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Impact of land use change and urbanization on urban heat island in Lucknow city, Central India. A remote sensing based estimate

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ABSTRACT

In this paper, the negative impact of urbanization over a time and its effect on increasing trend of temperature and degradation of urban ecology was assessed using the Landsat thermal data and field survey of Lucknow city, India. Land surface temperature (LST) estimation has been carried out using Mono-window algorithm, temporal land use change map, assessment of vegetation cover through Normalized Difference Vegetation Index (NDVI), and ecological evaluation of the city was carried out using the Urban Thermal Field Variance Index (UTFVI). Results indicated that the spatial distribution of the land surface temperature was affected by the land use-land cover change and anthropogenic causes. The mean land surface temperature difference between the years 2002 and 2014 was found is 0.75 °C. The observed results showed that the central portion of the city exhibited the highest surface temperature compared to the surrounding open area, the areas having dense built-up displayed higher temperatures and the areas covered by vegetation and water bodies exhibited lower temperatures. Strong correlation is observed between Land surface temperatures with Normalized Difference Vegetation Index (NDVI) and UTFVI. The observed LST of the area also validated trough the Google Earth Images. Ecological evaluation of the area also showed that the city has worst ecological index in the highly urbanized area in the central portion of the city. The present study provides very scientific information on impact of urbanization and anthropogenic activities which cause major changes on eco-environment of the city.

1. Introduction

Intergovernmental Panel on Climate Change (IPCC) projected that global average surface temperature could be increase around 1.4–5.8^{C} by 2100 and the concentration of atmospheric carbon dioxide could be double compared to pre-industrial concentration. Anthropogenic activities have changed the land use and land cover (LULC) in the developed and developing countries in the centuries (Liu & Tian, 2010). The land cover and its pattern changes are major cause of environmental degradation and changes in urban hydrology, rising urban heat Islands, climate change from local to regional scales (Denge & Srinivashan, 2016; Ho, Knudby, Xu, Hodul, & Aminipouri, 2016; Kikon, Singh, Singh, & Vyas, 2016; Zhoua et al., 2016). However, these environmental changes occur at multiple spatial and temporal scales that may highly differ among regions. LULC changes have a great impact on biodiversity, climate change and global warming both local and regional level and urbanization is one of the most dominant and visible anthropogenic forces on Earth. Since the second half of the twentieth century, the world has experienced its fastest rate of Urbanization, particularly in developing countries. It is well known and documented that urbanization can have significant effects on local weather and climate.

The most serious issues in urban areas are rising land surface temperature due to modification and transformation of natural vegetated and open areas into impervious surfaces and this problem is more common in unplanned cities. The changes in land use pattern affect the entire urban and sub-urban environment such as land surface temperature, evaporation rates and urban hydrology of the cities. Urban heat island (UHI) is one of the important outcomes induced by urbanization and anthropogenic activities influenced by land use pattern and it represents the difference in albedo, roughness, and heat flux exchange of land surface. The urban heat island (UHI) is a well-known phenomenon in which urban environments retain more heat than nearby rural environments, has a profound effect on the quality of life of the world's growing urban population. Urban heat island is one of the most accustomed effects (Landsberg, 1981; Streutker, 2002), which is the direct exemplification of environmental degradation (Lu, Feng, Shen, & Sun, 2009). Due to the expansion in urban area and energy

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consumption in urbanized areas, the problem of UHI has turned out to be very important over the last 50 years (U.S. Environmental Protection Agency, 2008). Luke Howard described the idea of urban heat island during the early 1833 and ever since this study has received a lot of attention (Camilloni & Barros, 1997; Detwiller, 1970; Fukui, 1970; Howard, 1833; Johnson et al., 1994; Katsoulis & Theoharatos, 1985; Lee, 1993; Tso, 1996; Wang, Zheng, & Karl, 1990). With the hastening of the process of urbanization, the problem of urban heat island has also become more and more significant as it has a severe impact on society and environment (Chen, Ren, Li, & Ni, 2009). The main reason of urban heat island is the transformation of the land surface in which the naturally vegetated areas are replaced by various buildings, roadways, pavements and other infrastructures that absorbs a lot of incoming solar radiations. Also, the heat released from vehicles, industries, factories, air conditioners, etc. adds warmth to the surrounding areas. In addition to it, the airflow is also decreased as the high rise buildings and narrow lanes heats up the air that is trapped in between further aggravating the heat island effect. Urban heat island can also have an influence on the local weather and climate by changing the local wind patterns and the rates of precipitation. Urban heat island can also aggravate human health causing various respiratory diseases because of the poor quality of air produced by various cooling agents (Liu & Weng, 2011; Liu & Zhang, 2011).

Recently large number of research work have been reported globally on impact of urban heat Island and its potential affect on urban vulnerability, risk and spatial distribution based on remote sensing and earth surface temperature data (Aminipouri, Knudby, & Ho, 2016; Aubrecht & Ozceylan, 2013; Bai, Woodward, & Liu, 2016; Buscail, Upegui, & Viel, 2012; Depietri, Welle, & Renaud, 2013; Díaz et al., 2015; Dugord, Lauf, Schuster, & Kleinschmit, 2014; Ho, Knudby, & Huang, 2015; Keramitsoglou et al., 2013; Kim & Ryu, 2015; Laverdière et al., 2016; Norton et al., 2015; Oven et al., 2012; Uejio et al., 2011; Van der Hoeven & Wandl, 2015; Zhu et al., 2014). The results observed from these case studies are justified that due to the fast rate of urbanization, deforestation and other associated

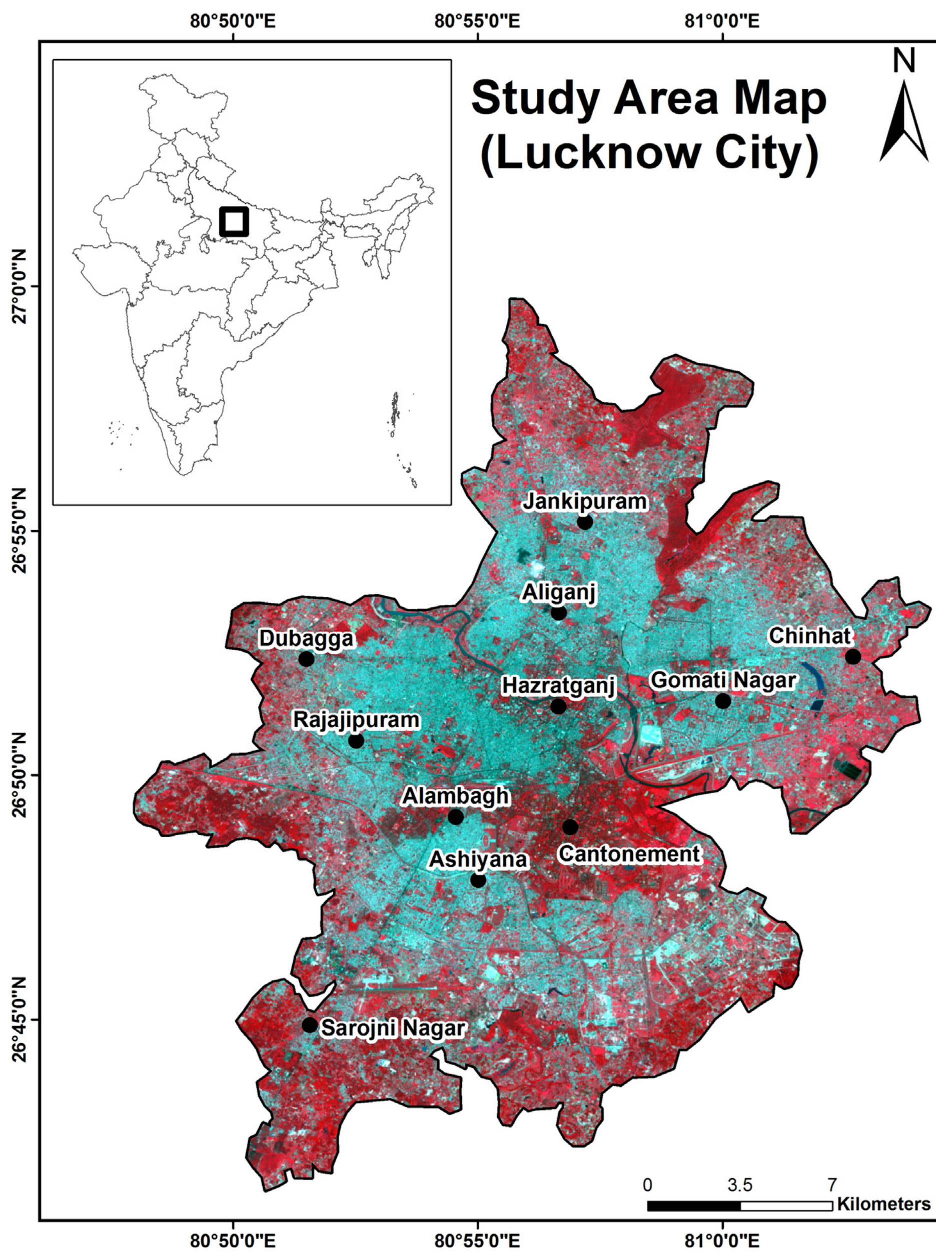


Fig. 1. Location map of Lucknow City, India. Location map of the Study area map.

anthropogenic activities in the urban and sub-urban areas cause a very serious health and environmental issues.

Recently some of the studies has been reported from Indian cities on impact of urbanization and land use change on environment and increasing trend of urban temperature based on multi-temporal thermal remote sensing data and field survey to estimate the Urban Heat Island and their spatial distribution (Kikon et al., 2016). Grover and Singh (2015) conduct a comparative study on urban heat island assessment for the Delhi and Mumbai city based on the thermal satellite data for assessment of rising trend of urban heat and its correlation with NDVI and they concluded that due to urbanization and declining trend of natural vegetation are the main cause of elevated temperature in urban area. A case study for the city of Delhi was carried out for evaluating and comparing the UHI hotspots based on in situ measurements and Remote Sensing observations and it is observed that higher temperatures were found in the areas, which are occupied by dense built up infrastructures and commercial centers and the intensity of UHI was found to be higher during midnight and afternoon hours (Mohan et al., 2012). A study was carried out by Venkatesh Dutta in 2012 for the city of Lucknow to assess the impact of changing land use dynamics on the peri-urban growth characteristics. As a result it was observed that the urban sprawl population was found to be 44.03 sq.km in 1901 which increased to 303.63 sq.km during 2011 and is expected to further increase to 414.34 sq.km in 2021 and at this rate based on the observations of urban sprawl population the intensity of UHI is also likely to increase over the years (Dutta, 2012).

Lucknow is the capital city; it is one of the largest metropolitan cities in the central India and one of the fastest growing economic and industrial growths. The spatial distribution of urban temperature in Lucknow area was studied, and the influences of LULC and vegetation cover were analyzed in the present work. Since mono-window algorithm is suitable for the retrieval of land surface temperature from a single thermal band data, so this algorithm has been used in this current study for the retrieval of land surface temperatures from Landsat TM and Landsat 8 TIR bands. The ecological evaluation for the city of Lucknow has also been carried out in this study to quantitatively describe the influence of urban heat island using urban thermal field variance index (UTFVI).

2. Geographic information of the study area

The city of Lucknow is situated in the state of Uttar Pradesh in Central part of India is a Capital city. The study area of Lucknow city covers an area of 429.50 km^2 (Fig. 1). Its boundary lies between the latitude 26°45′0″ N and 26°55′0″ N and longitude 80°50′0″ E and 81°5′0″ E. Lucknow has transformed from a small population center during the early 1990s to a big urbanized city having varied economic, physical and political features and emerging as becoming one of the most rapidly growing urban cities of Central India. Lucknow is located on banks of the Gomati River in the Central Ganga Alluvial Plain. The Ganga Alluvial Plain is located between the Indus Plain in the West and the Brahmaputra Plain in the East. It is an outstanding geographical feature characterized by its low elevation (300 m above mean sea level (AMSL)), low relief (20–35 m) and high population density. The Plain is drained by rivers originating from the Himalaya and also originating within the Plain. Rivers originating from the Plain are the groundwater-fed alluvial rivers. The Ganga Alluvial Plain represents characteristic geomorphic feature exhibiting network of river channels, their valleys and prevailing large areas referred as interfluve. The area has come under sub-humid climate and four well marked seasons are visible as follows: the Summer season (March–May) followed by the Monsoon season (June–September) of heavy precipitation,

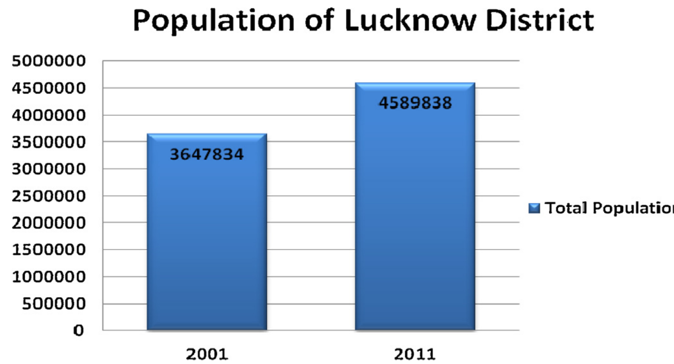


Fig. 2. Graph shows population growth in the Lucknow in last two decades.

Post-monsoon season (October–November) and then the Winter season (December–February). Fogs are common in late December to late January. The maximum and minimum temperature ranges from 40–45 °C to 5–15 °C. The average rainfall in the region is 904 mm. The growth rate of population in last two decades of Lucknow has increased drastically and the current population of the city is more than 45 lakhs (Fig. 2). The main cause of population growth is the capital city of the state and most of the rural population and nearby district are concentrated in the capital due better life style, job and academic facility. The population growth also responsible for conversion of natural and open lands into the urbanized landscape.

3. Data used

3.1. Satellite data and other auxiliary data

The details of satellite images used in the present work are given in Table 1 and other auxiliary data such as Survey of India Toposheets and MOSDAC data are also used.

3.2. Pre-processing

Landsat TM satellite dataset for the year 30th September 2002 and Landsat 8 satellite dataset for the year 23rd September 2014 was used in order to effectively classify the spatial distribution of land cover/land use (LULC) classes and for identifying the land surface temperature for the city. Data-preprocessing have been carried out using ENVI 4.7 software. Landsat TM and Landsat 8 comprises of independent different band images which was layer stacked and then combined to form a multi-band image. All these dataset's have been converted to 30 m cell size and brought to same projection in order to carry out the spatial analysis. The band 6 (thermal infrared band) of Landsat TM and band 10 (thermal infrared band) of Landsat 8 was used to retrieve the land surface temperatures by converting the Digital number (DNs) to radiances. This study also evaluated the normalized difference vegetation index (NDVI) in which the bands within solar reflectance spectral range were used for extracting the vegetation indexes. After the step of pre-processing, the satellite images were then used for the study of urban heat island. Further processing's has been carried out using ERDAS 9.1 and Arc GIS 10.2.1 softwares.

Table 1
Data used and their source.

Data used	Data acquisition date	Source
LANDSAT TM	30th September 2002	http://earthexplorer.usgs.gov/
LANDSAT 8	23rd September 2014	

3.3. Image classification

Supervised classification scheme has been used for the process of image classification in which training sets were selected for image classification using Maximum Likelihood classifier (MLC), a statistical decision in which the pixels are assigned based on the class of maximum probability. Image classification was used to define the Land use/Land cover types into seven classes, namely, Built up, Water logged areas/Wetlands, Wasteland (Salt affected land), Urban Plantations and Forest, Agricultural lands, Fallow lands and Water bodies have been categorized. As described by Lillesand, Kiefer, and Chipman (2014), confusion matrix was also generated from the classified image and signature file for the accuracy assessment. Overall accuracy of LULC map was 88.38% and Kappa coefficient was 0.832.

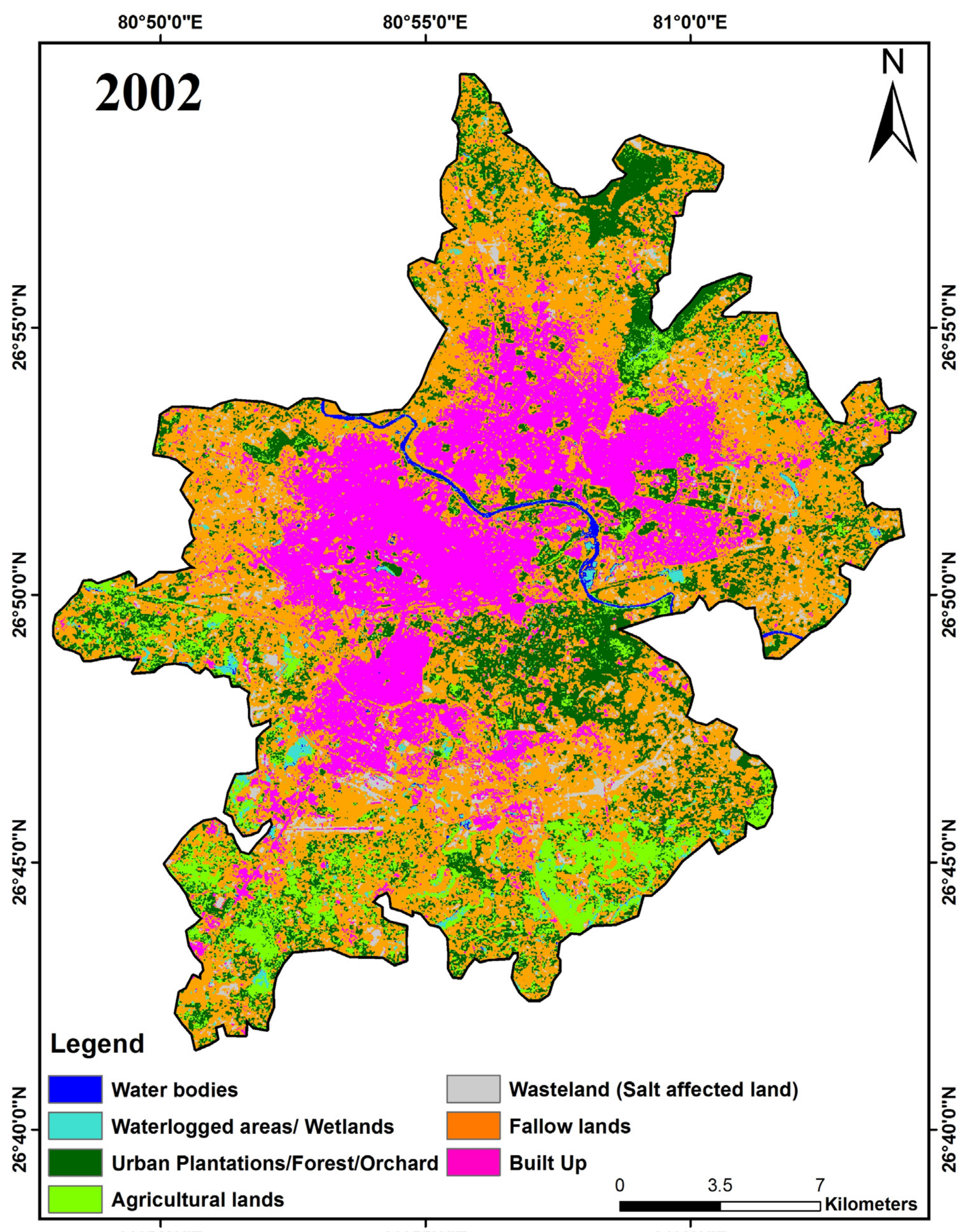
4. Methodology

4.1. Mono-window algorithm for the retrieval of LST

In this study, land surface temperature (LST) of Lucknow city was estimated from the thermal infrared bands of Landsat satellite data's using the mono-window algorithm proposed by Liu and Weng (2011), Liu and Zhang (2011) and Qin, Zhang, Amon, and Pedro (2001). This algorithm is carried out using three main parameters, namely, transmittance, emissivity and mean atmospheric temperature. TIR band 6 of Landsat TM and TIR band 10 of Landsat 8 records the radiation with spectral range ranging from 10.40 to 12.50 for Landsat TM data's and 10.60 to 11.19 for Landsat 8 data's.

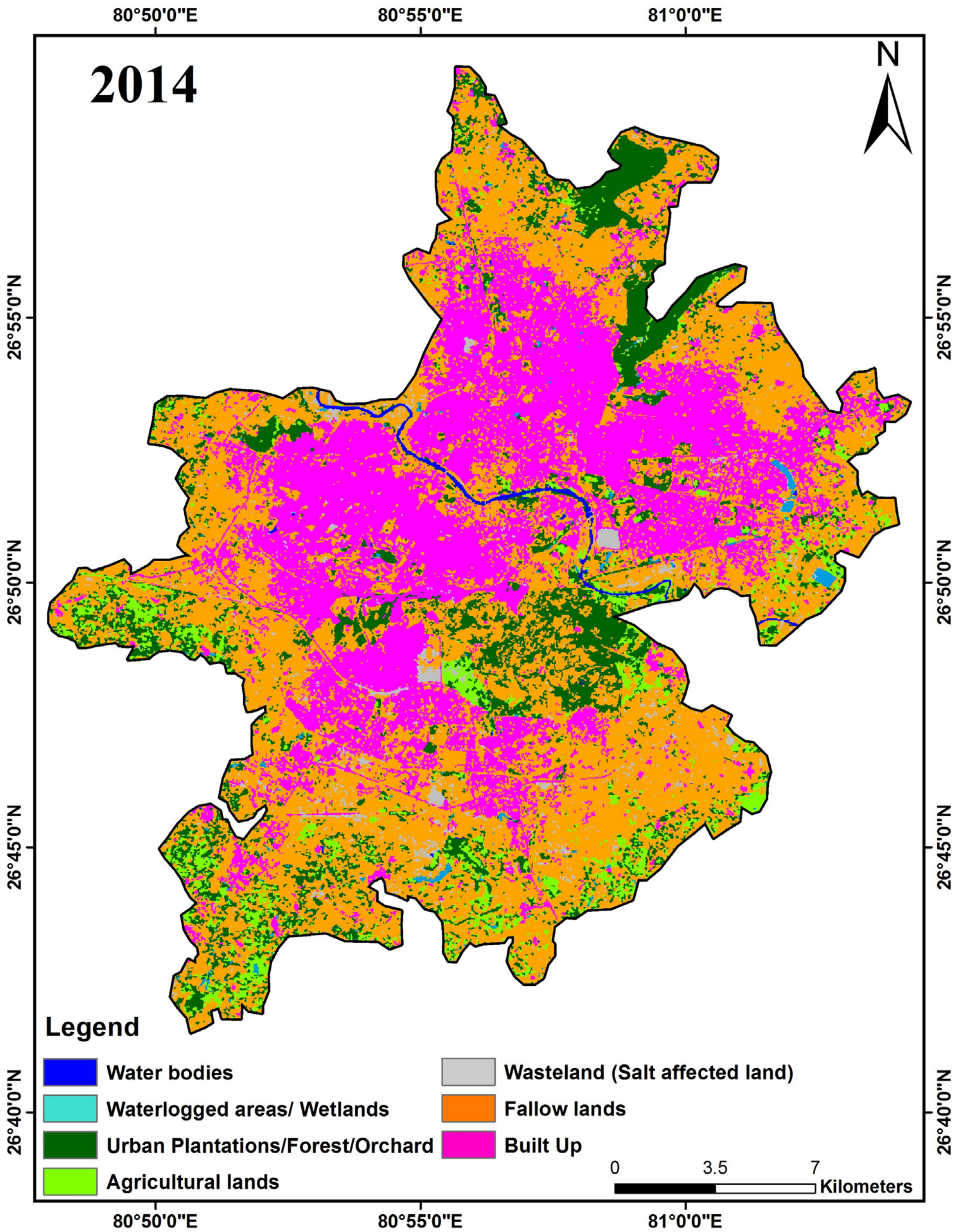
Formula:

$$T_c = \{a(1 - C - D) + [b(1 - C - D) + C + D]T_i - D * T_a\}/C$$



(a)

Fig. 3. (a) Land use/land cover map of Lucknow city for 2002 and (b) 2014.



(b)

Fig. 3. (*Continued*)

where $a = -67.355351$, $b = 0.4558606$, $C = \varepsilon_i * \tau_i$, $D = (1 - \tau_i)[1 + (1 - \varepsilon_i) * \tau_i)$, ε_i = emissivity and τ_i = transmissivity.

4.2. Conversion of digital number to radiance

For converting the DN's of band 6 of Landsat TM and band 10 of Landsat 8 into spectral radiance values, the equation can be written in band math of ENVI 4.7 software as:

(a) For Landsat TM

$$CV_{R1} = \frac{((LMAX_\lambda - LMIN_\lambda)}{(QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_\lambda}$$

where CV_{R1} is the cell value as radiance, $QCAL$ = Digital Number, $LMIN_\lambda$ = Spectral radiance scales to $QCALMIN$, $LMAX_\lambda$ = Spectral radiance scales to $QCALMAX$, $QCALMIN$ = the minimum quantized calibrated pixel value (typically 1) and $QCALMAX$ = the maximum quantized calibrated pixel value (typically 255).

(b) For Landsat 8

$$L_\lambda = M_L Q_{Cal} + A_L$$

where L_λ = TOA spectral radiance (Watts/(m^2 × srad × μm)), M_L = Band-specific multiplicative rescaling factor from the metadata (*RADIANCE_MULT_BAND_x*, where x is the band number), A_L = Band-specific additive rescaling factor from the metadata (*RADIANCE_ADD_BAND_x*, where x is the band number), Q_{Cal} = Quantized and calibrated standard product pixel values *(DN)*.

4.3. Calculation of brightness temperature

The inverse of Plank function is applied to the radiance values estimated from the DN's of the thermal bands to derive the temperature values (Wang et al., 1990).

$$T = \frac{K_2}{\ln\left(\frac{K_1 \times \varepsilon}{CV_{R1}} + 1\right)}$$

where T = Degrees (in Kelvin), CV_{R1} = Cell value as Radiance, K_1 and K_2 values can be obtained from the Meta data file.

4.3.1. Calculation of atmospheric transmittance

The "NASA webpage for atmospheric correction" modules have been used for calculating the atmospheric transmittance from Landsat TM and Landsat 8 data.

4.3.2. Calculation of land surface emissivity

NDVI is used for the estimation of Land Surface emissivity and when the value of NDVI ranges from 0.157 to 0.727, the following equation can be applied. This method was proposed by Van de Griend in the year 2003 (Van de Griend & Owe, 1993).

$$i = 1.0094 + 0.0047\ln(NDVI)$$

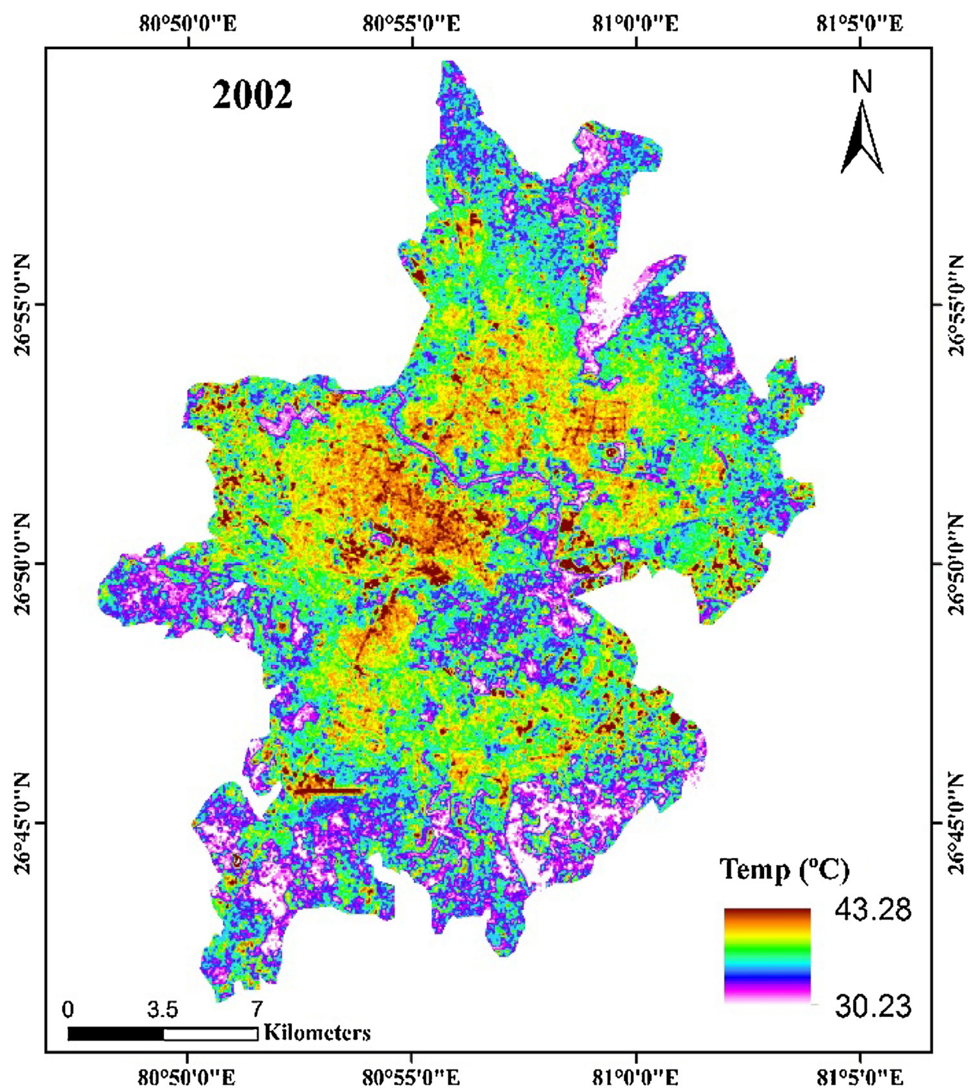
During 2006, another complete method for the estimation of land surface emissivity was also proposed by Zhang et al. and the following equations as shown in Table 2 below can be used for calculating Emissivity using NDVI (Zhang, Wang, & Li, 2006).

Table 2
Emissivity estimation using NDVI.

NDVI	Land surface emissivity (ε_i)
NDVI < −0.185	0.995
−0.185 ≤ NDVI < 0.157	0.970
0.157 ≤ NDVI ≤ 0.727	1.0094 + 0.047 ln (NDVI)
NDVI > 0.727	0.990

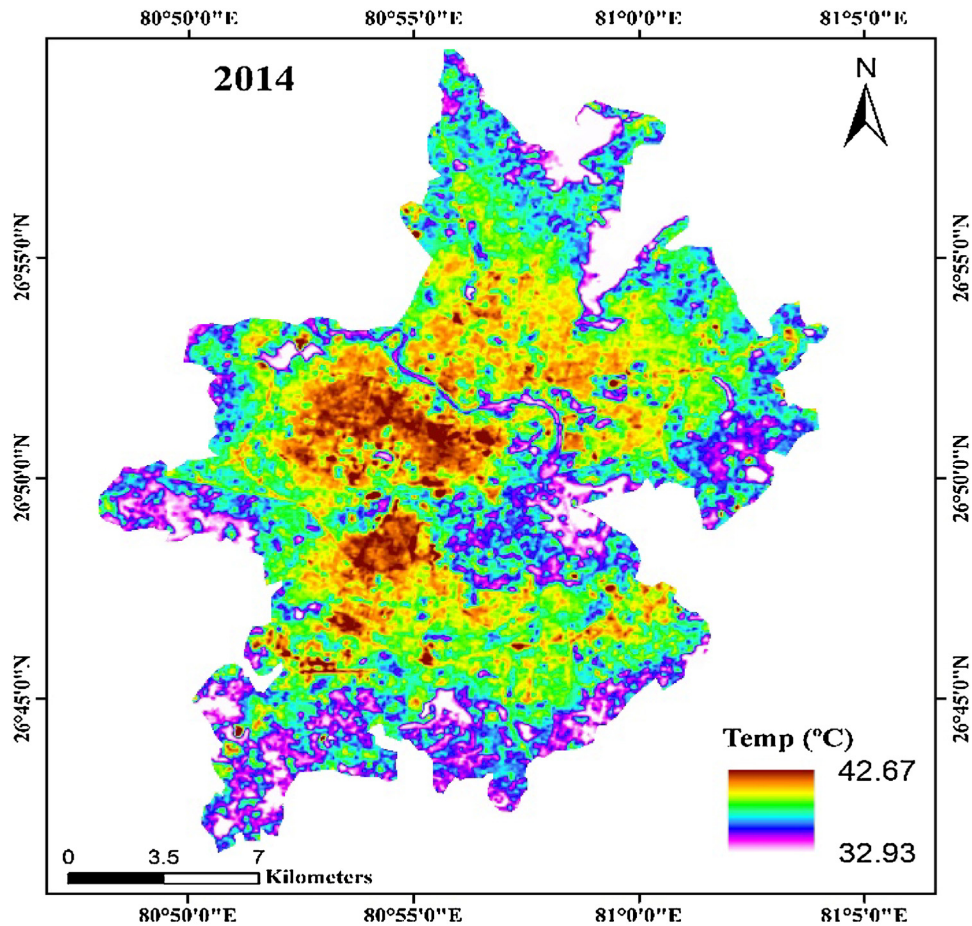
4.4. Estimation of normalized difference vegetation index (NDVI)

Vegetation density mapping from remotely sensed data is calculated by an index known as Normalized Difference Vegetation Index (NDVI). Using this algorithm, NDVI from multi-temporal images



(a)

Fig. 4. (a) LST map of Lucknow city for 2002 and (b) 2014.



(b)

Fig. 4. (*Continued*)

Table 3
Land use/land cover of Lucknow city during 2002 and 2014.

Lucknow temporal landuse (in sq.kms)		
LULC	30th September 2002	23rd September 2014
Built up area (urban and rural)	93.97	130.33
Waterlogged areas/wetlands	6.71	8.18
Wasteland (salt affected land)	14.68	12.11
Urban plantations and forest	75.97	50.27
Agricultural lands	32.37	25.03
Fallow lands	202.47	201.84
Water bodies	3.29	1.71

(2002 and 2014) from Landsat TM and Landsat 8 is calculated from reflectance measurements in the red and near infrared (NIR) portion where the wavelengths are segregated and normalized by dividing the overall brightness of each pixel (Liu & Weng, 2011; Liu & Zhang, 2011; Mallick, 2014). Classified Multi-temporal satellite data of 2002 and 2014 were used for NDVI change analysis and generation of Change matrices of the area using Arc GIS 10.2 and ERDAS IMAGINE 2014 software. The classified NDVI images were further reclassified in five categories based on the density of vegetation from very low (less than 0.1), low (0.1–0.2), medium (0.2–0.3), high (0.3–0.4) and very high (greater than 0.4) NDVI values.

Formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR = Band 4 (For Landsat TM) and Band 5 (For Landsat 8) and R = Band 3 (For Landsat TM and ETM) and Band 4 (For Landsat 8).

4.5. Urban thermal field variance index (UTFVI)

Urban Thermal Field Variance Index (UTFVI) was also calculated for the city to describe the effect of urban heat island quantitatively. UTFVI is based on the value of land surface temperature

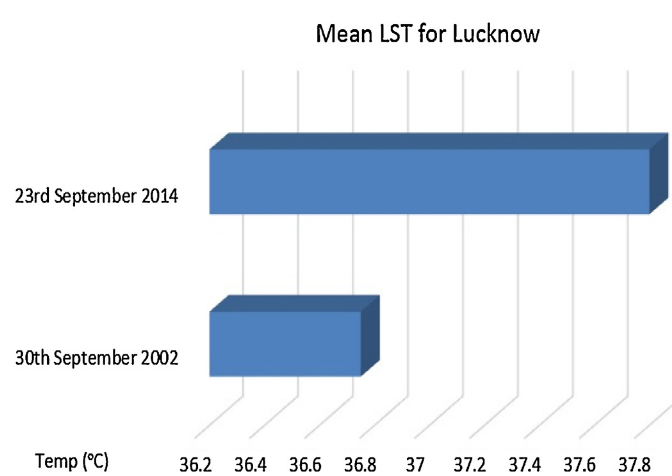


Fig. 5. Bar graph of mean LST of Lucknow city between 2002 and 2014.

of a particular area and accordingly the intensity of heat island is analyzed. The higher the value of land surface temperature, the more is the heat effect (Liu & Weng, 2011; Liu & Zhang, 2011). UTFVI is calculated using the equation given below.

Formula:

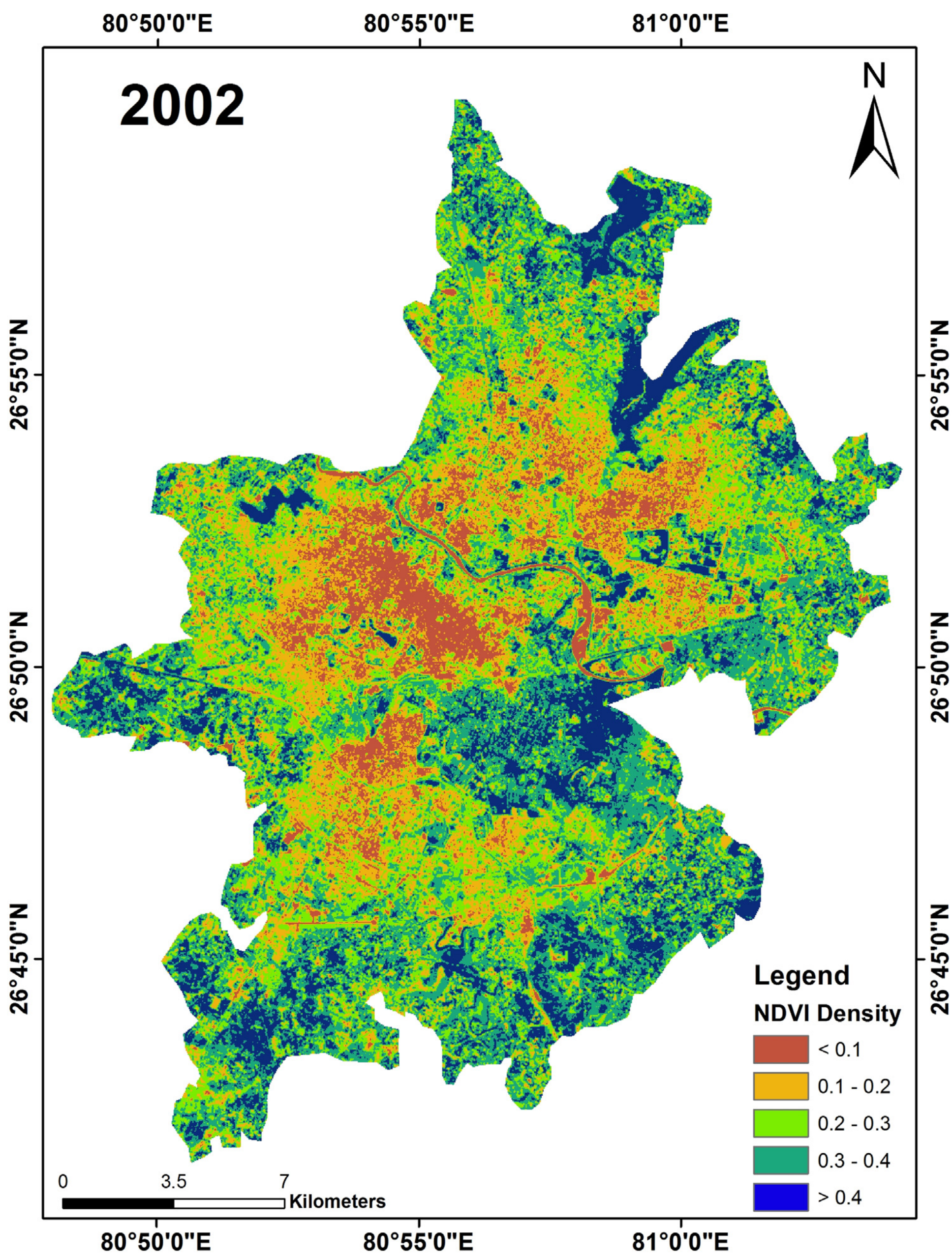
$$UTFVI = \frac{(T_S - T_{mean})}{T_{mean}}$$

where T_S = Land Surface Temperature of a certain point (in Kelvin) and T_{mean} = Mean LST of the whole study area (in Kelvin)

5. Results

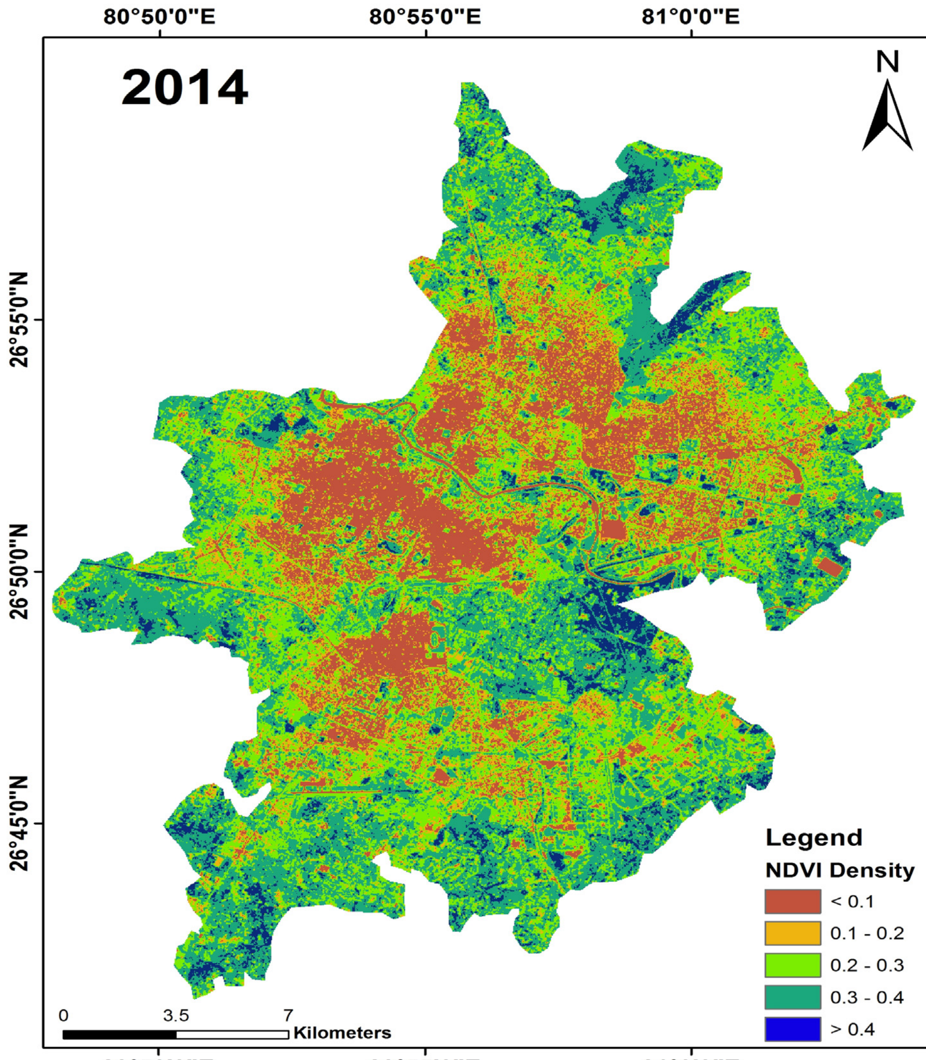
5.1. Relationship of LULC change with LST

LULC change and urbanization are the important physical change leading to increase in land surface temperature in urban environment. Spatio-temporal changes in LULC and its negative effect on urban heat island (UHI) are very important for the assessment of urban microclimate of any area. Lucknow is the capital and one of the most populated cities of the Central India which have very high population density and growth rate during last one decade (Fig. 2). LULC was used to analyze the relationships between land surface temperature (LST) and land use/land cover (LULC) qualitatively. The spatio-temporal LULC were generated for the year 2002 and 2014 for the Lucknow city using temporal landsat satellite images by applying standard image classification techniques and large scale field survey in the area using GPS receiver. The results observed from the classified images of the both the years shows a very notable change in the city in last two decades. The important LULC classes such Built-up, Urban plantations, Fallow lands, Urban Plantations and Forest, Agricultural lands, Wasteland, Waterlogged areas/Wetlands and water bodies were delineated (Fig. 3a and b).



(a)

Fig. 6. (a) NDVI density map of Lucknow city for 2002 and (b) 2014.



(b)

Fig. 6. (*Continued*)

The most vulnerable land use change was observed in the Built up area (Urban and semi-urban) which increased from 93.97 sq.km^2 during 2002 to 130.33 sq.km^2 in 2014. This is the major cause of elevated temperature in the city.

The growth of urbanization taking place on major agricultural land as well as natural vegetation and forest cover of the city and they were replaced by majority of mixed built up and open land in the areas. Agricultural land was found to decrease from 32.37 sq.km^2 during 2002 and 25.03 sq.km^2 in 2014. Simultaneously, the Urban plantations and forest area was also found to decrease from 75.97 sq.km^2 during 2002 to 50.27 sq.km^2 during 2014. The changes in the land use category also showed some positive change in Wasteland (Salt affected land), have decreased from 14.68 km^2 in 2002 to 12.11 km^2 in 2014 in the area due the land reclamation programs. A slight increase in waterlogged areas/Wetlands was also observed in the area from 6.71 sq.km^2 during 2002 to 8.18 sq.km^2 in 2014. The total areas covered by water bodies were also found to have decreased from 3.29 during 2002 to 1.71 sq. in 2014 (Table 3). The result revealed that, most urban built-up lands were located in the middle part, and high LST value are also associated with the central part of the city which is core urban setup of Lucknow city and having high population density (Fig. 4a and b). If we see the comparative assessment of changes in LULC, NDVI and UTFVI, it is clearly justified that the major locations which

Table 4
NDVI change value between 2002 and 2014.

NDVI density classes	2002 NDVI classes area		2014 NDVI classes area		Change between 2002 and 2014
	Sq km	%	Sq km	%	
Low (0.1–0.2)	73.27	24.06	134.99	31.48	61.72
Medium (0.2–0.3)	78.86	25.89	137.65	32.10	58.79
High (0.3–0.4)	78.35	25.73	133.22	31.07	54.87
Very high (>0.4)	75.9	24.92	22.89	5.34	−53.01
Grand total	304.55	100.00	428.75	100.00	

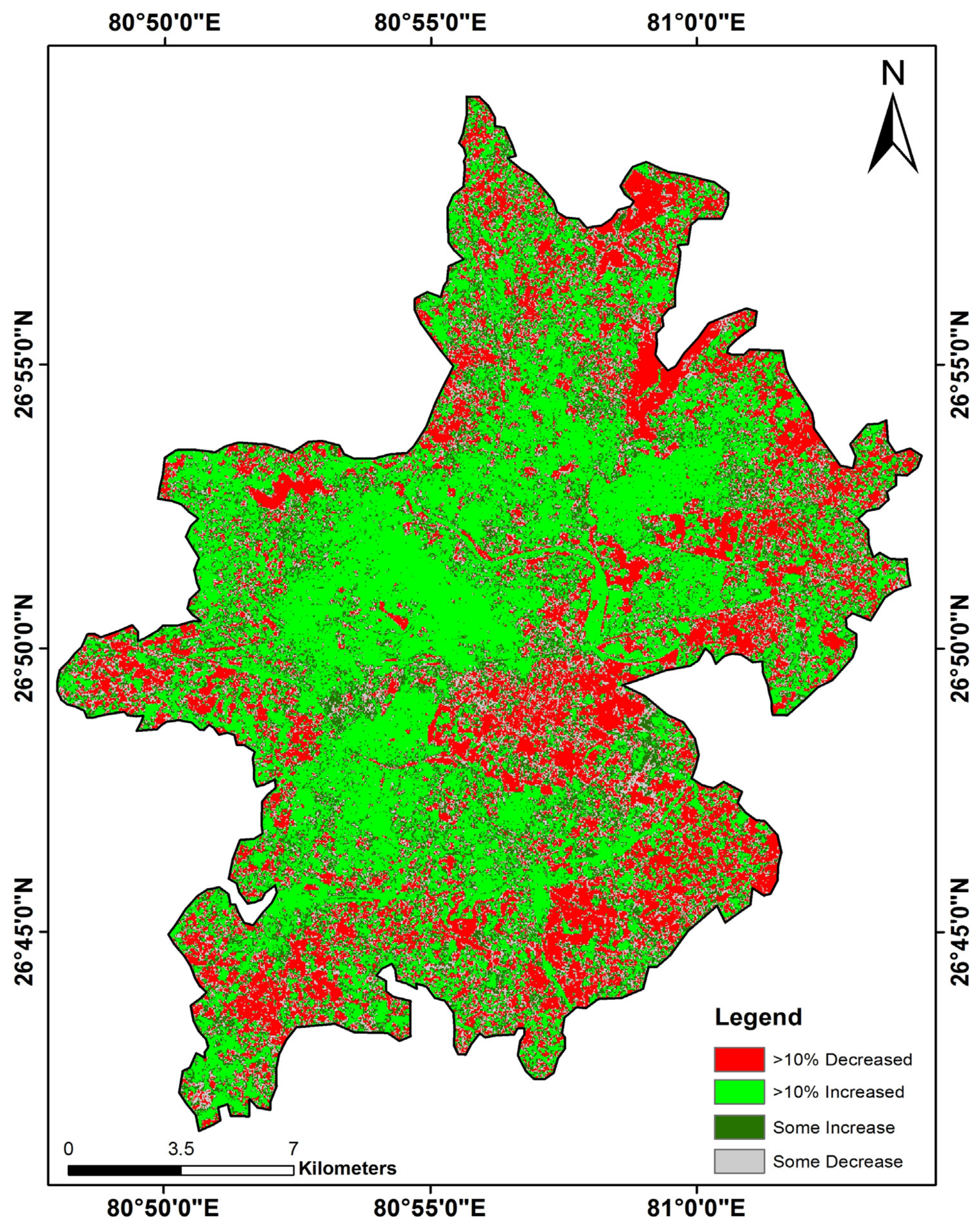


Fig. 7. NDVI change map of Lucknow city between 2002 and 2014.

represent high temperature are mainly associated with the area where changes taking place in urban area, vegetation, barren and open lands. Therefore, it is observed that urbanization and thermal environment of the city is mainly associated with urban built-up and barren land and decreased with vegetation cover (Fig. 4a and b).

Table 5
Threshold of ecological evaluation index.

Urban thermal field variance index	Urban heat island phenomenon	Ecological evaluation index
<0	None	Excellent
0.000–0.005	Weak	Good
0.005–0.010	Middle	Normal
0.010–0.015	Strong	Bad
0.015	Stronger	Worse
>0.020	Strongest	Worst

5.2. Relationship of NDVI with LST

The NDVI values observed in the study area range from −0.13 to 0.75 during 2002 and −0.44 to −0.64 during 2014. The classified NDVI values are again reclassified and values are grouped in many classes from very low density (less than 0.1), low density (0.1–0.2), medium (0.2–0.3), high (0.3–0.4) and very high (greater than 0.4). NDVI density map of 2002 and 2014 images show these density classes (Table 4).

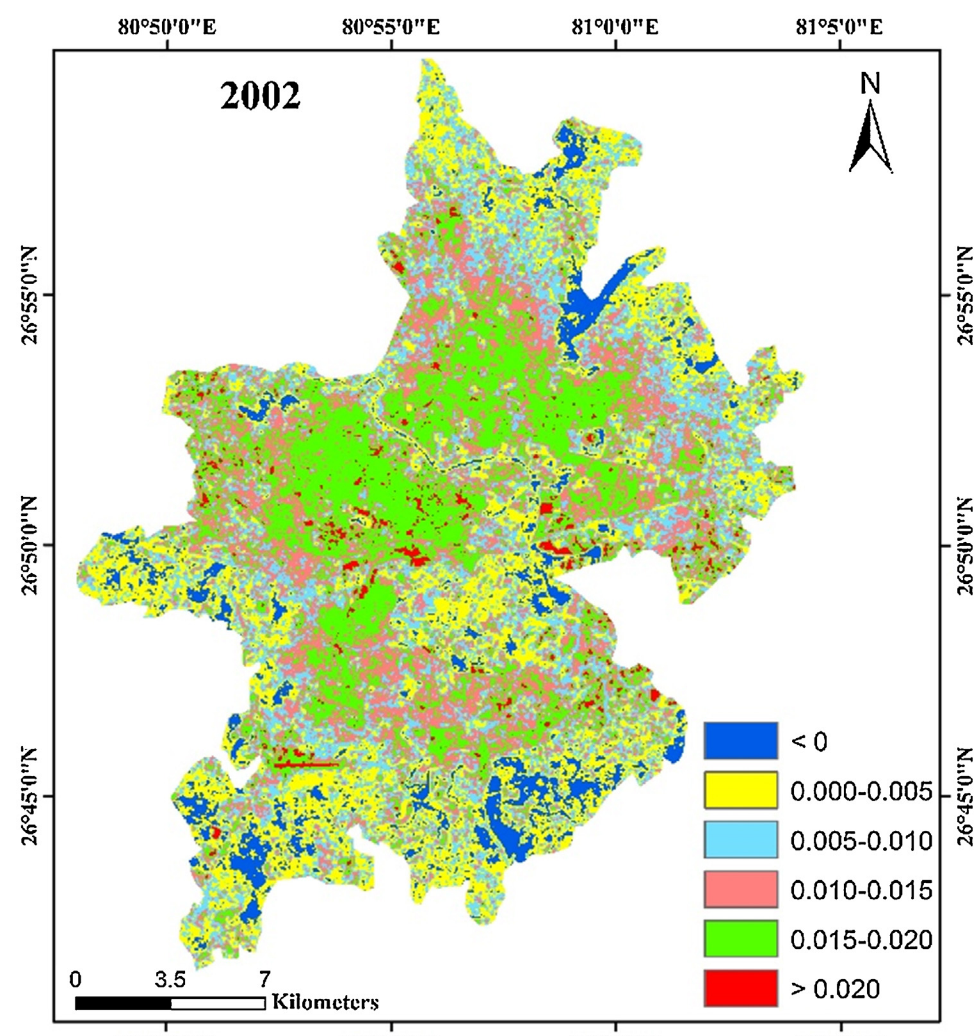
Most important changes are occurred in low and very high density classes of NDVI images. Very high NDVI value was reduced from 24.9% in 2002 to 5.3% in 2014. Whereas in low, medium and high NDVI values were increased. Differences between the two different years of NDVI 2002 and 2014 images of the area were calculated and the change detection map of NDVI shows the changes in vegetation area and the status occurred in two different times. Change detection map shows that the classes which comes

Table 6
Land use/land cover change of selected Google images in grid 1, 2 and 3 of 2002 and 2014.

Land use area under the grids in 2002 and 2014 (in sq.kms)				
LULC		1	2	3
Built up area (urban and rural)	2002	0.24	0.15	0.54
	2014	0.86	0.64	0.90
Waterlogged areas/wetlands	2002	0.06	0.07	0.12
	2014	0.03	0.01	0.09
Wasteland (salt affected land)	2002	0.28	0.06	0.49
	2014	0.12	0.10	0.40
Urban plantations and forest	2002	0.22	0.41	0.01
	2014	0.20	0.21	0.06
Agricultural lands	2002	0.008	0.13	0.14
	2014	0.02	0.07	0.09
Fallow lands	2002	3.57	2.31	2.26
	2014	3.17	2.13	2.07
Water bodies	2002	0.003	0.002	0.05
	2014	0.0009	0.0009	0.02

under in plantation/forest classes has major negative changes i.e. decreasing the vegetation cover whereas the built-up area has positive changes, it means that built-up area increases from 2002 to 2014 (Fig. 6a and b).

In change detection map of NDVI, The areas which are highlighted in red color represent that the areas underwent more than 10% decrease and green color represent the area underwent more than 10% increase of the vegetation cover. The areas come under in



(a)

Fig. 8. UTFVI map of Lucknow city for (a) 2002 and (b) 2014.

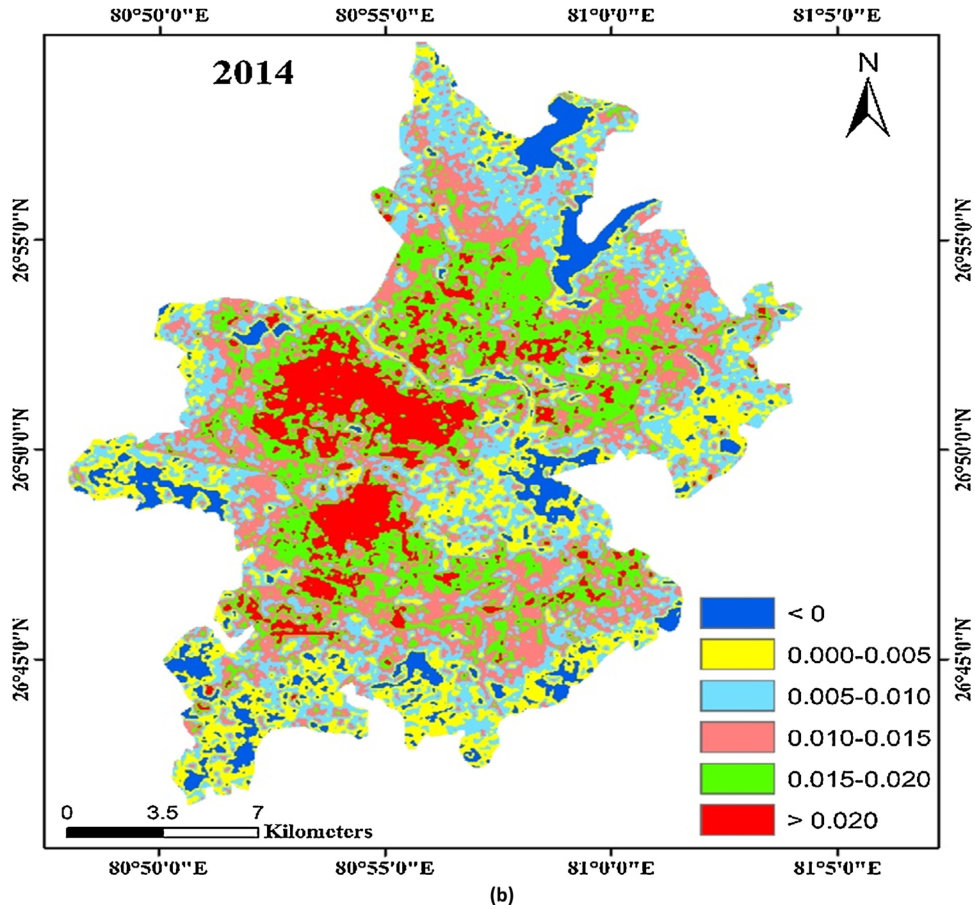


Fig. 8. (*Continued*)

dark green and gray color shows that the changes are less than 10% increase and decrease of vegetation respectively (Fig. 7).

The results observed that from the analysis of NDVI clearly shows that the decrease trend of vegetation leads to decrease evaporative cooling and finally contribute for high surface temperature.

5.3. Ecological vulnerability indexing

In the present work Urban thermal field variance index (UTFVI) is used for quantitative description of heat island effect on ecological degradation and its negative effect on public health and microclimate of the city. UTFVI is further classified into six levels to identify the spatial distribution of the heat island effect with six different ecological evaluation indices (Table 5). The urban heat phenomena was observed to increase from 2002 to 2014 and it is observed that during 2002 small central part of the city shows heat island phenomenon and have good ecological balance but in 2014 the heat island phenomenon has increased drastically and occupied almost the whole of the central region of the city (Fig. 8a and b). The worst ecological evaluation index was observed in the highly populated and densely complex urban structures which lead to the degradation of eco-environment of the city and rising trend of UHI.

The central parts were showing stronger heat island phenomena in 2014 as compared to 2002 because of the urbanization that had taken place over the years. Very few areas in 2014 were having <0 range which showed that ecological evaluation index has reached the worst level in the city, while the areas between the range of 0.005–0.010 were in the middle of the urban heat island phenomena and there ecological evaluation index was found to be normal. The observed information through UTFVI can be useful for environmental engineers and decision makers to maintain the eco-environment of the city. To protect the eco-environment of Lucknow city, the urban areas which are more prone to extreme urban heat island phenomenon needs to be seen practically for future development of the city. The results observed from urban thermal field variance index also suggested that the urban thermal environment of the city is not good due to the decreasing trend of vegetation.

6. Discussion

The important consequence of LULC change and urbanization is the development of urban heat island within the urban area compare to the surrounding rural area. Spatial-temporal Land surface temperature (LST) change is one of the most important climatic factors used for assessment of urban thermal Environment through remote sensing data. It is globally justified that the major cause of fluctuating urban thermal environment is due to the rising concentration of population and change in built up environment of the cities, particularly and urbanization and reducing vegetation cover.

The estimated land surface temperature of Lucknow city during 2002 range between 30.23 °C and 43.28 °C with a mean value of 36.75 °C and temperature variation in 2014 between 32.93 °C and 42.67 °C with a mean value of 37.8 °C. So, based on the

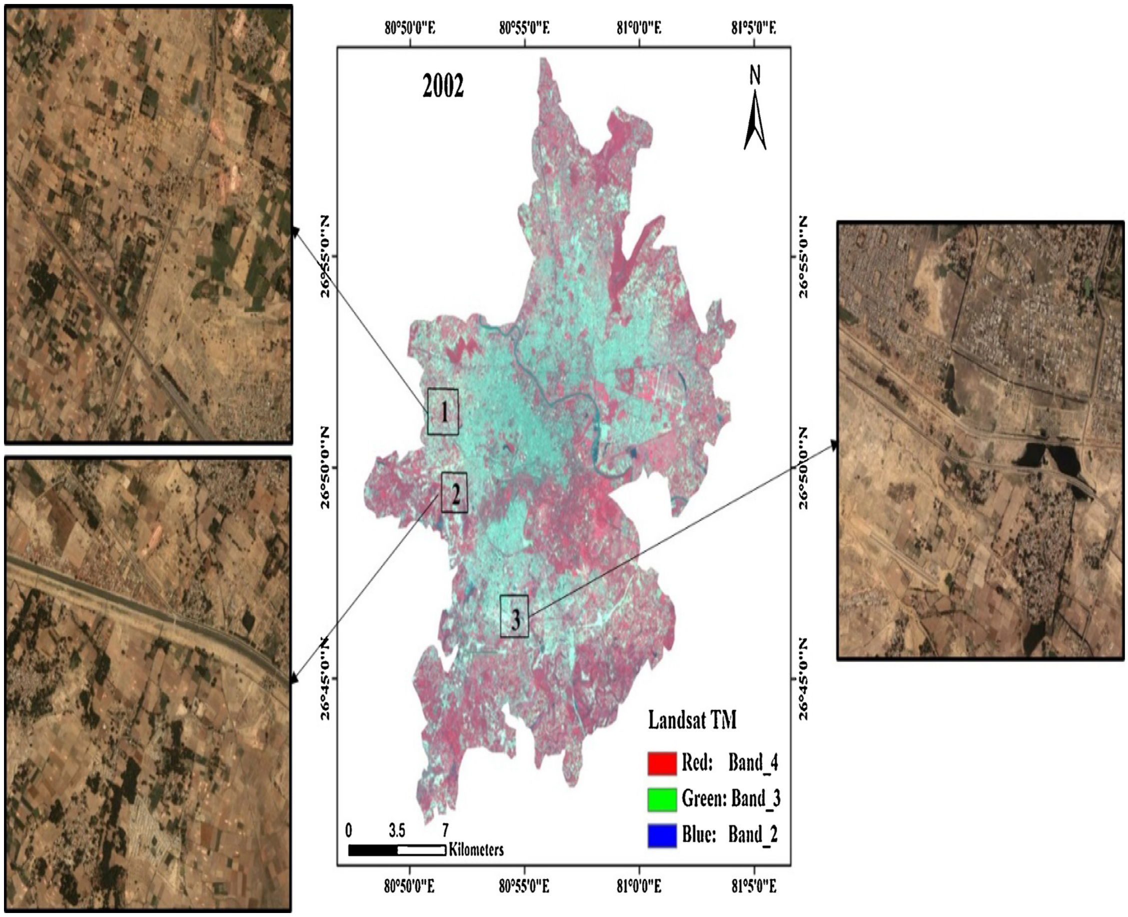


Fig. 9. Google satellite images of the selected locations of the city for 2002.

observations from 2002 to 2014, the maximum temperature was observed in the central portion of the city due to population growth and urbanization taking place, conversion of natural surface into anthropogenic land use such as asphalt-paved areas and other man-made coatings, as well as industrial, commercial, residential, and transport (Figs. 4 and 5). The air is also getting heated up due to the various emissions released from cooling agents used and also the building materials that are used nowadays is one of the main causes as the building materials consist of high percentage of non-reflective and water-resistant agents which tend to trap a the incoming solar radiation, which is then released as heat. The influence of vegetation is clearly seen as the areas covered by agricultural lands, urban plantations and forest were found to have lower temperatures. Water bodies exhibit minimum surface temperature. Based on the observation from 2002 to 2014, the vegetation cover in the city was found to have decreased drastically due to urbanization and other land conversions. It was seen that the areas having a low value of NDVI corresponds to high built up area i.e., in the central part, lower central part and lower northern part of the city. The areas having high value of NDVI were observed mostly in the outer portions of the city and the open areas. The results observed through the temporal vegetation analysis clearly indicate the environmental degradation in the city which causes the major change in local climate of the area.

The spatio-temporal assessment of NDVI and UTFVI of the city clearly indicates the effect of urbanization and mixed land use are the major cause of environmental degradation and change in UHI values of the city and rising trend of minimum temperature. It is also justified by the number of studies performed by the researchers throughout the globe as discussed in review literature part shows that the elevated urban temperature and change in local as well as regional climate of the cities are mainly due to the fast growth of urban built-up land and associated materials used in the construction of buildings and other important structures within the city. Another important aspect of rising UHI is the conversion of natural open land into the anthropogenic activities and lastly the decreasing trend of urban plantation and vegetation cover.

The classified temporal maps such as LST, NDVI and UTVFI of the city were crossed checked and verify with the help of GPS receiver, field visit and fine resolution Google Images and further analysis has been carried out by calculating the LULC changes in the selected portion of the images. The selected portions of the satellite images were assigned grid number 1, 2 and 3 for both the images of 2002 and 2014. The results observed from the images are clearly display that in last 12 years there is very positive change in the LULC classes in the city particularly concrete, road construction and mixed built-up land increased (Figs. 9 and 10). The statistical temporal changes in LULC over a time in the selected part has been also discussed in Table 6 and the results shown that major changes taking place in the Built-up over vegetation and open lands. The overall assessment from the historical Google Imagery and results from the analysis of LULC validate how urbanization has increased over the years and their negative impact on elevated temperature in the city. Through this analysis it can be inferred that built up and conversion of natural landscape has a direct effect on the rising temperature and degradation eco-environment of the city.

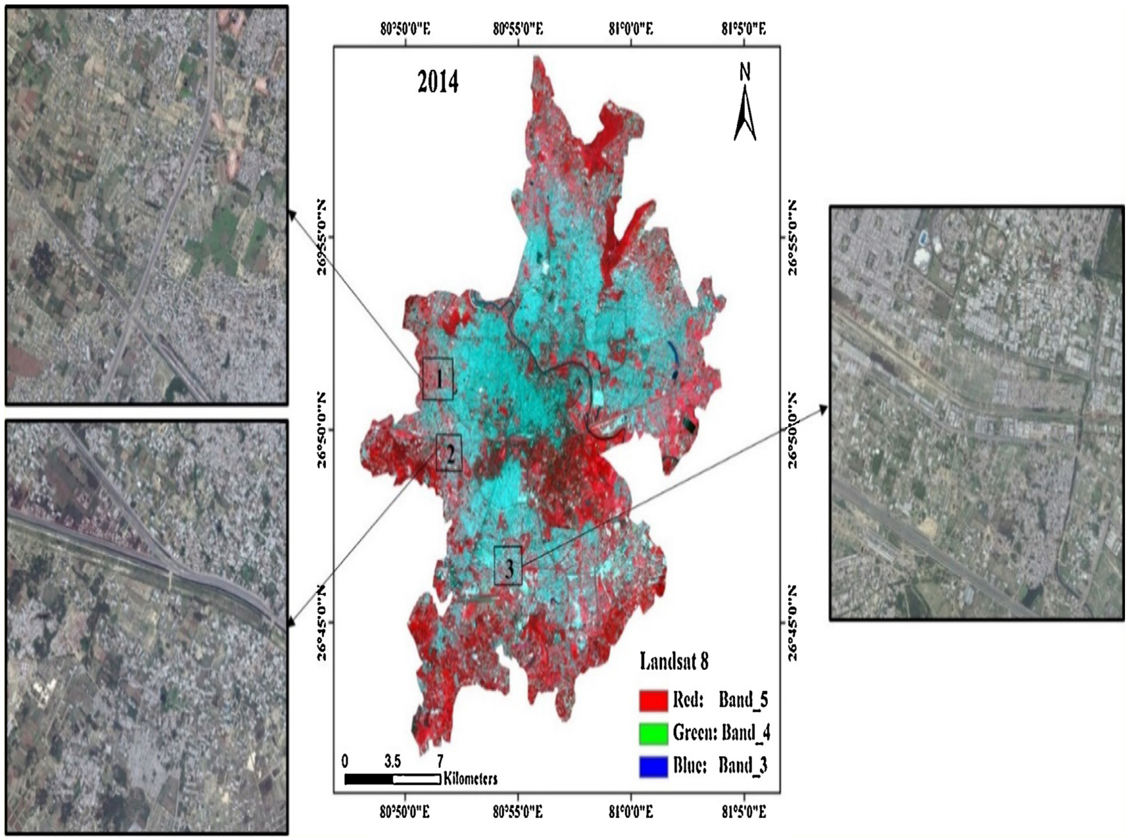


Fig. 10. Google satellite images of the selected locations of the city for 2014.

7. Conclusions

Assessment of the impact of urbanization on land surface temperature and local environment of the city are the major concern now days for environmental scientist and planners due to rising trend of urban temperature and its effect are very serious health issues in the urban setup. There is strong scientific evidence that the average temperature of the earth's surface is rising because of increased urbanization and other land transformation. The present study is based on the problem related to the assessment of urban heat and changes in the land use pattern of Lucknow city in integrated manner using thermal remote sensing data and GIS techniques.

For this, land surface temperature information is estimated from Landsat TM and Landsat-8 satellite data to study the spatial distribution of the LULC and its effects on surface temperature. The result showed that spatial distribution of LST was affected by urbanization and it was noticed that the temperature in the central portion of Lucknow was found to have increased from 2002 to 2014. At the same time, the surrounding areas which were further away from the densely built built-up areas were found to have comparatively lower temperatures.

Temporal NDVI of the city also analyzed and its shown falling trend in the vegetation cover from 2002 to 2014 and responsible of environmental change in the city. Thus it was seen that Lucknow has strongest urban heat island phenomenon and worst eco-environment, which strongly calls for more reasonable city layout and urban development in future.

Urban Thermal Field Variance Index (UTFVI) was also performed for the city of Lucknow and through this the ecological condition of the city was determined. It was noted that over the period of years the worst ecological evaluation index was observed in the highly rigorous urban areas which leads to the degraded eco-environment.

Remote sensing data like Landsat thermal imagery were ideal for analyzing UHI but it is difficult to select the images having same atmospheric and land surface conditions. One of the major disadvantage or limitation of the data was the resolution as it is difficult to study at micro level change. For more accurate analysis at micro level, fine resolution data with ground truth details are necessary and also the ground based thermal detectors are also the limitation of this work. Also, in future the results from this study could be used to help environmental planners and decision makers to make a plan sustainably.

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