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Influence of land use and land cover changes on the urban heat island effect over Islamabad

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ABSTRACT

In this paper, it has been examined how urbanization has affected the Land Surface Temperature (LST) of Islamabad. For this purpose, satellite-based remote sensing techniques were used. Five different images of 1995, 2000, 2010, 2015 and 2018 were selected for spatiotemporal mapping of Land use and Land cover (LULC). Cloud-free images were selected for summer months (May-August) for estimation of LST and Normalized difference Vegetation (NDVI) of the study area. Object orientated classification has been performed along with the multi-resolution segmentation algorithm on LANDSAT TM, ETM+ and OLI satellite images.Based on the ground knowledge, the study area was classified into the water, barren land (rangeland), built-up (residential area) and vegetation. Islamabad has been experiencing rapid urban sprawl from 1995 to 2018 as depicted in the classification results. The results based on classification indicate that the land cover patterns have changed significantly. Islamabad was developed according to the master plan but there is an irregular urban development in the city especially north-east and north-west directions. Due to irregular development along the Expressway, Barakahu and south-western parts of Islamabad, the barren land has been covered with in the built-up land. The LST values lie in the range of (20-45^{o}C) in summer months, while the observed maximum air temperature of Islamabad in summer remains in the range of (30-41^{o}C). Relatively higher LST regions are mainly concentred along the north-east, south-east and south-west side of the study region due to the low vegetation along the roads and construction of small urban areas irregularly. The thermal contrast between the city and the surrounding environment shows a higher temperature over the surrounding area comparatively then core city of Islamabad.

Keywords: LULC, LST, NDVI, Urbanization, Object-oriented.

INTRODUCTION

Urban Heat Island (UHI) effect refers to the phenomenon where an inner microclimate of a city has a higher temperature as compared to their neighbouring micro-climates (C, O'Malley et al., 2014). The study of the UHI also addresses urbanization and climate change those has been considered as major environmental challenges of this century (Stewart and Oke. 2012). Due to urbanization, natural vegetation and croplands are converted into impervious surfaces those strongly absorb the short wave radiation from the

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Sun. These changes can have a large effect on the surface temperature, surface albedo, thermal conductivity, heat storage, evaporation rate and the degree of air turbulence. The UHI effect could enhance environmental problems and health risks leading to poor air quality, higher energy costs and higher mortality rates in the cities. In the past, many efforts have been made to suggest mitigation measures to limit the UHI impacts such as use of high albedo materials, installation of green roofs and plantation of more urban trees. Therefore, It has become a major research area in urban climate analysis since first reported in 1818 (Weng. 2009).

To obtain a better understanding of the UHI variations, it is very important to provide a solid scientific basis. Traditional UHI studies used ground-based air temperature observations from one or more sites of urban and rural surroundings. Nowadays, with the advancement of remote sensing technology, it has become a powerful research tool to use satellite data to conduct UHI studies. Remotely sensed Thermal infra-red (TIR) band have been used in many urban climate and environmental studies (Voogt and Oke et al., 2003). Land surface temperature (LST) is one of the key parameter derived from TIR also called skin temperature of the Earth. It is very important variable to monitor urban climate, surface energy and climate change.

There has been significant number of efforts in recent years to examine the impacts of land use and land cover change (LUCC) on the Earth's system. Rao and Winston were the first persons who attempted to utilize remote sensing technology in the study of UHI. They found that surface temperature measurements in clear and dry regions is possible through the satellite data. In the preliminary studies, NOAA, AVHRR and MODIS data sets were used to retrieve LST (Li et al., 2013). But in an urban environment, coarse resolution of these data sets did not allow to characterize a more accurate relationship between LST and surface biophysical parameters. Since 1972, the Landsat programme has the longest and continuous temporal record of the Earth with higher spatial resolution. In this study, we examined the UHI effect on capital city, Islamabad by using Land Surface Temperature (LST) product derived from cloud-free Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI) and Thermal Infrared Sensor (TIROS) images during the period from 1995 to 2018. This paper aims to provide a comprehensive study to (i) examine the spatiotemporal changes in the thermal environment over the past 23 years (ii) map the clear picture of the influence of LUCC on UHI and to measure the intensity of UHI.

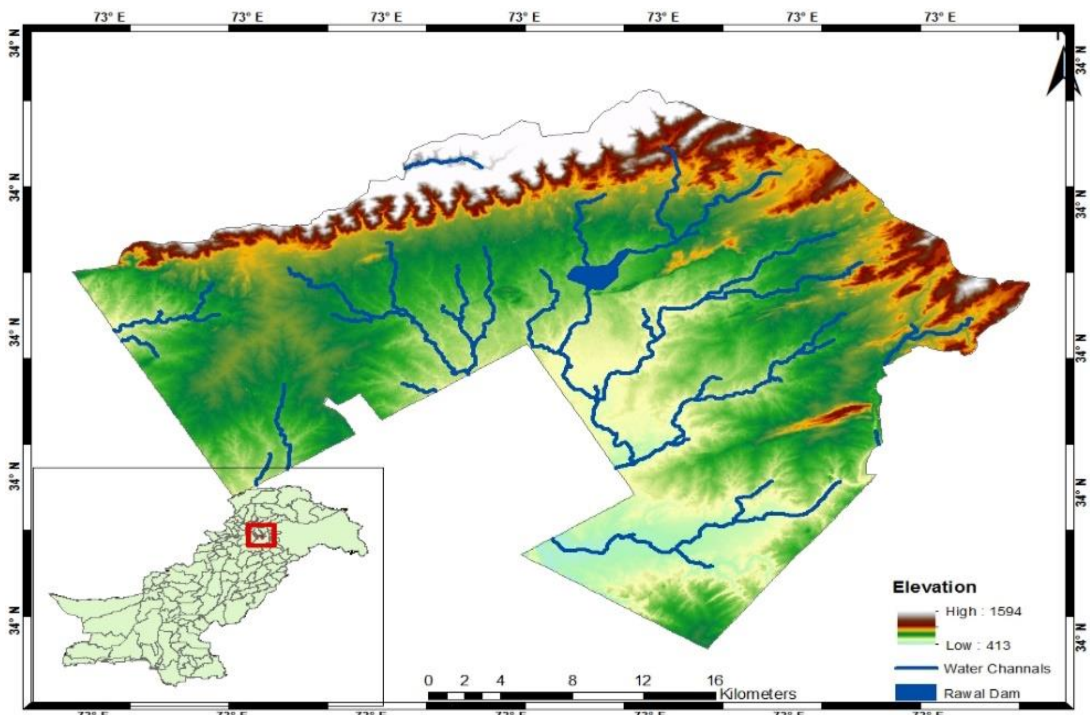

Figure 1. Geographical Location & Digital Elevation Model of Study Area

Study Area

The study area is the capital of Pakistan, located at 34^0 N, 73^0 E at the foot of Margalla hills shown in figure 1. The elevation of Islamabad ranging from 413 to 1594 meters. Its climate is classified as a humid sub-tropical climate. The hottest month is June when temperatures routinely exceed the monthly average of 38 °C. July and August are usually the wettest months with a mean precipitation of 368mm in July-August .Normally heavy rainfalls and eveningthunderstorms occur frequently in these months. In winter the mean minimum temperature of the city is mostly in range 2 to 3 ^{o}C. The January with an average low of 2 °C is the coolest month of Islamabad.

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MATERIAL AND METHODS

Data Sources

In this study, it has been examined how urbanization affected the Land Surface Temperature by using satellite and ground-based data. The satellite data from Landsat including Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) were used in this study to find the relationship between Land Use Land Cover (LULC) and Land Surface Temperature (LST). Five different images of 1995, 2000, 2010, 2015 and 2018 table 1 were selected for spatiotemporal mapping of Land use and Land cover (LULC). Cloud-free images were selected for summer months (May-August) for the estimation of LST and Normalized difference Vegetation (NDVI) of the study area.

The Landsat satellite provides free earth observation images at a spatial resolution of 30 meters for reflective bands and spatial resolution of 100 to 120 meters for thermal bands. Landsat data is a right choice for LULC and LST studies due to multi-decade record. The unavailability of cloud-free images is the biggest issue in Optical Satellite imagery. The study area lies in the humid zone that receives much of the rain from July to September. Due to cloudy weather in this season, sometimes it is very difficult to find a cloud free image at a particular day. Therefore, we have acquired cloud free images in summer months at slightly different dates to investigate LST.

Table 1 LANDSAT Imagery data acquisition

Image ID	Date	Sensor	Spatial resolution
LT5L1TP1500371995176	25th June	TM	30 Meter
LT5L1TP1500372000158	6th June	TM	30 Meter
LT5L1TP1500372010169	18th June	TM	30 Meter
LC8L1TP1500372015167	16th June	OLI	30 Meter
LC8L1TP1500372018143	23rd May	OLI	30 Meter

LST extraction from Thermal Band

Conversion of the Digital number (DN) to Spectral Radiance (Lλ)

The process of converting raw satellite images from DN to spectral radiance is called radiometric calibration. It improved the quality of the data before the LST, LULC and NDVI mapping. The radiometric correction is performed to reduce the errors in DN values of the images. The spectral radiance (Lλ) is calculated by using the following equation.

$$\boldsymbol{L\lambda} = \boldsymbol{ML}\boldsymbol{Q}cal + \boldsymbol{AL} \ldots \ldots . . Eq\ (1)$$

Where,

***M**L*= Band specific multiplicative rescaling factor from the metadata file (RADIANCE_MULT_BAND_x, where x is band number)

***Q**cal*= Quantized and calibrated digital number of each pixel

***A**L*= Band specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x)

Since the values of multiplicative and additive rescaling factors may differ from Landsat TM to OLI and also from image to image, therefore it was made sure to pick these values from metadata file of every scene.

Conversion of Spectral Radiance (Lλ) to Satellite Brightness Temperature (TB)

At-sensor brightness temperature of thermal band can be calculated by using the following equation.

$$TB = \frac{\mathrm{K2}}{\ln\left(\frac{\mathrm{K1}}{\mathrm{L}\lambda} + 1\right)} - 273.15 \ldots \ldots \ldots \ldots Eq(2)$$

Where,

T_B= At-sensor brightness temperature

Lλ= Spectral radiance w.m^{-2}.sr^{-1} .µm^{-1}

K_1& K_2= Calibration constant for thermal bands from metadata

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Table 2 TM, ETM⁺ and TIRS Thermal Band Calibration Constants

	K_1(w.m^{-2}.sr^{-1} .μm^{-1})	K_2(Kelvin)
Landsat 5-TM	607.76	1260.56
Landsat 7-ETM$^+$	666.09	1282.71
Landsat 8-TIRS Band-10	774.88	1321.07

Calculate the NDVI, Proportion of Vegetation Pv and Land Surface Emissivity LSE

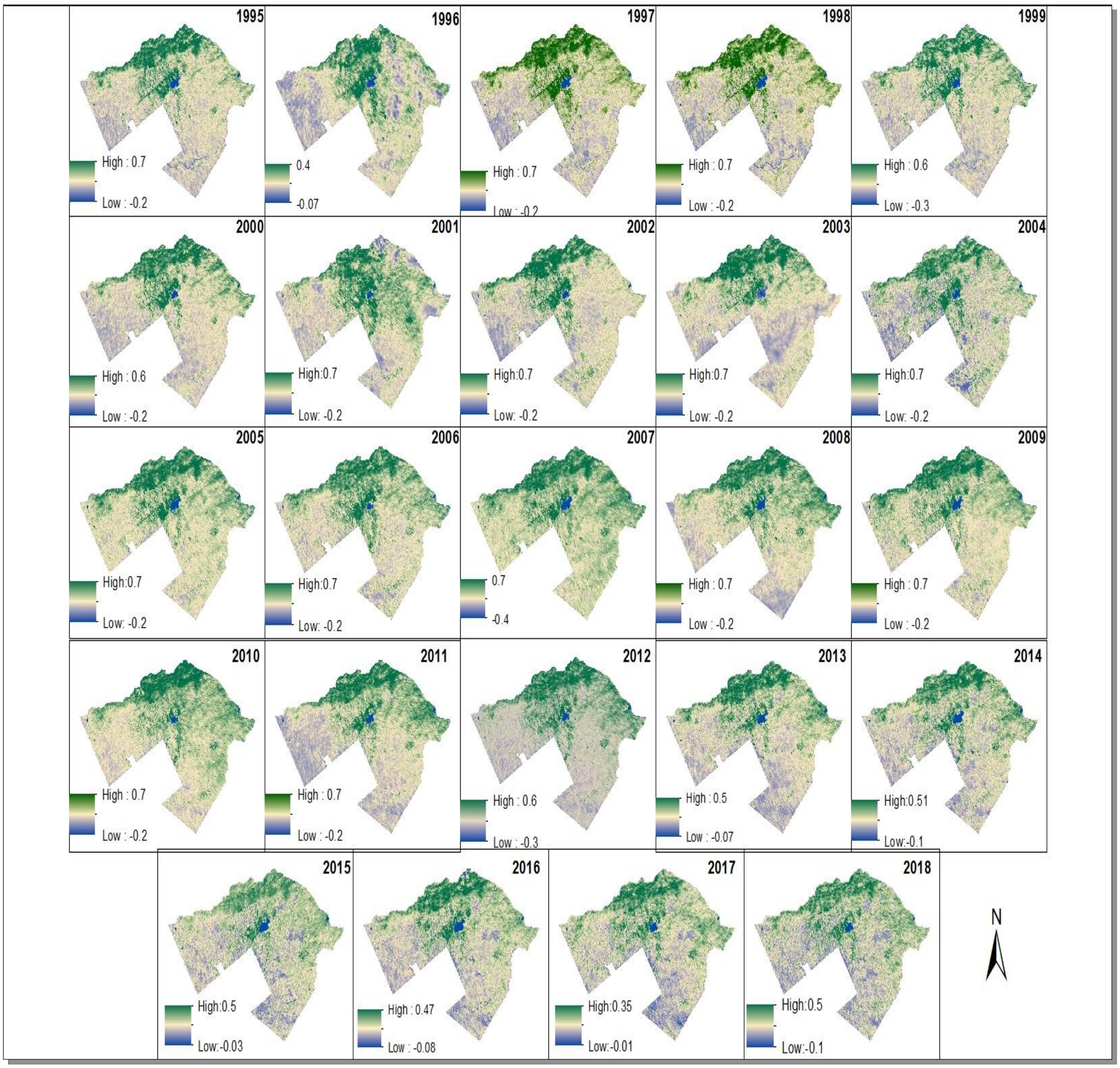

Figure 2 NDVI derived from Landsat TM, ETM+ & OLI imagery for summer months from 1995 to 2018

Normalized Difference Vegetation Index (NDVI) has been used as an indicator of urban climate since long (Gallo at el. 1993).The relationship between NDVI and LST was examined.

It was learnt that the relation between NDVI and surface temperature are inversely proportional. Usually, lower LST found in the areas with higher vegetation cover. The NDVI values of the study region were derived by using the difference between the

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reflectance of Near-Infrared (NIR) and visible (Red) band as given in the equation (3) by the method of Town shed and Justice (1986).

$$NDVI = \frac{\varrho\text{NIR} - \varrho\text{Red}}{\varrho\text{NIR} + \varrho\text{Red}} \ldots \ldots \ldots \ldots Eq(3)$$

Generally, NDVI values range in between -1 to +1. The value near to +1 means higher density of vegetation and the value is less than 0 or -1 is classified as water. Figure (2) depicts the NDVI of Islamabad from 1995 to 2018. Throughout the study period NDVI value slightly different to some extent. The land is covered with soil NDVI value from 0 up to 0.2. However, the value found 0.3 to 0.4 on sparse vegetation across the roads and near to 0.7 found over the Margalla hills.

Proportion of vegetation and land surface emissivity were calculated by the following equation.

$$Pv = \text{square}\left(\frac{\text{NDVI} - \text{NDVImin}}{\text{NDVImax} - \text{NDVImin}}\right) \ldots \ldots \ldots \ldots Eq(4)$$

$$LSE\ (\epsilon) = 0.004 * Pv + 0.986 \ldots \ldots \ldots \ldots Eq\ (5)$$

Pv is the proportion of vegetation or fractional vegetation cover can be obtained from the maximum and minimum values of NDVI according to Carlson and Ripley (1997).The Land Surface Emissivity (LSE) is a ratio of a radiant energy emitted from the surface (Artis and Carnahan, 1982) and the value range between 0.97 to 0.99 (Pal and Ziaul,2016). Finally the emissivity corrected land surface temperature is computed by the following equation.

$$LST = \frac{\text{TB}}{1} + \left\{\left(\lambda * \frac{\text{TB}}{\rho}\right) * \ln(\epsilon)\right\} - 273.15 \ldots \ldots \ldots \ldots Eq\ (6)$$

Where,

LST is emissivity corrected in degree Celsius

T_B = at satellite brightness temperature

λ= Average wavelength in meters of thermal band 10

ϵ= Land surface emissivity

ϱ = h*c/ Ō which is equal to 1.438 x 10-2 mK in which, σ is the Boltzmann constant (1.38 x 10-23 J/K), h is Plank’s constant (6.626 x 10-34) and c is the velocity of light (3 x 108 m/s).

RESULTS

Land use Land cover Classification

Figure 3, depicts the dynamics of LULC classification of Islamabad for the year 1995, 2000, 2010, 2015 and 2018 from LANDSAT TM, ETM+ and OLI imagery. In this study, object orientated classification has been performed with the multi-resolution segmentation algorithm. The eCognition software was used for image classification. Based upon ground knowledge, the study area was classified into water, barren land (rangeland), built-up (residential area) and vegetation. Moreover, the classification results showed that the study area experienced more urbanization from 1995 to 2018.

Similarly, the LULC changes for all four classes (water, barren land, built-up and vegetation) from the year 1995 to 2018 are highlighted in the Figure (4). It was found that barren land is decreasing but the vegetation cover is increasing from 1995-2015. But in 2018 classified map the situation is slightly different because of the increasing trend of barren and decreasing trend of vegetation cover evidently with respect the 2015 classified map. The classified results indicated that the city has experienced rapid urbanization and the land cover patterns have changed significantly. The city of Islamabad developed according to master plan but the Irregular urban development found from the year 1995 to 2018 especially north-east and north-west direction. Moreover, the barren land has been covered with the built-up land and the small towns expanded gradually by merging surrounding smaller settlements and becoming small urban areas especially along the Expressway, Barakahu and south-west parts seen throughout the period according to our results.

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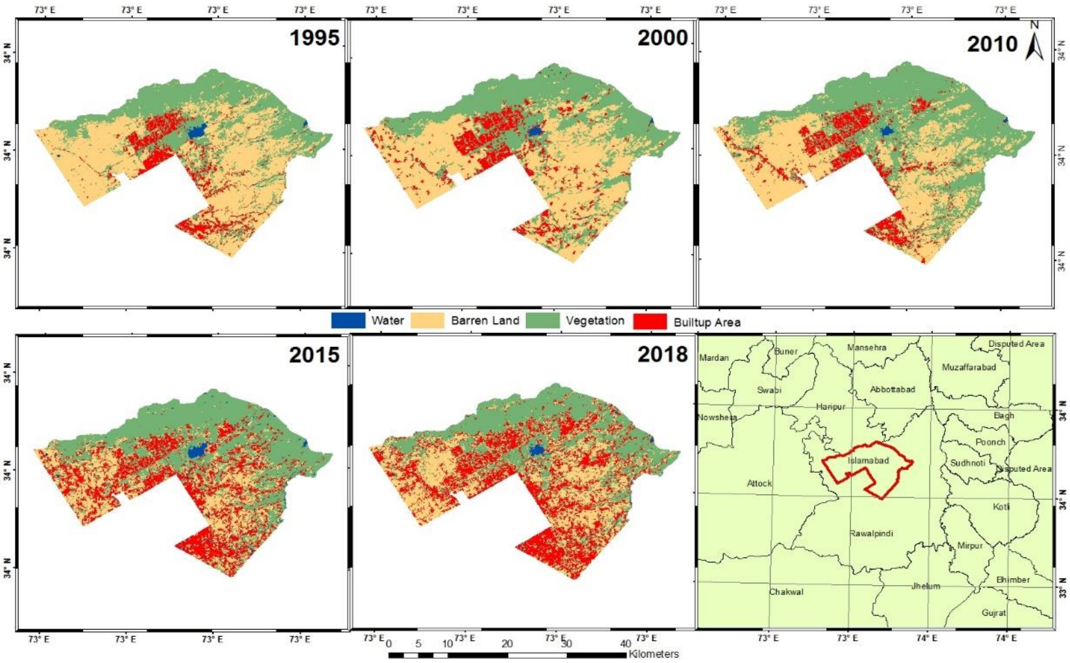

Figure 3. LULC Maps on 1995, 2000, 2010, 2015 and 2018

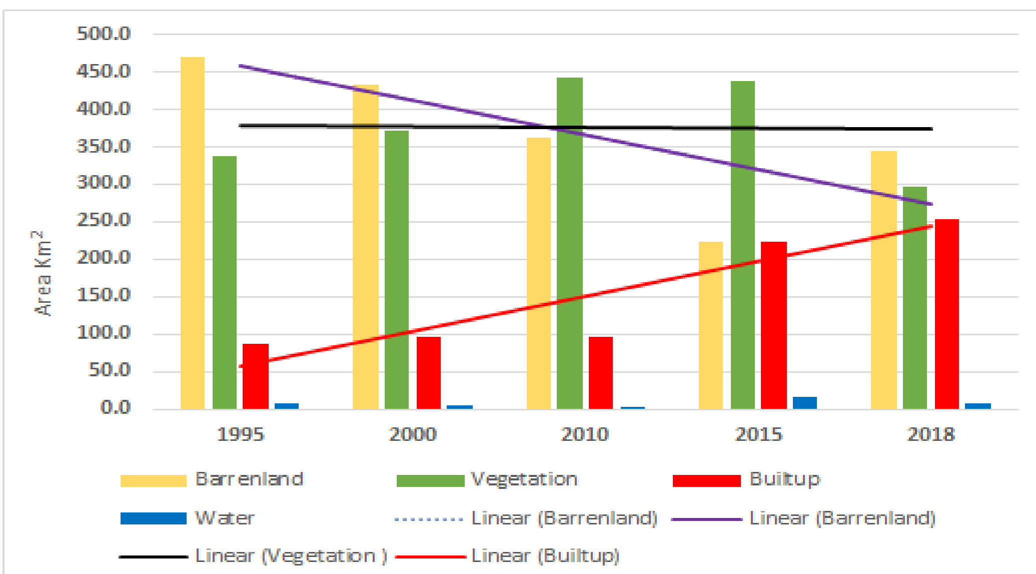

Figure 4. Land cover Statistics of Islamabad from 1995 to 2018

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Land Surface Temperature

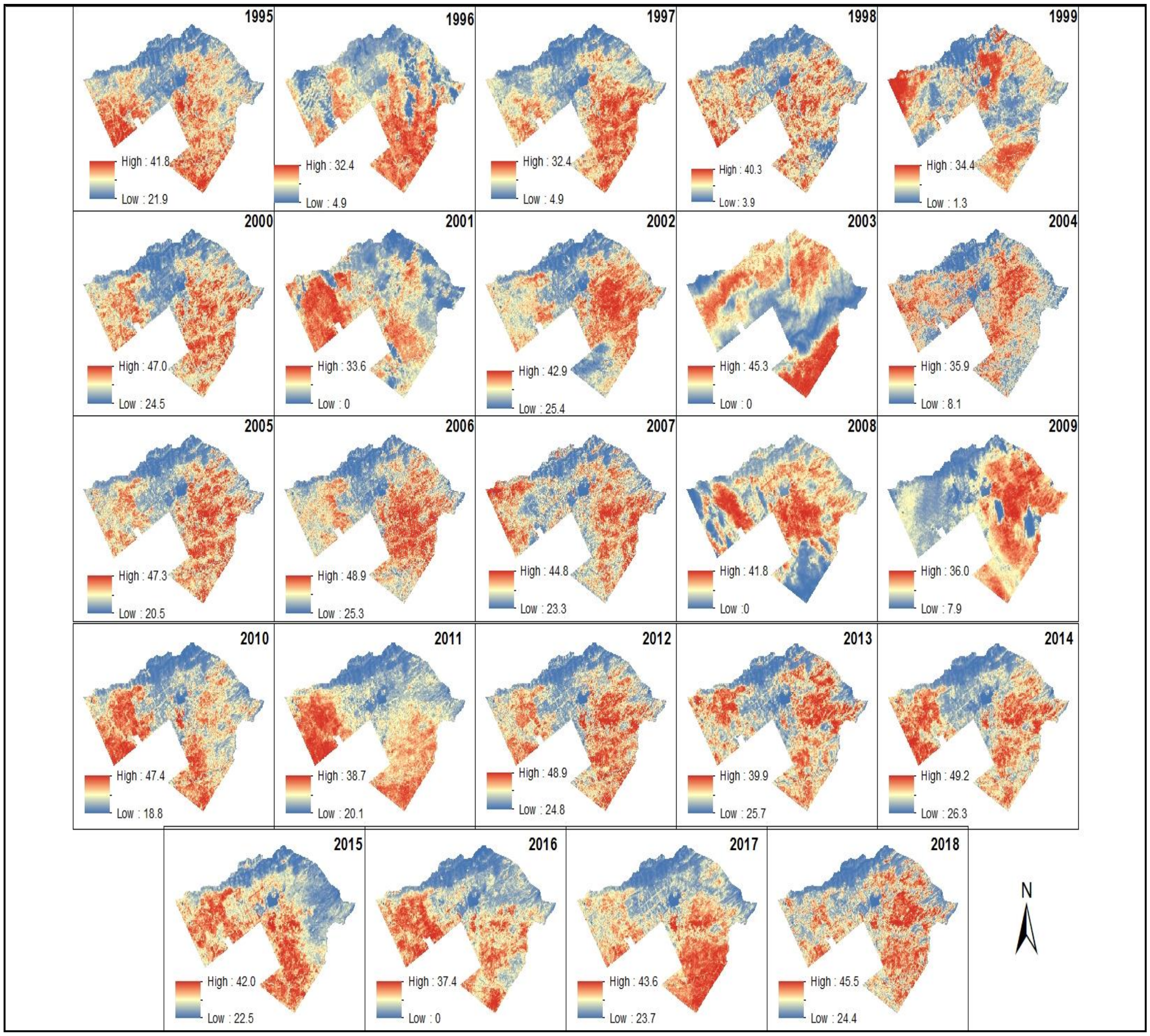

Figure 5. Surface temperature distribution of Islamabad from 1995 to 2018

Figure 5, indicates the spatiotemporal maps of surface temperature from 1995 to 2018. This analysis is carried out in the summer months from May to August, the image is cloudy from July to August due to monsoon season. Usually, the LST is confined within the range of 20 to 45^{o}C, the observed maximum air temperature of Islamabad lies in the range from 30 to 41^{o}C in summer months (Fig (6)). Relatively higher LST regions mainly concentred along the north-east, south-east and south-west direction of the study area due to low vegetation along the roads and housing schemes, while it can be seen that the LST of the central urban areas is significantly lower than that of the surrounding due to spare vegetation along housing colony and roads.

The thermal contrast between the city and the surrounding shows that the temperatures are higher in the core city as compared to the surrounding areas. On the other hand, the higher-LST characteristics are more prominent in the surrounding. Figure (7&8) depicts the comparison of vegetation with LST for the 1995 and 2018 image. Figure (7), showed the variation of NDVI and LST from 1995 to 2018 for Barakahu situated north-east to Islamabad. It can be seen that higher denisty vegetation cover and lower surface temperature observed in 1995 fig (7 a&b). In 2018, the density of vegetation cover reduced by built-up area in Barakahu that resulted significant rise in surface temperature observed from earlier to recent images. Figure (8 a-d) showed the NDVI and LST of 1995 and 2018, LST of core urban area is influenced by the vegetation cover. The uncontrolled urbanization and deforestation of the city has negatively impacted the local climate. The modification of Landcover from the forest and barren to built-up land is the main cause of Urban Heat Island (UHI).

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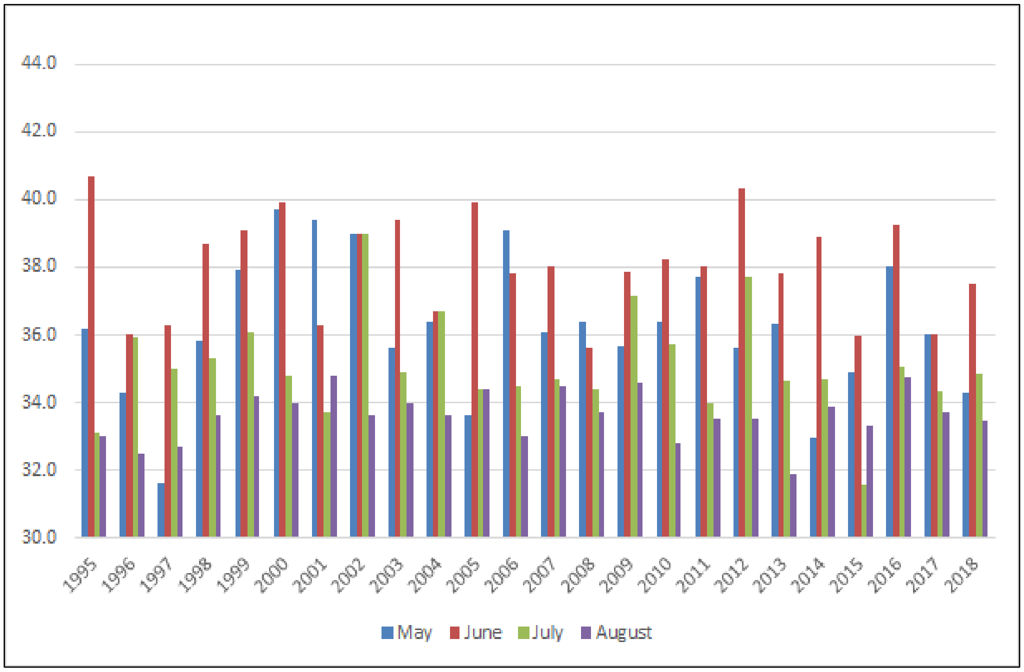

Figure 6. Time series of observed maximum temperature of Islamabad from 1995 to 2018

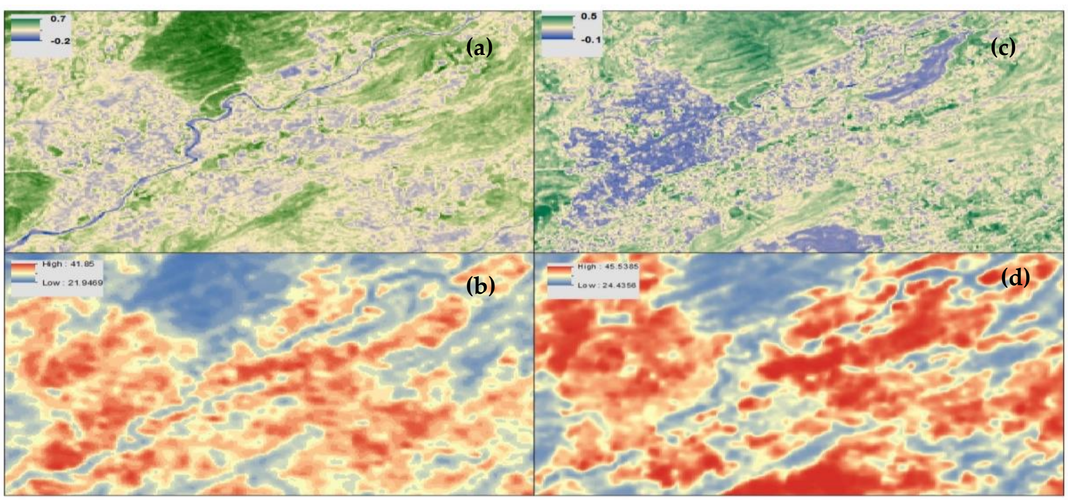

Figure 7. Comparisons (a) NDVI , (b) LST 1995 and (C) NDVI, (d) LST of 2018 for Barakahu

UHI is the difference of average surface temperature of urban and surrounding (non-urban areas). LST is important for UHI monitoring, it can be seen that higher surface temperatures are found over the regions where the rapid urbanization has been observed.

DISCUSSION

In this study, all the analysis were carried out on medium resolution satellite imagery and we tried to find out the comparison between LST, NDVI and LULC. The decreasing vegetation cover along with considerable reduction in the number of shady trees and vegetation and rapid urbanization over the recent years had a major contribution to intensify the surface temperature. The LST results show that the highest temperature range 39-47^{o}C was observed over Barakahu, DHA, south-western parts and the housing

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schemes along the Islamabad Expressway. These areas suffered a rapid growth of built-up land. Since thermal conductivity, thermal diffusivity, and heat capacity have positive effects on the maximum temperature. Therefore, one of the reason of higher temperature for these regions was greater heat storage of urban surfaces during a sunny and very warm summer days because of specific thermal properties (i.e. heat capacity and conductivity) of man-made materials. It can be seen that the urban development of Islamabad has rapid growth that is affecting other classes simultaneously; the trends of the barren land and vegetation have been changed. The built-up area has more capacity to absorb the solar radiation that resulted higher surface temperatures over those regions.

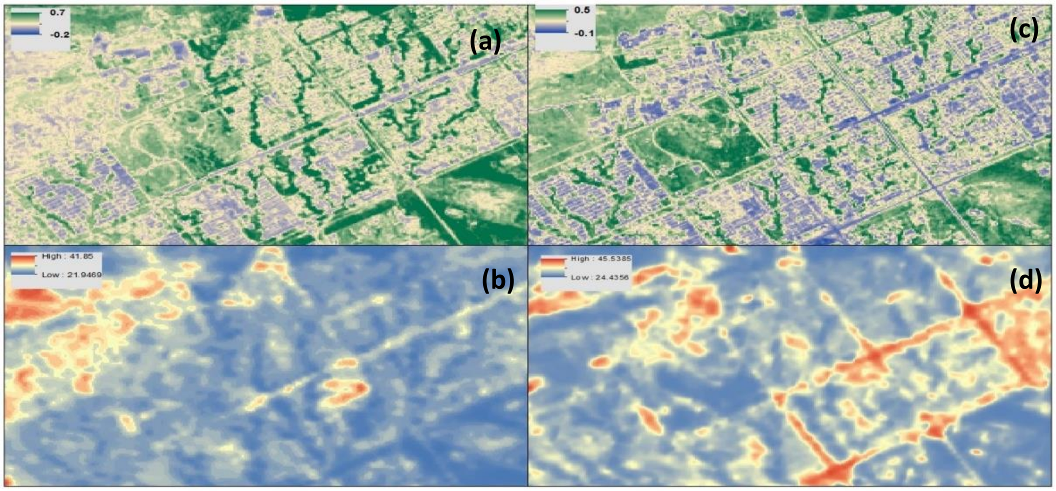

Figure 8. Comparisons (a) NDVI , (b) LST 1995 and (C) NDVI, (d) LST of 2018 for Core Islamabad

CONCLUSION

This study investigated the relationship between LULC, LST and NDVI, the results showed that the surface temperature has been increasing due to the positional influence of the existing LULC. The Higher temperature on the surface was observed in the north-east, south-east and south-west of Islamabad due to the low vegetation along the roads and housing schemes, while, it can be observed that the LST of the core urban area is significantly lower than that of the surrounding. Moreover, the results indicated that the city has experienced rapid urbanization and the LULC patterns have changed significantly. The thermal contrast between the city and the surrounding shows that the temperatures are higher over the surrounding areas as comparative to the core city of Islamabad. In addition, a considerable reduction of vegetation cover and rapid urbanization over the recent years had also contributed to higher LST.

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Conflict of Interest

The author declares that they have no conflict of interest.

Data and materials availability

All data associated with this study are present in the paper.

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