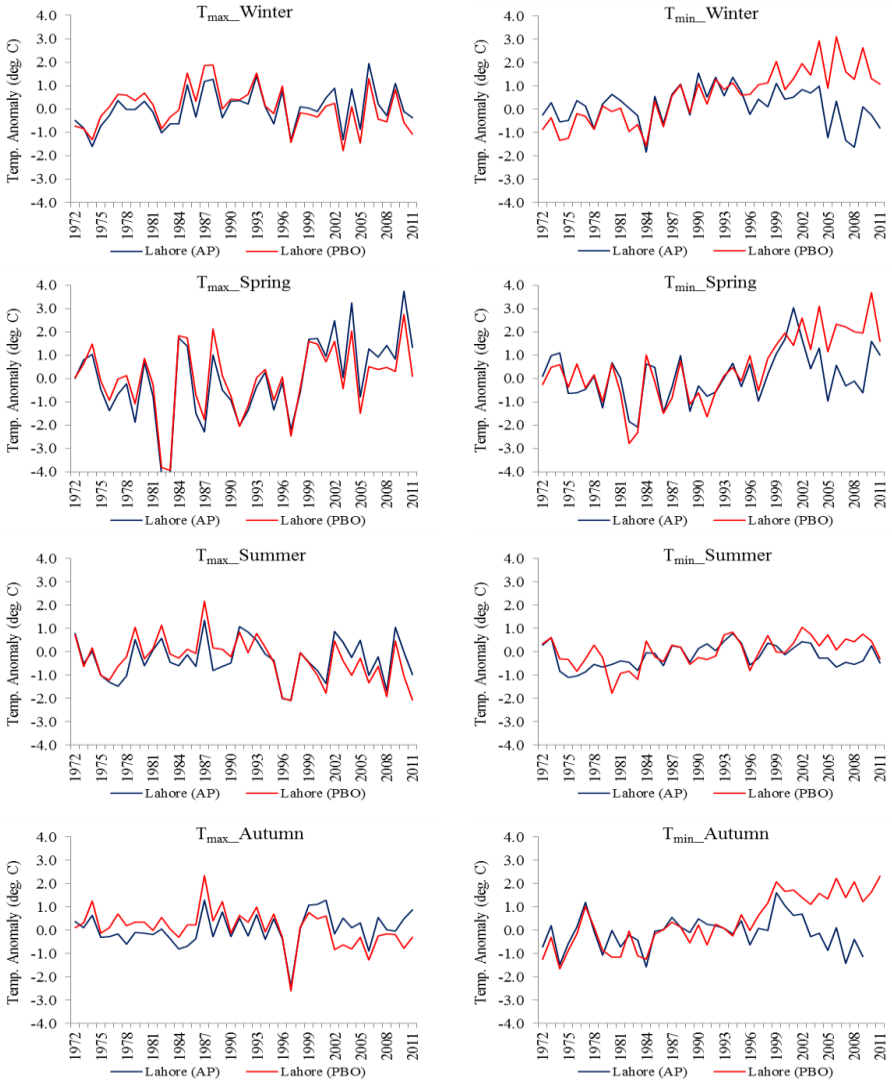

Figure 3: Representation of dT_{min} and dT_{max} of Lahore urban station (given in red solid line) and Lahore airport (blue solid line) for the period of 1972 to 2011.

3.

2 Annual changes

Figure 3 intricate the analysis of minimum and maximum temperature of the both stations. The results of the moving trends show the higher increasing tendency in temperature at urban area whereas this change is observed higher after 1998, the warmest year of the history. Since 1972 to 1997, there is less difference in temperature of the two stations while it had been increasing faster after 1998 especially at urban station.

Figure 4 is elaborating the variability in mean annual minimum and maximum temperature of both urban and rural type stations. The figure highlight that the after 1995, minimum temperature started to increase faster as it was the era of speedily urban development of Lahore city.

Figure 5 is highlighting the effect of urbanization in respect of increasing population. There is observed an analogous proportion in increase of minimum temperature of urban station and population of Lahore city throughout the deliberated period. The minimum temperature had been escalating as the population had been increasing. The noteworthy propensity of raise in minimum temperature is glimpse after 1990s in which the urban population amplified to 5 million which was just 0.8 million in early 1950s.

Figure 5 highlights the long-term UHI of Lahore by comparing the temperature of two stations of Lahore (urban – rural) where urban site is at Shadman and rural site is at Lahore airport. It is observed that difference in minimum and maximum temperature between urban and rural area is mounting due to effect of urban heat island phenomenon. Figure 6 explains the rapid land-use change and population growth and its relationship with changing temperature. As the vegetation cover is transformed into built-up area, it has higher effect on minimum temperature than maximum temperature. It also highlights that urban sprawl in term of increasing built-up area and population, is affecting minimum temperature more than maximum temperature.

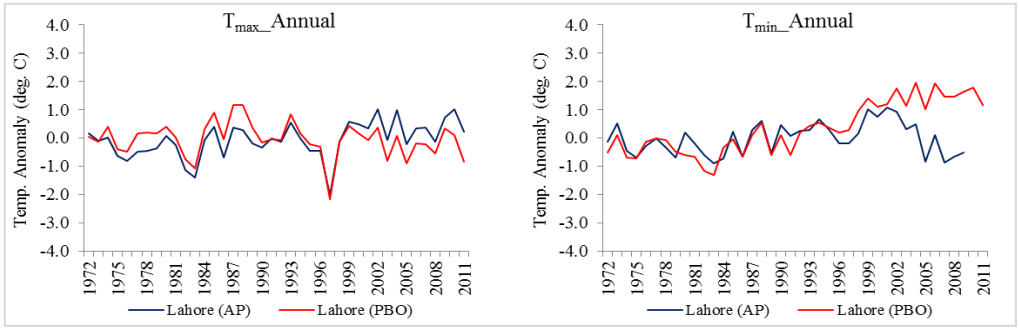

Figure 4: The mean maximum temperature variations of Lahore at Lahore Airport and Shadman observatories.

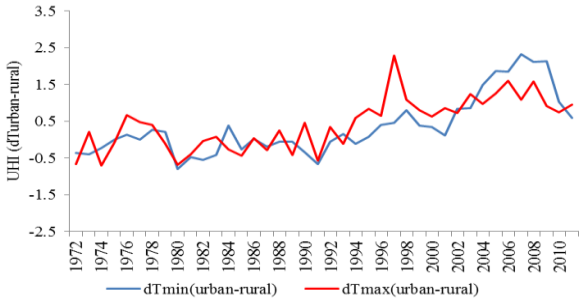

Figure 5: Long term difference in urban and rural site minimum and maximum temperature trends to represent long term UHI.

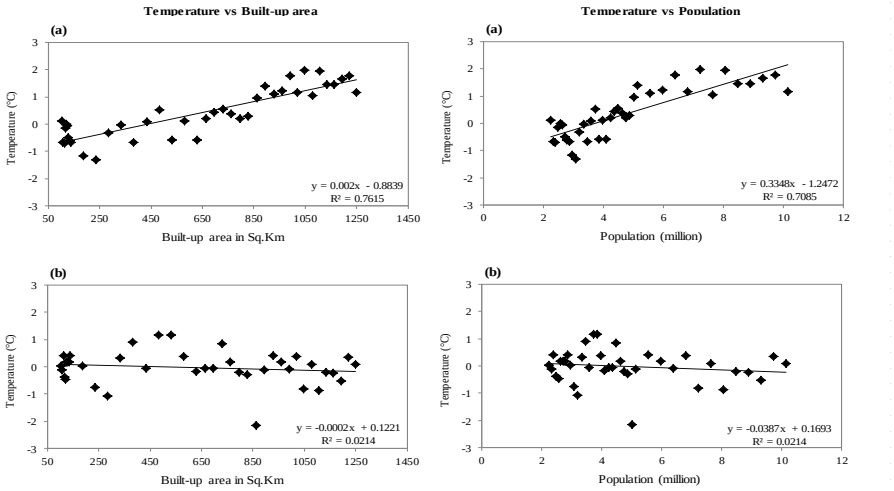

Figure 6: In left panel is given the change in minimum (a) and maximum (b) temperature as a function of built-up area of Lahore from 1972 to 2010 and in right panel is given the change in minimum (a) and maximum (b) temperature as a function of built-up area of Lahore from 1972 to 2010.

4. CONCLUSION

The awareness about the urban environment is being one of the striking issues not only for the developed world but especially for the developing countries. Pakistan is the country with 180 millions of population and where 72 million of people live in urban areas. The mass growth of urban areas has started to show its impacts on local urban climate. Lahore is one of the major cities of Pakistan which is also found at the risks of increasing UHI as compare to its nearby areas.

In the present study, the data of minimum and maximum temperature collected from Pakistan Meteorological Department was analyzed by using linear regression. The results highlighted that minimum temperature increased more than maximum temperature at urban station and at airport; there is no significant change in minimum and maximum temperature. The maximum temperature is not increasing significantly at both stations. So the mean maximum temperature has not significant effect throughout the calculated period except from 1974 to 1993.

REFERENCES

[1] Chung, Y-S., Yoon, M-B., and Kim, H-S., "On climate variations and changes observed in South Korea", Climatic Change, 66(1-2): 151-161(2004).

[2] Liu, W., You, H., and Dou, J., Urban-rural humidity and temperature differences in the Beijing area, Theor Appl Climatol, Volume 96, Issue 3-4: 201-207(2008).

[3] Catherine, S. and Sue, G., "Applied climatology: urban climate," Progress in Physical Geography,

30(2): 270-279(2006).

[4] Lin, N., Zhou, Z., and Zhu, L., "An analytical study on the urban boundary layer," Advances in Atmospheric Sciences, 15(2): 258-266(1998).

[5] Alam, M. and Rabbani, G.M.D., "Vulnerabilities and responses to climate change for Dhaka," Environment and Urbanization, Vol. 19(1): 81-97(2007).

[6] WMO, "Proceedings of the technical conference in Mexico City: urban climatology and its applications with special regard to tropical areas. Some aspects of the urban climates of tropical South America: the Brazilian contribution," WMO – No. 652. 166-198(1986).

[7] Chung, U., Choi, J., and Yun, J.I., "Urbanization effect on the observed change in mean monthly temperatures between 1951-1980 and 1971-2000 in Korea," Climatic Change 66: 127-136(2004).

[8] Liu, W., Ji, C., Zhong, J., Jiang, X., and Zheng, Z., "Temporal characteristics of the Beijing urban heat island," Theor. Appl. Climatol. 87: 213-221(2007).

[9] Du, Y., Xie, Z., Zeng, Y., Shi, Y., and Wu, J., "Impact of urban expansion on regional temperature change in the Yangtze River Delta." Journal of Geographical Sciences, 17(4), 387-398(2007).

[10] Ackerman, B., "Temporal march of the Chicago heat island,". J Climate Appl Meteor 24: 547-554 (1985).

[11] Jauregui, E., "Heat island development in Mexico City," Atmos Environ 22: 3821-3831(1997).

[12] Montavez, JP., Rodriguez, A., and Jimenez, J.I., "A study of the urban heat island of Granada." Intl J Climatol 20: 899-911(2000).

[13] Shirazi, S.A., and Kazmi, S.J., "Analysis of Population Growth and Urban Development in Lahore-Pakistan using Geospatial Techniques: Suggesting some future Options." South Asian Studies, 29(1), 269-280(2014).