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Monitoring Temperature Variations and Urban Heat Island of Lahore, Pakistan

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Abstract: The phenomenon of Urban Heat Island (UHI) is a result of various factors ranging from increase in urban built-up land to human activities and has affected the climate in urban areas. Therefore, the main objective of the current study is to monitor the temperature variations and assess the UHI in Lahore city. In order to calculate the temperature variations and UHI, the meterological data were collected by installing Weather station 1080, at two selected sites of Mozang (urban site) and Sarang (rural site) from January 15 to 18, 2015 (4 days) in winter season. The analysis was performed in SPPS 17 and MS Excel 2010 softwares for description of data by creating graphs, while study area map was created in ArcGIS 10.3. The results of the study reveal that notable variations of temperature were recorded between Mozang and Sarang. The mean day-time temperature (23.9°C) was higher at Sarang than at Mozang (22.8°C), whereas, the temperature at night was higher at Mozang and lower at Sarang. The R_2 value of 0.0041 also demonstrates positive relationship between UHI and dew point at Mozang. The speed and direction of wind also influences the intensity of UHI. During the observational days, the range of UHI was 4.3°C to 6.2°C. Hence, the difference between the minimum and maximum temperature was almost 2°C which indicated that the UHI was enhancing. Lastly, few suggestions were proposed to mitigate the issue of UHI in Lahore district.

Keywords: Urban heat island, urbanization, Lahore, climate change, weather station 1080.

Introduction

Urban Heat Island (UHI) is a phenomenon in which temperature of atmosphere and surface is higher in urban areas than the surrounding rural areas. This phenomenon is mostly pragmatic in cities, irrespective of their size and location (Connors et al., 2013). The UHI is mostly caused due to the adaptation of earth surfaces by urban development. Moreover, an increase in built-up land and anthropogenic activities are also responsible for UHI (Yang et al., 2016). It has created an unintentional climatic modification due to urbanization that changes the temperature with the growth of cities and may also affect the temperature trends by accumulation of short-wave radiation (Voogt, 2004; Solecki et al., 2005; Brandsma and Wolters, 2012). Ratio of urbanized versus green places for every entity spot, atmospheric surroundings (e.g., humidity, wind, temperature) and social and economic actions verify the development of the UHI (Huang et al., 2011). With the increase of urbanization, the land area which is covered with trees, shrubs and vegetation area is transferred into residential, pavement, and industrial area. Besides this, the dry permeable area is transferred into impermeable area, resulting in formulation of an 'island' which is warmer than the surrounding area, known as urban heat land (Lillesand et al., 2014). Particularly earth surface distinctiveness is mostly represented by land use and land cover (LULC) and as it changes, its impact is inflicted on land surface temperature (LST) and air temperature. Therefore, the link between the LST and LULC has been the centre of attention of many studies on the UHI (Buyantuyev and Wu, 2010: Pal and Ziaul, 2017). The other familiar causes of UHI in an urban centre are large buildings with thermal mugs, heat emissions, pollution and consumption of energy in a city, lack of green areas, pressure of low albedo material, pressure of low speed wind, and loss of long wave radiation at night in low rate (O' Malley et al., 2014).

The effect of UHI is different in different locations of a city. It is greater at the densest (central) part of the city having maximum temperature. The effect of UHI is classified into two major classes such as people and micro-climates. UHI is playing a foremost impact on the micro-climate, it alternates the local climate such as wind pattern, humidity, frequency of floods, storms, and local ecosystems. Moreover, it also contributes in the increase of global warming by adding greenhouse gases into the atmosphere through consumption of energy, extra use of air conditioners and heat emissions being released from the local environment (O' Malley et al., 2014). UHI is the joint reaction of several elements. Which can be classified into controllable and uncontrollable factors and subdivided into short-term

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effect variables like air speed and cloud cover and cyclic effect variables such as solar radiations and manmade heat resources (Rizwan et al., 2008). UHI has also caused greater transmission of dengue, in high temperature, low vegetated and more polluted areas i.e. the findings of a case study of Sao-Paulo (Brazil) has summarized that 7,415 cases (93.1%) of dengue were recorded at 28°C. Among these, 72.3% cases were in low vegetated cover areas and 3.2% cases in high vegetated cover areas (Araujo et al., 2015).

UHI is studied by various researchers at various times in various locations by looking at its impact on energy consumption in buildings, and its effect which increases the urban temperature and causes an increase in the demand of electricity for cooling (Kolokotsa and Gobakis, 2014). During a study conducted in Padua city (Italy), the data of air temperature, humidity and global solar radiation was acquired from the period of 2010 and 2011 and were measured from different angles across the city from city to sub-urban and rural areas. The results show the increase of up to 6°C UHI in city as compared to the sub-urban and rural areas (Busato et al., 2014). In New York, a study found the differene of temperature 2°C between the vegetated and non-vegetated areas of the city (Hafner and Kidder, 1999). Similarly, in Singapore the difference of 4°C is found between urban and rural areas (Wong and Yu, 2005). The greater contributor of UHI is the residential area followed by an industrial area (Li et al., 2011).

UHI mitigation is classified into two major classes, first by planting the trees and vegtation by providing the shade in an urban area and second by making the urban surface into white roofs and concrete material by absorbing solar radiation like two walls of houses may reduce the temperatures from 11°C to 25°C, vines on the wall reduce the temperature (20°C) and trees in the parking area reduce the temperature (25°C) to its surrouding and sub-urban area (Cleare, 2006; Doick and Hutchings, 2013). A study was conducted to mitigate the urban heat island through a global climatic model by using white roofs, and the results show that all the urban areas have decreased 33% temperature. Urban diurrnal temperature is reduced to 0.6°C while daily minimum temperature is reduced to 0.3°C, and such a difference in temperature is due to absorption of solar radiation. Therefore, the use of white roofs is beneficial for the reduction of UHI (Voogt, 2004). A study was conducted in California (USA) with over 250 participants who planted trees in gardens outside houses. An average of 3 trees were planted from a distance of 10 feet (3m) from the houses, and results showed that energy used for heating was reduced by approximately 2% and the energy that was used for cooling was saved by 1% (Solecki et al., 2005). Vegetation and water are the two ways by which UHI is mitigated. Therefore, in Phoneix city, two third of municipality water is used for the maintenance of shrubs, trees, vegetation, grass, and pool evaporation (Larson et al., 2013).

The issue of UHI in Pakistan is also accelerating, causing serious environmental and health concerns in mega urban centers e.g. Karachi, Lahore, Islamabad, Rawalpindi, Gujranwala, Multan etc. A recent study conducted in Lahore reported that just in a decade from 2000 to 2011, the temperature is raised by 0.73% in the entire city, due to the relationship of UHI and LULC (Shah and Ghouri, 2015). Minimum temperature is increasing in Lahore as compared to maximum temperature particularly in the spring season (Sajjad et al., 2015a). Similarly, a study conducted in twin cities Islamabad and Rawalpindi revealed the increase of UHI from 0.193 ± 0.0440°C during summer and 0.349 ± 0.0300°C during winter seasons (Memon, 2014). Hence, keeping in view the literature, the objectives of the current study were to monitor the temperature variations and to asses the Urban Heat Island in Lahore city.

Materials and Methods

Study Area

Lahore is the 2nd largest urban center of Pakistan having a population of 11,126,285 (PBS, 2017). Geographically, it is located between 31°15' to 31°43' North latitude and 74°10' to 74°39' East longitude. Lahore district is adjacent to district Kasur and Sheikhupura (Sajjad et al., 2009). The district has a hot semi-arid type of climate. The alarming growth rate in urban population has boosted up population congestion, environmental pollution, commuting problems and improper provision of civic services to the citizens.

Selection of Study Sites

The selection of the study sites from where the data derived is an important aspect of any study. Therefore, two sites were selected to install the weather station. A village named Sarang located in west of Lahore as a rural site and Mozang as an urban site were selected after survey of these areas. Mozang is often known as the heart of Lahore as it is a congested area and has many government and semi-government offices, shops, small industries, and the houses of employees. Traffic is also at its peak, which produces many harmful pollutants causing many diseases, which may lead to death. Energy consumption is also greater in Mozang as compared to the rural site Sarang.

Data Collection

In order to obtain temperature and meteorological data to monitor the temperature variations and UHI, the Weather Station (WS) 1080 (Digital Data Receiver) is used by keeping it in nearby places i.e. garage, open space with a specific range. It has the capacity to receive the data within the transmission range of up to 100 meters (330 feet). The relevant instrument (WS 1080) is much more reliable to collect the data, not only for this study but also for meteorological studies of various types and applications (Fig. 1). The brief specifications of the weather station 1080 are enlisted below: Table 1.

Outdoor temperature range	40°C to 65°C (104°F to 149°F)
Indoor temperature range	0°C to +50°C (-32°F to 122°F)
Humidity range	10% to 99%(1% resolution)
Rain volume	0 to 999mm show
Wind speed	0 to 100 (mph)
Transmission range	up to 100m (330 feet)

Fig. 1 Weather station 1080 used to collect meteorological data

The major data measuring instruments in the weather station were wind wane, anemometer, rain gauge, hygrometer and thermometer. For this, two ground-based weather stations were installed about 1.5 meters above the surface of the earth (as an international standard to install a weather station), one at rural site (Sarang), and another at urban site (Mozang). The data were measured with a resolution of 30 minutes of interval. The approximate distance between the urban and rural stations was measured as 13 km.

Data Analysis

After obtaining the data, the analysis of the data was performed for different time periods, which were based on:

a) Monitoring period

b) Night-time and day-time periods

It is known fact that the intensity of urban and rural temperature difference can alter on daily (or diurnal) and seasonal basis (Soltani and Sharifi, 2017). Therefore, the meteorological data were collected on diurnal basis from 15-01-2015 midnight to 18-01-2015 till midnight (96 hours or 04 days) with an interval of 30 minutes. The study period was in winter season and the selection of this short period was because of the calm winds and a clear sky during the study which helps to study the temperature variations and UHI without biases of external climatic factors i.e. hazy or cloudy weather, very strong winds etc. Finally, the data were coded and analyzed in SPSS 17 by applying descriptive statistics and correlation. The MS Excel was used for preparing graphs. Arc GIS 10.3 software was employed for creating maps.

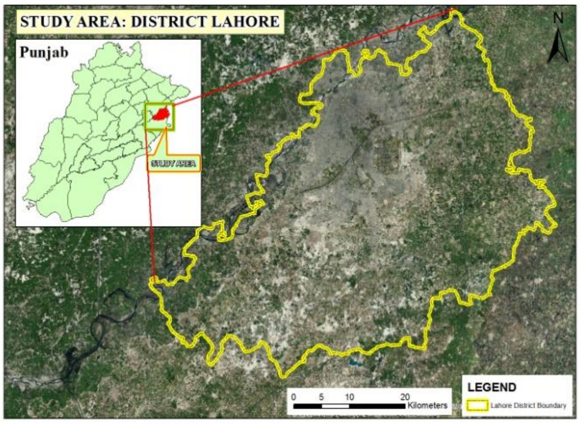

Fig. 2 Location Map of District Lahore.

Results and Discussion

Table 1 elaborates and Figure 3 visualizes the variations of the minimum and maximum temperatures of the data collected from urban and rural study sites to find out the temperature variations and subsequently the UHI of the study area. A recent study also found that the surface UHI is highly associated with the land use of the surface (Azevedo et al., 2016). The difference in maximum temperature at rural and urban sites was almost equal with the difference of 1°C. On the other hand, there was great difference in minimum temperature of rural and urban sites. The lowest range of temperature during the study period at rural site was 6.7°C to 4.8°C and highest range of temperature at rural station was 22°C to 23.9°C. The lowest range of temperature at urban station was 8.8°C to 10.8°C and the highest range of temperature was 22.5°C to 23°C. This shows the temperature difference between the rural and urban sites. This difference is also highlighted due to surface variability as the rural site has much land under vegetal cover, therefore, trees that absorb heat greatly during day, emit it in the form of moisture at night (Fig. 4). A previous study also concluded that trees and shrubs in places with greenery lessen the mean maximum daily surface temperature in the summer by 5.7°C as compared to non-woody vegetation, but are inclined to maintain slightly higher temperatures in winter (Edmondson et al., 2016). On the other hand, the urban site of Mozang lacks the green patches and vegetation, as it is a congested and populous area, occupied mostly by concrete structures, buildings, roads and traffic. A previous study in Egypt found that the mean temperature of UHI in urban areas of Al-Arbin and Al-Suez districts was 7.5°C higher than the mean temperature of the district (Ahmed, 2018).

Table 1. Minimum and maximum Temperatures of urban (Mozang) and rural (Sarang) sites during observational period.

Date and Day of the Survey	Sarang (Rural Site) Max temp. (°C)	Sarang (Rural Site) Min temp (°C)	Mozang (Urban Site) Max temp (°C)	Mozang (Urban Site) Min temp. (°C)
Thursday 15-1-15	22	5.8	22.5	8.8
Friday 16-1-15	23.7	5.6	23	9.9
Saturday 17-1-15	23.9	6.7	22.7	10.9
Sunday 18-1-15	23.4	4.8	22.8	10.7

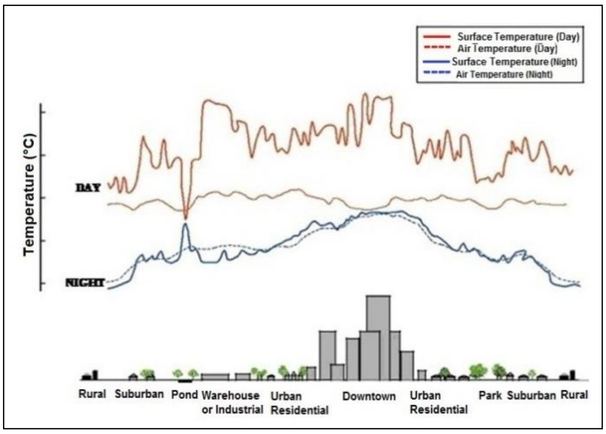

Fig. 3 Model of minimum and maximum temperature variation during days and nights of urban and rural areas (modified from Voogt, 2004)

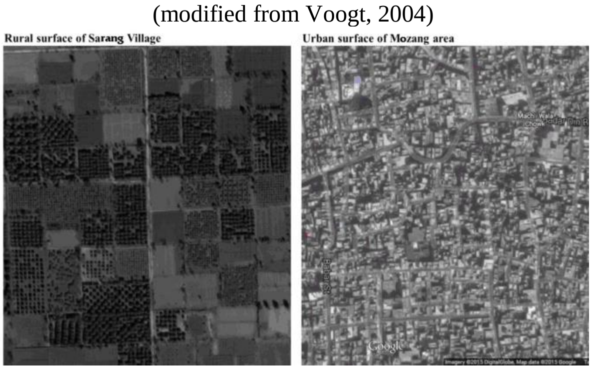

Fig. 4 Surface structure of rural (left panel) and urban (right panel) study sites

Figure 5 shows the direction of the blowing wind, during the days of data collection. It was mostly from north to north east, north, west and east sides. All these days have shown different scenarios according to the speed of wind. The speed of wind was medium at the northern side, high at the eastern side and low at the north-western side. Temperature were low as compared to other days when the wind blowing. But when the wind was not blowing, temperature was high as compared to wind blowing days. So, wind blowing days have minimum UHI as compared to non-wind blowing days. Results show that the speed of wind was at a maximum on Thursday (3km/hr) and UHI was 5.2°C while on Sunday the wind speed was at its lowest level (less than 1km/hr) and UHI was 6.2°C. This shows that wind is also playing a major role in the formation of UHI. Whereas, on Friday and Saturday the speed of wind was medium (1-3 km/hr) and the UHI was also normal as 5.4°C and 4.3°C respectively.

The cooling of different urban and rural areas results in atmospheric UHI. The cooling rates were different on calm and clear days and nights as compared to cooler areas that became cool more rapidly than the urban areas. Sometimes, intense UHI is produced during mid-afternoon, late-afternoon or after the few hours of sunset. In some case studies, it is experienced that UHI intensity might not reach its peak level until morning or after sunrise, as it is measured 5.9°C in Adelaide (Australia). However the maximum UHI intensity is measured during the late afternoon, when the variation is 2°C between the CBD and the green urban area (Soltani and Sharifi, 2017). In another study when the UHI is measured, the study shows the variation in temperatures in built-up and rural areas, and the highest intensity of UHI is observed at Sargodha on Sunday at 5.7°C (Sajjad et al., 2015b).

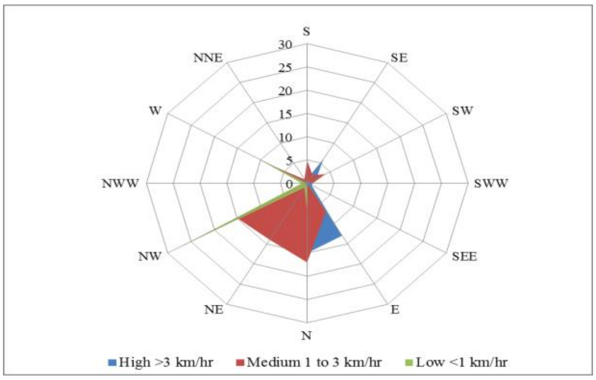

Fig. 5 Wind Direction during the Data Collection Days

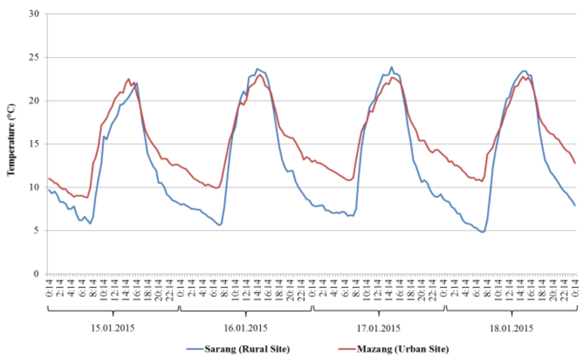

Fig. 6 Variability of temperature of urban (Mozang) and rural sites (Sarang).

Figure 6 shows the variation of temperature between rural (Sarang) and urban (Mozang) sites from 15th to 18th of January 2015. The interval of data was 30 minutes of resolution. The variations between temporal and spatial temperature can be easily observed. The temperature (23.9°C on Saturday) at rural site (Sarang) was higher in the day-time than that of the urban site (Mozang) which was recorded to be 22.8°C on Sunday. On the other hand, the temperature at night-time as it is observed, was higher at the urban site (Mozang) and lower at the rural site (Sarang). In a study, it is found that the urban-rural temperature varies between 5-10°C under ideal conditions of a clear sky and light blowing winds. In many cases, the UHI is substantial at night i.e. a study in Paris summarized that the intensity of the night-time UHI was up-to 7°C than that of day-time UHI (Lac et al., 2013).

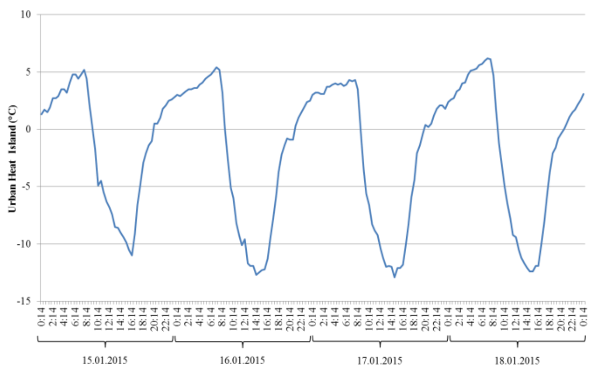

Fig. 7 Variation of urban heat Island of study area from 15th to 18th of January 2015.

Figure 7 shows the UHI of the study area and the variability in its intensity that is derived after making comparison of urban and rural stations of Lahore from 15 to 18th January 2015. On Thursday, 15th of January 2015, UHI was 5.2ºC, on Friday 16th of January 2015, the UHI was 5.4ºC, on Saturday 17th January 2015, the UHI was 4.3ºC and on Sunday 18th of January 2015, the UHI was 6.2ºC. This showed that the derived UHI of 6.2ºC was maximum on Sunday morning at about 4:14 am to 6:14 am, while there was a minimum 4.3ºC UHI was on Saturday. During this period, the range of UHI was 4.3ºC to 6.2ºC. Hence, the difference between the minimum and maximum temperature was almost 2ºC. A study conducted in Singapore shows that in day-time, the order of temperature at different urban places like industrial, commercial, residential areas, parks and airport was higher. On the other hand, the order of temperature at night-time in commercial, residential, industrial areas, parks, and airports was low as compared to day-time (Jusuf et al., 2007). But, it is very interesting to note that this increase in the temperature on Sunday happened perhaps due to the large number of people present in the city for shopping on weekends/holidays. Rest of the days, the working class of the city remained busy in offices, shops, colleges, universities, and other work places, but on Sunday they feel relaxed and use the energy consumption machines and appliances without any pressure. A study conducted in Sargodha city also verified the present study findings where the intensity of UHI is measured maximum on Sunday 5.7C° (Sajjad et al., 2015b).

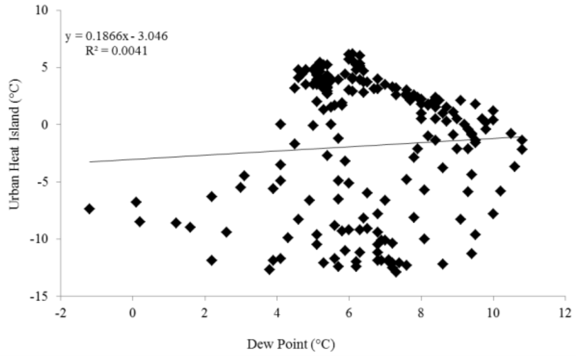

Fig. 8 Relationship between UHI and dew point at urban site (Mozang).

Figure 8 shows the relationship between dew point and UHI of urban site (Mozang). The R_2 (coefficient of determinant) value of 0.0041 is found between UHI and dew point at urban site Mozang. Although due to foggy days, the dew point data is not well observed, yet there is a neutral relationship between these two variables and that is positive.

Conclusion

Lahore is the 2nd largest city of Pakistan and it is facing serious issues of rapid urbanization and gradual increase in temperature. Increasing temperature is playing a vital role in changing the urban climate greatly as the consumption of more energy resources and the emissions of gases are resulting in pollution, greenhouse gases and urban heat island (UHI) phenomena. The results of the present study show strong evidence that UHI is present due to lack of vegetation, rapid increase in urbanization, and use of more energy resources. Particularly, the inner urban site Mozang which has maximum urban population and energy consumption was facing high temperature and UHI as compared to the rural site Sarang. The notable variations have been recorded in the day-time and night-time temperatures between the urban and rural sites. The highest day-time temperature was recorded at Sarang, whereas, the temperature at night-time was higher at Mozang than at the rural site Sarang. Similarly, there was a high difference between minimum and maximum temperatures and UHI. The highest UHI was recorded on Sunday and lowest on Saturday. Moreover, calm winds contribute to enhance the UHI and there is also a positive relationship between UHI and dew point at Mozang that validates the high UHI on Sunday during the morning hours. Hence, it is concluded that the UHI has become an alarming problem for the city of Lahore.

Suggestions

In order to prevent the rapid urbanization and to reduce the UHI in the Lahore city, following suggestions are proposed that could be used to mitigate the issue of UHI.

- There is dire need to reduce the greenhouse gas emissions by opting environment friendly energy resources in Lahore district and city managers are required to carry legislation in this regard.
- Rural-urban migration should be minimized by equally providing facilities at rural areas in the study area.
- Parks, green belts and tress along the roads should be planted to keep the temperature moderate in Lahore city.
- Planned new towns and colonies should be built to tackle urban congestion, keeping in view the Master Plan of Greater Lahore 2023.
- The people of Lahore should be given awareness and education about environmental protection and safe and smart living by reducing the pollution and waste materials.
- Green roofs culture should be introduced by local authorities and environmental organizations to control the rising temperature at local and regional levels.

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