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Assessing the Impact of Builtup Areas on Development of Urban Heat Island in Lahore, Pakistan

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Abstract: The aim of present study is to evaluate and assess the impact of built-up areas on development of the urban heat island (UHI).The study mainly focused on Lahore, which is one of the mega cities of Pakistan. In terms of population size, Lahore is the second largest city of Pakistan with 11.13 million inhabitants. The geospatial techniques (Remote Sensing and Geographical Information System) along with statistical applications were applied to find out the Land Cover Land Uses changes and consequent development of builtup areas over the period of 2000 and 2015. To study the UHI, the meteorological data of each 30 minutes for 36 days starting from 30th June 2015 to 4th August 2015 were collected through direct on site observation by using digital weather station. The results of UHI were cross checked by obtaining land surface temperature by using thermal infrared (TIR) band 6 of the Landsat-7 TM. The results show that the LCLU and built environment have direct impact on development of UHI. The areas where there was more vegetation cover had less temperature while in urban areas, the temperature was measured higher. Over the period of 36 days, the average UHI remained 5.5°C and the highest intensity of UHI was observed as 8.3°C thus augmented research rationale. The study suggests establishment of a thick network of automatic weather stations in Lahore to gauge the urban heat island intensity and to plant indigenous trees on vacant swaths and develop urban forest to mitigate city's rising temperature.

Keywords: Land cover land use, urbanization, urban heat island, Landsat images.

Introduction

The alteration of natural surfaces into built-up land is common feature for urban sprawl and its physical development. During the day, the built-up area has great characteristics to absorb the heat received from solar radiation, trap the infrared radiation in urban canyon and re-radiate or emit it at night (Oke, 1982; Quattrochi et al., 2000). The increased urban temperature is also because of the processes of urbanization which modifies the surface albedo, evapotranspiration, increased aerosols and anthropogenic heat sources, thereby creating UHI (Arnfield, 2003).This also brings changes in regional precipitation patterns (Seto and Shepherd, 2009). In this context the most important feature of urban climate is the development of urban heat island (UHI) where the temperature of urban areas is normally measured higher as compared to their non-urbanized areas (Voogt, 2002). In some cases UHI is taken as an average temperature of urban areas at different locations relative to one or average of several non-urban locations (Taha, 1997). The difference between the maximum and minimum urban and rural temperature is known as Urban Heat Island intensity (Vasilakopoulou et al., 2014). Small areas or cities produce less heat island and large cities produce large heat islands and as cities decreases heat island and its effects will decrease (Akbari et al., 2001). In urban areas, there are multiple land features such as extensive impermeable surfaces (roads, buildings, paved material) and less green surfaces (open fields, parks, vegetation cover, domestic plants etc.). Such type of urban surface structures affect differently on development of UHI. In fact, the UHI increases with the growth of cities as its central business district expands and the growth of cities may also effect the temperature trends (Brandsma and Wolters,2012).

However the magnitude of the difference in temperature of urban and rural areas may be quite large at the same times. It depends on urban thermal, physical and geometrical characteristics, weather conditions and major sources of anthropogenic moisture present in the city or nearby rural area (Changnon, 1976,1981).

There are two major causes of urban heat island that are contributing to a great extent, off them first are dark surfaces and second is scarcity of vegetation (Sajjad et al., 2015) . The contribution of dark surfaces is due to their low albedo. In urban areas dark surfaces such as roads made up of asphalt and buildings with dark material; invariably absorbs sunlight. The absorption of sunlight is the source for generating thermal energy, making the surface hotter and hotter. While on the other hand, light surface, such as natural ground and forest, have high albedo (Voogt, 2004). Similiraly, the external building surfaces and city's blue structure has net effect on reducing phenomean of urban heat island (O'Malley. et. al., 2015). Consequently, temperature on ground (LST-Land Surface Temperature) increases due to creation of UHI, which may dislocate class symphony and division (Niemela,1999) by changing the length and extent of prevalent seasons, change in air movement which is crucial to greater health risks among the inhabitants (Patz, J.A et.al., 2005). The objective of this study was to elaborate the relationship between LCLU and UHI of Lahore. The study was conducted in three phases: first to evaluate the LCLU change of Lahore since 2000 by using GIS and Remote sensing, second to measure the UHI through observational data collected through digital weather station and finally to study the land surface temperature by using thermal infrared (TIR) band 6 of the Landsat-7 TM.

Materials and Methods

This study focused on Lahore, the metropolitan city of Pakistan. Geographically it is located in eastern part of Punjab province (Fig. 1). Surrounded by alluvial flood plains, it has flat surface by lying within 31°32′59″N and 74°20′37″E. In terms of population size it is the second biggest city after Karachi in Pakistan. The total population of Lahore as enumerated during 1998 Census was 5.1 million which has surpassed 11.13 million in 2017, double within period of 19 years. The fast growth of urban population has significant environmental consequences for the future of sustainable cities in years to come. The study area experience a semi-arid type of climate where temperature remains high during summer's months (April-June) with monsoon rains in late summers with high humidity. This type falls into the sub-tropical continental low lands type of climate, where winters are short with low temperature (Dec.-Jan.).

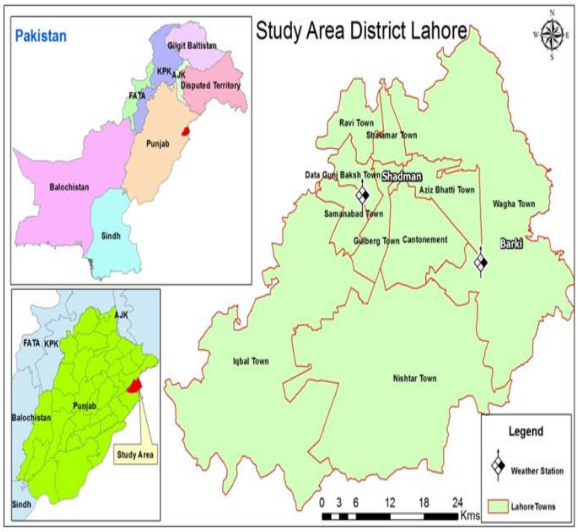

Fig. 1 Location map of study area with demarcation of sites of meteorological stations.

The temporal and spatial patterns of UHI are mostly exacerbated from population dynamics and expansion of build-up areas. Exclusively, urban formation (e.g., height-to-width proportion of buildings and streets), ratio of urbanized versus green places for every entity spot, weather conditions (e.g., wind and humidity, relative humidity temperature), and socioeconomic actions verify the development of the UHI. As many of these factors, particularly earth surface distinctiveness are mostly represented by land-cover and land-use (LCLU), the link between the LST and LCLU has been the centre of attention of many studies on the UHI (Buyantuyev and Wu, 2010). This is appropriate to the reality that vegetation has higher evapotranspiration and lesser emissivity than urbanized areas, and hence has lower surface temperatures. Trees and other plants facilitate to cool the atmosphere. The objective of this study is to elaborate the effect of land cover on development of UHI in Lahore.

As a mandatory requirement to observe the presence of UHI within Lahore district, two suitable sites one with rural and the other with urban characteristics were selected. The selection of these two sites was mainly based on the LCLU characteristics. For the observation of meteorological data, solar powered touch panel weather stations WS-1080 were used. For the observation of temperature changes, the digital weather stations were installed at two different sites: one at Shadman (urban site) and the other at Barki (rural site). Shadman has typically urban characteristics having composed surfaces covered with paved material and lesser vegetation cover. This site is one of the densely populated areas of Lahore. This is residential and commercial area where huge rush of people and traffic remains in all months of the year. In Barki, where the weather station was installed has a typically rural characteristic with less paved surface and more vegetation cover. Barki is located in east of Lahore and the distance between two meteorological stations was 23.7 km.

The digital weather station with PC interface has the ability to accurately measure the meteorological data such as wind direction, wind speed, precipitation, humidity and temperature. The weather station has automatic power system which is charged through the built-in solar panel and has capacity to store the data within the system and to transfer to te personal computer through radio signals. The meteorological data of two different sites; one in urban area and the other outside urban area and were used to observe for outdoor temperature (°C), humidity (%), wind direction and wind speed (km/hour). For this study the data was collected for 36 days starting from 30th of June 2015 at 12:56 Pakistan Standard Time (PST) to 4th August 2015 until 11:26 PST. The data interval for each observation was fixed as 30 minutes. The observed meteorological data were analyzed by using statistical tools in which regression tool was adopted and the outcome was given as linear graphs.

To assess the urban growth and change in land cover of Lahore city, Landsat images of 2000 (acquired on 30.05.2000) and 2015 (acquired on 09.06.2015) were classified by using geospatial techniques like Satellite Remote Sensing (SRS) and Geographical Information System(GIS). The spatial resolution of both images was 30 meter and thermal infrared resolution was 60 meter and 100 meter, respectively. After detection of LULC changes, the Land Surface Temperature derived from Landsat image of 2015 was processed to understand the relation between LULC with UHI. In order to have accurate and authentic results, the supervised classification has been used to both images and results have been categorized into four classes

Results and Discussion

For the last four decades, Lahore is experiencing momentous urban development, increase in areal extent and urban population. This trend still continued in wake of many mega projects like Metro Bus and under constructed Orange Line Train. According to Demographia (2014), the population of Lahore city in 2014 was 8.3 million which has increased to more than 13 million in 2017. The massive urban development is the major cause of the removal of tress and vegetation from many part of Lahore and consequently removal of vegetation led into built-areas and sealed surfaces. In 1972 the urbanized land use of Lahore was 103.42 km^2 that increased to 1250 km^2 in 2010 with an increase of 1108% within 39 years. It reflects the rapid urbanization and urban development in Lahore.

Figure 2(a) highlights the LULC change as a result of urbanization of Lahore in 2000. Landsat image of 2000 is classified into four major classes such as built-up area, vegetation cover, open land and water bodies. All kinds of vegetation is merged into one class to show it as green spaces. All types of paved surfaces such as roads, buildings, streets etc. are classified as one class of builtup surfaces. Figure 2 shows that major concentration of built-up area is towards north-west of the district Lahore, where the city of Lahore exists. Figure 2(b) imitates that the city expanded rapidly towards the south of city center.

Table 1 elaborates the comparison of LULC change during 2000 to 2015. In 2000 the built-up area of Lahore city was only 405 km^2 which reached to 774 km^2 in 2015. During the phase of 15 years, almost 91%, of natural surface converted into paved surface. This rapid growth in built-up area reflects the higher urbanization. Contrary to built-up area, vegetation cover decreased from 2000 to 2015. It is observed that in 2000 the green space covered an area of 1032 km which reduced to 703 km with a reduction of 46 per cent within 15 years. The results show that open land also reduced to 20 per cent while the water show an increasing surface that may be the result of pre-monsoon as the Landsat image of 2015 was taken in June 2015.

Table 1 LCLU change of Lahore city during 2000 to 2015.

Landcover type	2000		2015	
	Area (Sq. Km)	%	Area (Sq. Km)	%
Built up Area	405.07	22.86	774.33	43.7
Vegetation	1032.37	58.26	703.36	39.69
Open Land	323.09	18.23	269.57	15.21
Water	11.47	0.65	24.74	1.4
Total	1772	100	1772	100

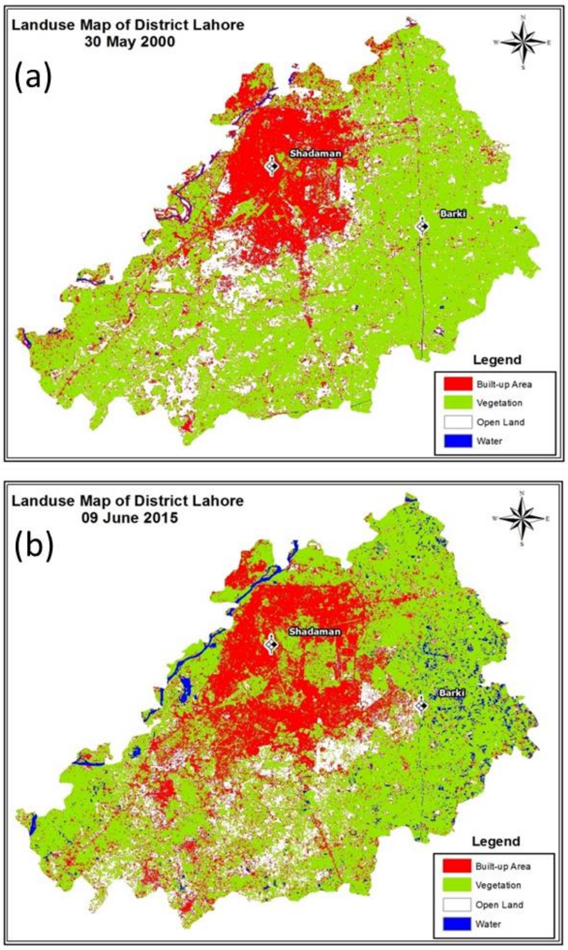

Fig. 2 LCLU change as a result of urbanization of Lahore during 2000 to 2015.

Table 2 highlights the highest, lowest and diurnal temperature range of observational meteorological data of Shadman and Barki from 30th June to 1st August 2015. The purpose of this table was to measure the extreme temperatures in terms of minimum and maximum temperature and to find the diurnal temperature range (DTR) at two stations. Higher the DTR at a station reflects the less difference between minimum and maximum temperatures at that station. During the observation period of this study the highest DTR is mainly observed at rural station. While, DTR at urban station is observed significantly lower than the rural station that is mainly because of higher minimum temperature at urban station than its surrounding rural site. This phenomenon leads to development of UHI in city of Lahore.

Table 2 Highest, lowest and diurnal temperature range of observational meteorological data of Shadman and Barki from 30th June to 1st August 2015.

Date	Time (PST) Time format: 24h	Shadman (Urban site)			Barki (Rural site)		
		Highest temperature	Lowest temperature	Diurnal temperature range (DTR)	Highest temperature	Lowest temperature	Diurnal temperature range (DTR)
30.06.2015 to 02.07.2015	12:56 to 11.26	40.7	29.8	10.9	40.8	25.3	15.5
02.07.2015 05.07.2015	11:56 to 11.26	42.5	29.5	13.0	43.5	26.6	16.9
05.07.2015 to 08.07.2015	11:56 to 11.26	41.7	24.8	16.9	40.7	23.9	16.8
08.07.2015 to 11.07.2015	11:56 to 11.26	39.1	25.9	13.2	40.5	25	15.5
11.07.2015 to 14.07.2015	11:56 to 11.26	35.7	25.1	10.6	39.3	24.4	14.9
14.07.2015 to 17.07.2015	12:56 to 11.26	41	25.9	15.1	41.6	25.4	16.2
17.07.2015 to 20.07.2015	12:56 to 11.26	38.1	24.7	13.4	39.3	22.6	16.7
20.07.2015 to 23.07.2015	12:56 to 11.26	37	25	12.0	36.6	25.9	10.7
23.07.2015 to 26.07.2015	12:56 to 11.26	37.4	25.2	12.2	37.7	24.4	13.3
26.07.2015 to 29.07.2015	12:56 to 11.26	36.7	27.9	8.8	37.2	26	11.2
29.07.2015 to 01.08.2015	12:56 to 11.26	36.6	27.5	9.1	36	26.6	9.4
01.08.2015 to 04.08.2015	12:56 to 11.26	37.1	26.1	11.0	37.1	25.6	11.5

June to 1st August 2015 and shows the variability in temperature of Shadman (urban) and Barki (rural) from 30th June 2015 to 2nd July 2015, 2nd July 2015 to 5th July 2015 and 14th July 2015 to 17th July 2015, respectively. The results show that UHI frequency and intensity during the observational period does not remain same. There was great variability in UHI from day to day during 36 days. The highest UHI was observed from 17th to 20th July. It was observed further that on average, the UHI was 5.5°C which means the temperature of the city was higher due to the presence of the paved surface while due to vegetation cover at rural site, the temperature is down. The significance of the UHI is that the higher UHI may cause demand more energy for the human thermal comfort.

Table 3 Temperature difference between urban and rural meteorological sites (UHI) observed from 30th June to 1st August 2015.

Date	Time (PST)	ΔT_{u-r} (UHI) in °C
30.06.2015 to 02.07.2015	12:56 pm to 11.26 am	5.4
02.07.2015 to 05.07.2015	11:56 am to 11.26 am	5.9
05.07.2015 to 08.07.2015	11:56 am to 11.26 am	5
08.07.2015 to 11.07.2015	11:56 am to 11.26 am	6
11.07.2015 to 14.07.2015	11:56 am to 11.26 am	2.6
14.07.2015 to 17.07.2015	12:56 am to 11.26 am	4.8
17.07.2015 to 20.07.2015	12:56 am to 11.26 am	***8.3***
20.07.2015 to 23.07.2015	12:56 am to 11.26 am	***6.1***
23.07.2015 to 26.07.2015	12:56 am to 11.26 am	***7.7***
26.07.2015 to 29.07.2015	12:56 am to 11.26 am	3.4
29.07.2015 to 01.08.2015	12:56 am to 11.26 am	5.7
01.08.2015 to 04.08.2015	12:56 am to 11.26 am	3.5
Average UHI over a period of 36 days		**5.5**

Fig. 3 Land surface temperature of Lahore as observed on 15th June 2015 by using thermal infrared (TIR) band 6 of the Landsat-7 TM.

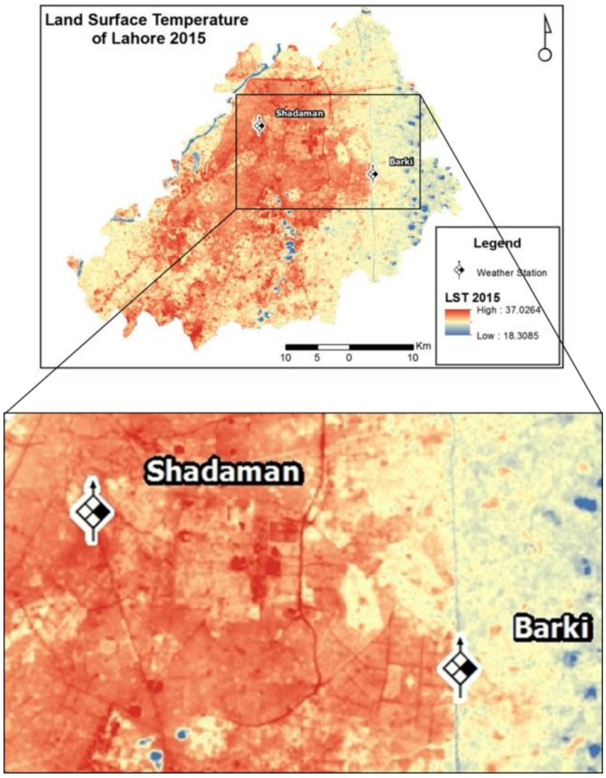

Fig. 3 Land surface temperature of Lahore as observed on 15th June 2015 by using thermal infrared (TIR) band 6 of the Landsat-7 TM.

Rapid urbanization all over the world has significant effects on local climate. However intensity of the consequences caused by urbanization varies according to the size and LCLU changes of a particular city depending upon the regional location of the city. In Pakistan rapid pace of urbanization after 1970s ominously affected the local climate in terms of the development of UHI mainly in major cities of Pakistan such as Lahore and Karachi.

The results reveal that there is relationship between LCLU and development of UHI in the study area. The findings of this study are supported by the measurement of the land surface temperature by using thermal infrared. The variation of UHI is mainly based on LCLU change and that the areas within city, where vegetation cover is significantly less, the UHI is higher that makes the city warmer than its surrounding rural areas.

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