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Original Article

Assessing role of LULC change in inducing UHI in Jaipur district, Rajasthan, India*:* A case study from 2009 – 2019

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Abstract

The purpose of this study was to evaluate the decadal changes in the Land use/Land cover (LULC) pattern of the Jaipur district that affect the occurrence of Urban Heat Island (UHI) from 2009 to 2019, by using remote sensing and GIS data. The Landsat 7 and Landsat 8 datasets were classified using Supervised Maximum Likelihood classification method into classes: Urban, Vegetation, and Other. Further, using heatwave-based approach on land surface temperature (LST) maps, occurrence of UHI was determined. The results indicate a 26.55% increase in the urban area cover with a subsequent rise of 5^{0}C in the mean LST from year 2009 to 2019. With the increase in LULC and LST over the study period, intensification in the occurrence of Urban Heat Islands has been observed both in terms of their number and temperature. Interestingly, a 5.97% increase in vegetation cover has also been observed during the decade, but the effect of increase in vegetation was negligible and could not prevent the UHI effect in the area. Furthermore, Jaipur master development plan 2025 indicates expansion in terms of urbanisation and industrialization, so this study will be valuable for urban planners, policymakers, and relevant authorities in order to achieve sustainable development.

Keywords: GIS, land surface temperature (LST), land use/land cover, urban heat island

1. Introduction

Land Use/Land Cover (LULC) change studies are paramount as they truly represent the impact of socio-economic activities on the regional environment. Land cover refers to the physical and biological cover of the Earth's surface described by classes such as build-up areas, forests, agricultural areas, wetlands, (semi) natural areas, and water bodies (Rawat, Biswas, & Kumar, 2013). When this land is assessed in the context of social, economic, cultural and political development, it is termed Land Use analysis (Virghileanu & Mihai, 2016). The shift in the properties of the ground layer affects radiation absorption and the development of secondary pollutants such as ozone.

Human induced LULC changes alter the microclimatic conditions and increase the energy demand thereby adding up pollutants in the environment. Several studies have been done to measure the air pollutants using remote sensing and GIS (Kumar, Chu, & Foster, 2008; Rush, Dougherty, & Engel-Cox, 2004; Symeonidis, 2017).

Increased LULC changes due to urbanisation, industrialisation, and agricultural intensification have also been shown to increase the flow of sediments and nutrients into waterbodies, compromising their quality (Astuti, Sahoo, Milewski, & Mishra, 2019). As a result, shifting land-use practices modify climatic conditions, altering water and nutrients cycling in urban centers (DeFries & Eshleman, 2004; Joorabian Shooshtari *et al.*, 2017; Saddique, Mahmood, & Bernhofer, 2020).

Finding the correlations between development and the above-mentioned dynamic variables is of enormous importance for urban planning and development, policy framework and its implementation, and for adopting sustainable mitigation measures.

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Population explosion over the years has created exponential increase in urbanization and industrialization, thereby stressing the natural environment and causing deforestation, loss of biodiversity, water scarcity, and mismanagement of agricultural, urban, range and forest lands (Chotchaiwong & Wijitkosum, 2019; Mourya, Rafi & Shamoo, 2021; Ramachandra, Bharath & Sowmyashree, 2015; Sankhala & Singh, 2014). Moreover, the prodigious transformation of rural areas into urban areas greatly affects the ecosystem balance, thus triggering severe environmental problems such as Urban Heat Island (UHI) effect, global warming, climate change, and making the environment prone to various natural and anthropogenic disasters (Islam, Jashimuddin, Nath, & Nath, 2018). These changes ultimately affect the food availability, energy supply, and biodiversity, which is the main fuel of the modern world (Heald & Spracklen, 2015).

The foremost effect of these environmental alterations is an increase in the Land Surface Temperature (LST). LST is a manifestation of surface-atmospheric interactions and energy fluxes occurring between the atmosphere and the ground (Khandelwal, Goyal, Kaul, & Mathew, 2018). It is one of the most important parameters, which not only acts as an indicator of climate change but also governs the surface energy balance in the ecosystem (Sun, 2008).

For collecting LST data, a special category of sensors which works in the thermal infrared region of the EMR spectrum can be used (Mallick & Bharath, 2008). Determination of LST has its implications in several fields such as soil moisture, vegetation monitoring, hydrological cycle, climate change, LULC, and most importantly in the evaluation of Urban Heat Islands (UHI) (Solanky, Singh & Katiyar, 2018; Sun, 2008). Many researchers have attempted to study the impacts of LST on urban climate and urban heat islands (Abutaleb *et al.*, 2015; Al Kafy *et al.*, 2020; Gupta, 2012; Jusuf, Wong, Hagen, Anggoro, & Hong, 2007; Karakus, 2019; Khandelwal *et al.*, 2018; Pal & Ziaul, 2017; Senanayake, Welivitiya & Nadeeka, 2013; Sun, 2008; Su, Gu, & Yang, 2011).

The crafting of impermeable construction materials on the Earth's surface causes entrapping of more atmospheric heat in the urban areas. This contribution to temperature in urban areas, in contrast to the surrounding rural areas, is defined as the Urban Heat Island (UHI) effect. The major factors that bring about this effect are changes in energy fluxes by low albedo construction material, high evapo-transpiration rate, and reduced green cover (Jalan & Sharma, 2014). All these factors modify the urban environment and increase episodes of morbidity and mortality due to heat waves. The intensity of UHI effects is dependent on LULC pattern, city structure, city size, seasonal variations, urban geometry, meteorological conditions, topography, and location of the study area (Aslan & Koc-San, 2016). Properties like solar reflectance, heat capacity and thermal emissivity of the construction materials, along with the human induced emissions, also contribute to the formation of UHIs. Heat islands also exacerbate the magnitude and duration of heat waves, which are periods of abnormally hot and often humid weather. Excessive heat can cause dehydration, heatstroke, heat exhaustion, heat cramps, heat syncope, heat oedema, heat rush, psychiatric illness, and even death (World Meterological Orhanization [WMO] & World Health Organization [WHO], 2015). The phenomenon of UHI is more prominent in the summer season and increases as the size of city and population in the city increase.

The changes in the land use and land cover manifest changes that are either natural or manmade, having a bearing on the reflectance patterns of incident radiation due to the changes in the vegetative cover, soil moisture, or the various modifications of the Earth's surface. Since the changes in land use and land cover are more or less unidirectional, without much oscillation, it is safe to extrapolate the changes in spatial extent, and also to calculate the rates of changes. A very important tool in this regard is the Geographical Information System (GIS) (Roy and Roy, 2010).

The present study focuses on assessing the changes in LULC pattern of the Jaipur district and its role in inducing Urban Heat Island. Located between Delhi and Agra, it is part of the golden triangle, making the region a popular tourist destination well-known for its heritage, legacy, and culture. On February 5, 2020, UNESCO designated the district's Jaipur city as a world heritage site during the 43rd meet of UNESCO world heritage committee at Baku. Over the years the district has witnessed rapid urbanization and population growth with increased industrial development majorly in the part of Jaipur city and Bagru region (Jaipur Development Authority, Master Development Plan, Vol III, 2011). Such rapid urban densification and industrialization in the district creates the need for framing a sustainable and economically viable urban development plan.

According to the literature reviewed and to the best of the writers' knowledge, no previous study has assessed the urban heat island using the heatwave criteria approach with the help of GIS as used in the present study. However, a few studies have reported the impact of UHI on the occurrence of heatwaves on the basis of LST (Tan *et al.*, 2010). In contrast, in the present study an attempt has been made to identify the UHI on the basis of heatwave criteria as prescribed by Indian Meteorological Department (IMD) to address the three major objectives: (a) to assess the LULC of Jaipur district, (b) to identify the UHIs, and (c) to assess the correlation between LULC and UHIs.

2. Study Area

The study area comprises the Jaipur district, which is among the 33 districts of the Rajasthan state of India (Figure 1). It is situated in the North-eastern part of the state between 26º23' - 27º51' North latitudes and 74º55' - 76º50' East longitudes. It consists of the Jaipur city, which is the largest city and the capital of Rajasthan (Sharma and Jalan, 2015). The district is conjoined in Northwest by Sikar district, in Northeast by Alwar district, in East by Dausa, in South by Tonk, in Southwest by Ajmer, and in West by Nagaur.

The district occupies 3.3% by area of the state, with the geographic region of about 12 thousand sq. km. The Jaipur district is constituted by 13 tehsils namely Amer, Chomu, Jamwa Ramgarh, Shahpura, Viratnagar, Kotputli, Dudu, Phagi, Phulera, Bassi, Chaksu, Jaipur, and Sanganer, with the Jaipur tehsil being the most populous among these (Master development plan, 2025, Jaipur Development Authority, 2011).

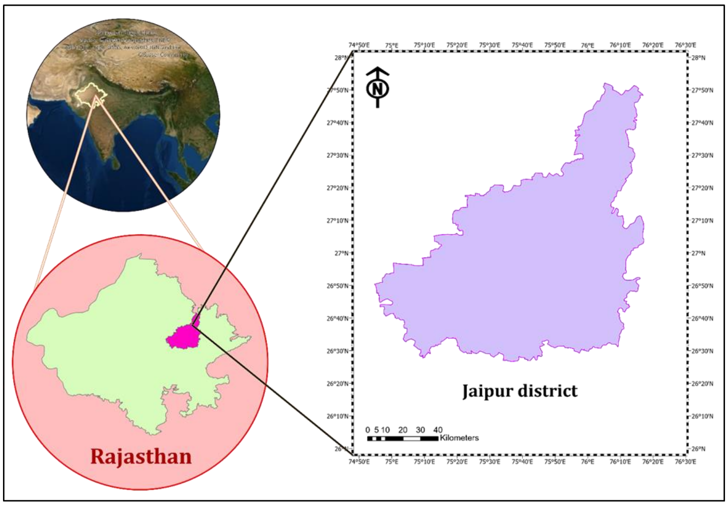


Figure 1. Study area

Located within a semi-arid plain, the district experiences dry climate with a hot season. The hot season starts from March and lasts until mid-June, with a mean maximum temperature of 45^{o}C.

3. Datasets and Methodology

3.1 Satellite datasets and preprocessing

The study utilizes Landsat 7 ETM+ (Enhanced Thematic Mapper) and Landsat 8 OLI-TIRS (Operational Land Imager/Thermal Infrared Sensor) imageries, retrieved from USGS Earth Explorer data portal (https://earthexplorer.usgs.gov/) for the years 2009 and 2019 respectively. The imageries were obtained for 17th May 2009 and 5th May 2019 at the spatial resolution of 30km.

The image preprocessing was done using ArcGIS Pro software prior to the classification. Layer stacking was performed on the imageries of both of the years to convert 3 band (bands 1,2 and 3 /bands 2,3 and 4) images into a single layer image.

3.2 Land use/land cover change estimation

The Supervised Image Classification method was adopted, which is the most frequently used method for classification, specifying sample pixels to the desired class based on the spectral signatures (known as training samples) for classifying the image into different classes. In this study, the Maximum Likelihood (ML) algorithm as supervised classification method was employed. The imageries retrieved from Landsat 7 and 8 were classified into three classes namely Built-up, Vegetation and Other for preparing LULC maps (Table 1).

In order to obtain the decadal changes in LULC pattern, pixel-based approach was used to calculate the area covered by each class followed by estimation of magnitude of change in each land class. The magnitude of change is a measure of positive or negative impact on the LULC class size in the given time period (Islam *et al.*, 2018; Kafi, Shafri & Shariff, 2014). The difference in area coverage between the

Table 1. Description of LULC classification scheme

Land cover class	Description
Built-up	Residential, commercial, industrial, transportation, roads, other urban structure
Vegetation	all types of plantations, forest, crop fields
Other	Barren land, hilly areas, mountains, water body

years 2009 (1st year) and 2019 (2nd) was calculated by using Equation (1).

Magnitude change = area coverage during 2nd year – area coverage during 1st year (1)

Further the percentage change was estimated using the formula in Equation (2).

Percentage change = (Magnitude change / 1st year area) *100 (2)

3.3 Estimation of land surface temperature (LST)

In order to determine the LST, thermal infrared bands of Landsat 7 (Band 6 'high gain') and Landsat 8 (Band 10) were utilized. Landsat 7 thermal data was acquired in 60m resolution (for the wavelength range 10.40 -12.50 µm) while Landsat 8 thermal data was acquired in 100m resolution (for the wavelength range 10.6 – 11.19 µm). LST retrieval method as mentioned in Landsat 7 and 8 Science Data book was followed for LST estimations in the study (Department of the Interior U.S. Geological Survey, 2016; Irish, 2000) (Figure 2). The following 5 steps were used for the retrieval of LST.

Step 1. The pixels of the images were converted from Digital Number (DN) value to Radiance Value using formula:

For Landsat 7

$$L_\lambda = \frac{Lmax_\lambda - Lmin_\lambda}{Qcal_{max} - Qcal_{min}} (Qcal_{max} - Qcal_{min}) + Lmin_\lambda \quad (3)$$

For Landsat 8

$$L_\lambda = M_L * Qcal + A_L \quad (4)$$

where L_λ refers to the spectral radiance measured in Watts/m^2*ster* µm; Q_{cal} refers to the quantized and calibrated pixel values in DN; Q_{cal} max is the maximum number of each band which corresponds to 255 and Q_{cal} Min is the minimum number of each band which corresponds to 1. The $Lmin_\lambda$ and $Lmax_\lambda$ denote the minimum (3.200) and maximum (12.650) value of the spectral radiance in Watts/m^2*ster* µm. ML refers to Radiance multiplicative Band no. (0.0003342) and AL refers to Radiance add band no. (0.10000). All the values are as per the metadata file of the satellite imageries.

Step 2. Spectral radiance was converted into brightness temperature.

$$BT = \frac{K2}{\ln\left(\frac{K1}{L_\lambda}+1\right)} \quad (5)$$

where BT refers to the brightness temperature in Kelvin; L_λ refers to the spectral radiance in Watts/m^2*ster* µm; K1 and K2 are thermal band calibration constants of Landsat 7 (K1= 666.09 and K2 = 1282.71 Watts/m^2*ster* µm) and Landsat 8 (K1=774.8853 and K2 = 1321.0789 Watts/m^2*ster* µm) respectively.

Step 3. The brightness temperature (T) was then converted from Kelvin to degree Celsius.

$$T(^oC) = BT-273.15 \quad (6)$$

Step 4. Land surface Emissivity (LSE), was calculated in order to estimate LST because it is the ratio of radiance emitted by the object to the radiance emitted by the black body at the same temperature.

$$LSE= 0.004*PV+0.986 \quad (7)$$

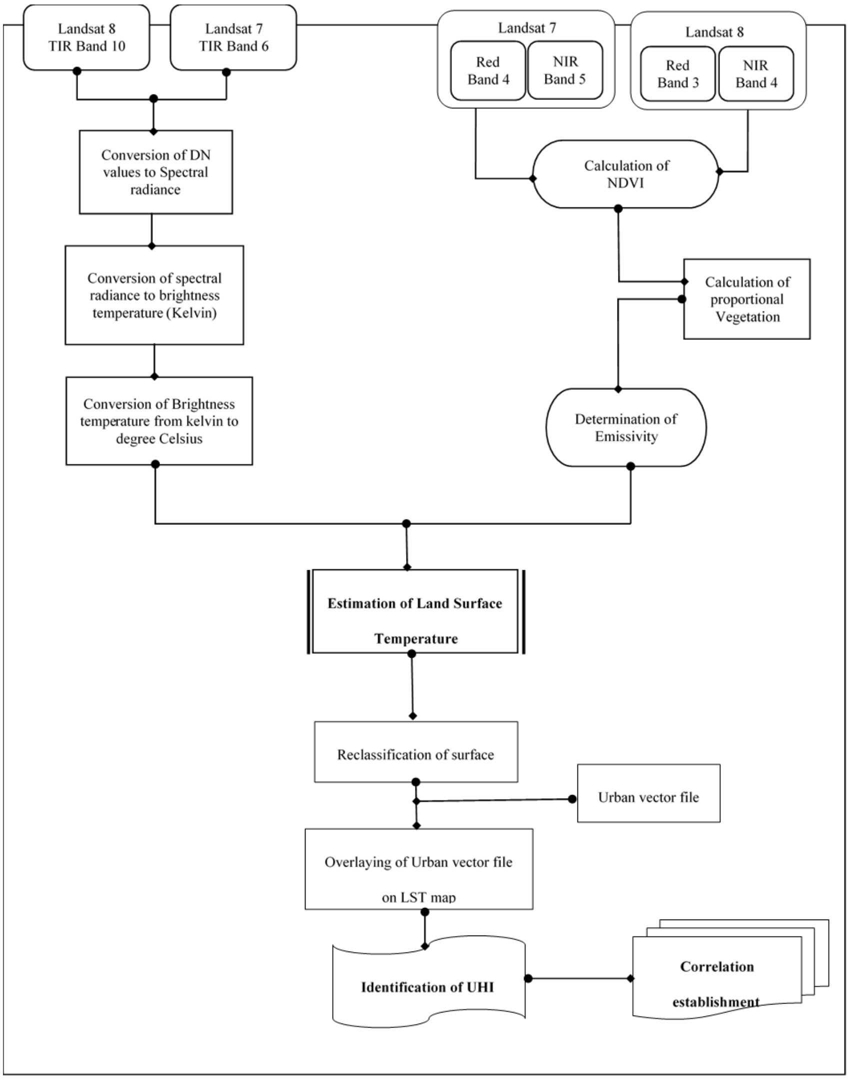


Figure 2. Workflow of LST and UHI estimation

where PV is proportion of Vegetation, which is in turn calculated using Normalized Differential Vegetation Index (NDVI) values (PV= (NDVI - NDVI min / NDVI max – NDVI min)^2).

Step 5. Finally, LST values were computed from brightness temperature.

$$LST= T/ [1 + (\lambda * T/p) * \ln(e)] \quad (8)$$

where LST refers to the Land Surface Temperature in °C; T is brightness temperature in °C; λ is the wavelength of emitted radiance; p is the calculated value of h*c/s which is equivalent to 14,380.

3.4 Identification of UHI

To understand the effects of LULC on occurrence of urban heat islands, heatwaves were identified during the study period (between 2009-2019). The heatwave - based approach is utilized in the present study as heatwaves are known to cause dreadful impacts on the human health and the environment (Earth System Science Organization, Ministry of Earth Sciences, 2020; Pai, Nair & Ramanathan, 2013). In the present study, the heatwave criteria prescribed by IMD (Indian Meteorological Department) were considered for categorization of the LST values (Table 2). The LST values were first classified into 9 classes on the bases of temperature variation. For determination of heat islands, the LST values were reclassified and the classes with temperature of 45^{0}C or more were extracted. Two temperature categories were formed on the basis of heatwave criteria namely 45-47 ^{0}C (denoted as Urban Heat Island) and 47-49 ^{0}C (denoted as severe Urban Heat Island). To demarcate the heatwave areas, the pixels in the images with 45^{0}C – 47^{0}C were assigned value 1 and the pixels for 47^{0}C - 49^{0}C were assigned value 2. The urban vector file of both the years was applied on the reclassified LST maps of the respective years and area under class value 1 was considered as UHIs while area under class value 2 was considered as severe UHIs.

4. Results and Discussion

4.1 Change in LULC from 2009-2019

The findings of the study reveal that the district has undergone a rapid increase in LULC between 2009 and 2019 both in terms of physical expansion and internal densification particularly in the North, Northwest, East and Southwest directions of the district (Figure 4). As per the results obtained in the present study, urban area has increased from 388.19 km^2 to 491.26 km^2 that accounts for 26.55% increase between years 2009 and 2019 (Table 3). The results are in line with outcomes reported by Sankhala & Singh, 2014 in Jaipur city. Similar increases in urban area of other regions over the years have also been reported by Chotchaiwong and Wijitkosum (2019), Jalan and Sharma (2014), Mourya, Rafi, and Shamoo (2021), Ramachandra, Bharath, and Sowmyashree (2015).

The surge in urban category can be attributed to the increasing population due to increased job opportunities in the district as a result of growing industrialization and development of the region during the past decade (Master development plan, 2025, Jaipur Development Authority, 2011).

Table 2. Heatwave criteria based on actual maximum temperature of the plains

Criteria	Temperature
Heat wave:	When actual maximum temperature ≥ 45^{0}C
Severe heat: Wave	When actual maximum temperature ≥ 47^{0}C

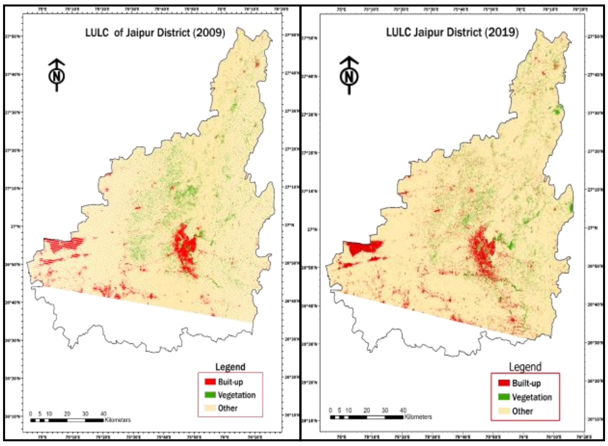


Figure 3. Land use Land cover map, 2009 and 2019

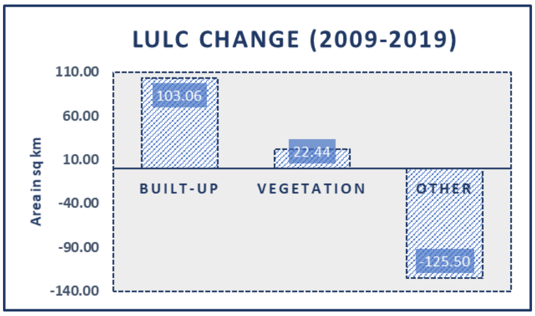


Figure 4. Changes in extent of selected LULC classes from 2009-2019

Table 3. Quantitative assessment of LULC in Jaipur district during 2009 and 2019

Class	2009		2019		Magnitude change	% change, between 2009 and 2019
	Km^2	Percentage	Km^2	Percentage		
Built-up	388.19	4.62	491.26	5.85	103.06	26.55
Vegetation	375.74	4.48	398.18	4.74	22.44	5.97
Others	7632.26	90.90	7506.76	89.41	-125.50	-1.64
Total	8396.20	100	8396.20	100		

During the study period, in addition to increased urban area, an increasing trend was also observed in vegetation class with an overall increase of 22.44 km^2 which accounts for a 5.97% increase with respect to 2009. This increase in the vegetation cover can be reasonably due to the increase in natural reserves, agricultural activities, and croplands present in the district. During the study period the government has also focused on conserving the forest resources of the district with a resultant increase in the forest cover of the region (Forest Survey of India, 2019). However, the increase in the vegetation cover of the overall district is very negligible relative to the increase in areal extent of the urban category.

Regarding the class categorized as 'other', which occupies almost 90% of the study area, it has declined concomitantly due to urban sprawl, accounting for a -1.64% decrease during the decade.

4.2 Association between LULC, LST & UHI

With the changes in LULC pattern, the mean land surface temperature of an area also changes considerably over the time. During the present study, a significant increase of 5^0C in the mean land surface temperature (LST) has been recorded from the year 2009 to 2019 (Table 4 and Figure 5). The maximum temperature pixels were found in the district's barren area. Within the city, the inner city, specifically the walled city, which is distinguished by the high built-up area was observed within the maximum temperature range, whereas the outer city of the region, which is distinguished by barren land, limited vegetation and built-up area, was observed to have a relatively lower temperature range. These spatial and temporal variations in the LST patterns greatly highlight the rapid urbanization in the district at the expense of fallow land.

Figure 6 (a) and (b) demonstrates the spatial pattern of UHIs in the study area. UHI is indicated with red markers and Severe UHI is indicated with black markers. It is evident from these figures that severe UHIs were absent during 2009, whereas they are highly observed during 2019 distinctly indicating the impact of increased urbanization over the decade. Severe UHIs were detected in the district in 2019, with temperatures ranging within 47-49^o Celsius, but no such severe heat islands were observed in 2009. The share of UHIs increased mostly in Jaipur city region, particularly in the West, Northwest, and Southeast. These areas make up the majority of the city's industrial sector. Similar result were reported by other studies where UHI intensities were found to be increased with increase in surface temperature as a result of increased built-up area (Aslan & Koc-San, 2016; Halder, Bandyopadhyay, & Banik, 2021; Karakus, 2019; Puppala & Singh, 2021).

Increased conversion of arable land into impervious one profoundly changes the land use patterns. The increase in LST can be attributed to (i) reduced evapotranspiration rate due to less vegetation cover, (ii) higher absorption of solar radiation due to lowered albedo, and (iii) restricted air flow due to higher rugosity and larger amount of anthropogenic heat emissions, which lead to the formation of UHI (Akbari, Pomerantz, & Taha, 2001; Santamouris, Paraponiaris, & Mihalakakou, 2007). Similar phenomenon was also observed by Khandelwal, Goyal, Kaul, & Mathew (2017) in Jaipur city. In addition to the above factors, internal densification of the urban area further contributes to the higher absorbance and re-emittance of the solar radiation, thereby increasing the temperature of the hot spots.

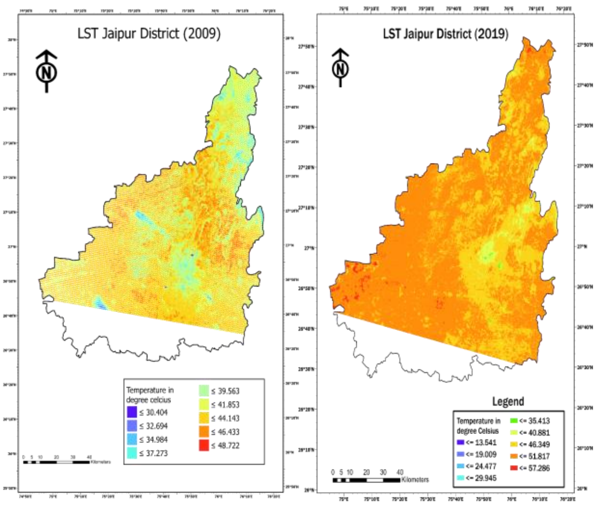
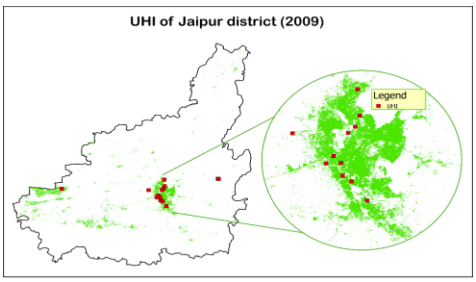


Figure 5. LST maps- 2009 and 2019

Table 4. Statistical LST values 2009 and 2019

Year	Minimum temperature (^{0}C)	Maximum temperature (^{0}C)	Mean temperature (^{0}C)	Standard deviation (^{0}C)
2009	28.11	48.69	41.92	2.06
2019	8.07	57.29	47.02	2.73

(a)



(b)

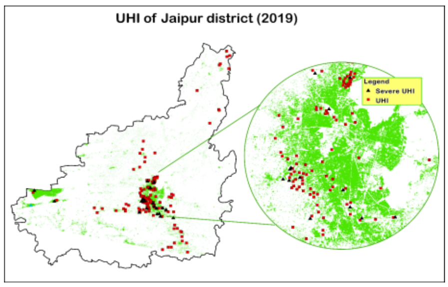


Figure 6. Map showing severe and moderate UHI for the year (a) 2009, and (b)2019

5. Conclusions

The current study examined LULC variations and their effects on LST and as a consequence, increased UHIs in the Jaipur district. The results of the study clearly indicate a rise in LST by 5% with an increase in LULC by 26.55%. This change in LST has induced UHIs in the study area. The Heat Islands (heat spots) were found to be increased in number as well as their temperature was also found to be higher when compared to an earlier year. With the district's ever-increasing population, the need for land and resources has grown exponentially over the years. Human-induced LULC changes have manifested in increasing trend of the surface temperatures, creating an ideal setting for the formation of hot spots. Such urban sprawl situations have emerged as one of the potential threats to sustainable development. In such circumstances, urban planning with appropriate resource management and infrastructure allocation has become a key concern for urban planners. The intensification of heat islands not only increases energy demands, but also has detrimental consequences on human health and the environment.

As a result, the study clearly highlights the need for continuous monitoring of LULC in the area along with the development of rational, scientific and sustainable urban land use plans by the policy makers. The study also signifies the potential use of remote sensing and GIS technology for effective monitoring of the spatio-temporal growth of the district, to understand the driving forces and key hot spots, and to devise sustainable land use plans and policies for reducing impacts and maintaining balance in the ecosystem.

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