Assessment of Urban Heat Island in Bhilai-Durg Area, Chhattisgarh, India, Using Remote Sensing and GIS Technologies

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Abstract: *Industrialization, urbanization and other human activities result in gradual rise in air temperature in most of the cities. One of the major causes of rising Land Surface Temperature (LST) is the drastic modification in landuse and landcover that reduce the greeneries in urban areas. This distinguished climatic condition termed as 'Urban Heat Island' (UHI). Industrialization in Bhilai-Durg urban area of Chhattisgarh resulted in remarkable UHI. Spatial variation of Land Surface Temperature (LST) can be used to decipher its mechanism and to find out possible solution. The main objective of study was to identify the landuse types which are causing increase of ambient temperature in Bhilai-Durg city. For the present study Landsat 7 ETM+ data of 2002 and Landsat 8 TIRS data of 2017 were obtained from USGS (United State Geological Survey). Bands1 to 4 and 7 of Landsat 7 ETM+ and 2 to 5, 10 and 11 of Landsat 8 TIRS. These data were used for detecting the landuse /landcover pattern, Land surface temperature and Normalized Difference Vegetation Index (NDVI). Nine classes of Landuse/landcover which were considered for the study are Agricultural land, Builtup land, Heavy industry, Industrial dust, Light industry, Mixed builtup land, Open area, Vegetation and Water bodies. The digital values of thermal infrared band were converted into spectral radiances using the equation of planks law. The surface emissivity based on NDVI classes was used to retrieve the final LST. Maximum LST values were detected from the industrial, built up and barren land areas and minimum LST values were detected from water body and healthy vegetation areas. The LST was ranging from 21.58°C to 54.01°C in 2002 and 27.64°C to 58.06°C in 2017. NDVI and LST were found to be inversely proportional. The study reveals that appropriate measures are required to be taken up for planning and sustainable management of landuses in the study area to decrease and manage the LST.***

Keywords: *Land Surface Temperature, Landuse/landover, Normalized Difference Vegetation Index, Urban Heat Island.*

1. INTRODUCTION

Sand Urban Heat Island occurs when cities replace the natural land cover with dense pavement, building and other man made surface cover that absorb and retain heat. In recent time urban man-land ratio is highly increasing due to industrialization and urbanization that has significantly influenced Land Surface Temperature.

"Studied about landuse through a nested hierarchy of landcover. Change vectors of Tasseled Cap brightness, greenness and wetness of Landsat Thematic Mapper (TM) images are combined with the brightness, greenness, wetness values from the initial date of imagery to map four stable classes and changes classes. Most of the landuse change is conversion from agricultural land to urban areas" (Seto et. al. 2002)

"Strong negative correlation is observed between surface temperature with Normalized Difference Vegetation Index (NDVI) over different LU/LC classes and the relationship is moderate with fractional vegetation cover" (Mallik et. al. 2008)

Remote sensing (RS) and Geographic Information System (GIS) have wide applications in areas of climate change analyses and can also be used for LST calculation. There are various sensors whose data are useful in generating LST such as: advanced very high-resolution radiometer (AVHRR), moderate resolution imaging spectroradiometer (MODIS), Landsat-8, and many more. (Solanky et. al. 2019)

Before the invention of earth observation satellites (EOS), it was hard to estimate the LST of an area. Normally, it used to be calculated for a particular set of sample points and interpolated into isotherms to generalize the point data into area data. Nowadays remotely sensed data is being used for LST estimation by using thermal data. LST greatly affected by the increasing greenhouse gases in the atmosphere. As it rises, it melts the glaciers and ices sheets in the polar region. It also increases flood and sea level. Increase in LST also affects the climatic condition of the monsoon countries leading to unpredictable rainfall hence vegetation and the entire Earth surface will be affected by this (Rajeshwari and Mani 2014). The indices Modified Normalised Difference Water Index (MNDWI) and NDVI provided better information on wetlands as well as vegetation (Karmakar and Bej, 2021).

2. OBJECTIVES

The main objectives of the study were as follows:

1. To estimate Land Surface Temperature (LST)
2. To find out the relationship between LST and Normalized Difference Vegetation Index (NDVI).
3. To find out the relationship between LST Landuse /landcover and of the study area in 2002 and 2017 respectively.

3. STUDYAREA

The Bhilai-Durg city in Durg District in the Indian state of Chhattisgarh, situated 133 km (83 miles) north of the state capital, Naya Raipur with a population of 693,851. Bhilai-Durg city situated on the banks of Shivnath River and bounded by latitude 21° 08'0" N to 21° 15'12" N and longitude 81°15'03" E to 81° 31' 30" E . The climate is tropical, with hot summers and moderate winters. The peak temperature reaches 45°C in May- June, while the winter temperature is 23°-27° C.

The average humidity is 78% and the average annual rainfall is 103 cm. Bhilai-Durg gets its rainfall from both the south-west monsoon and north-east monsoon. The topography of Bhilai-Durg is flat with a few small to medium sized hills. It has a major railway junction connecting all states in the country. The Bhilai-Durg city is the commercial capital of the state of Chhattisgarh. The geographical location of the study area is shown in Fig. 1.

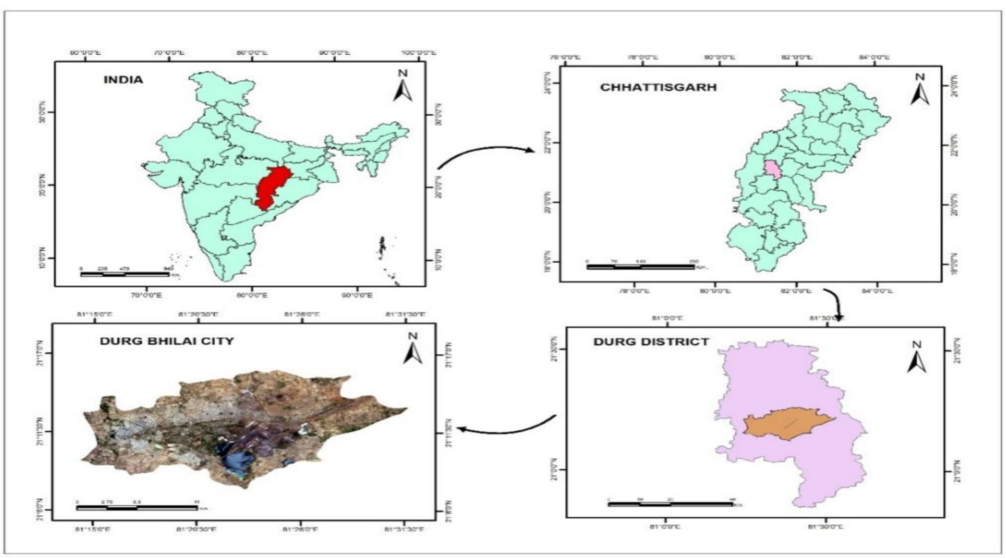

Figure1: Location map of the study area

4. DATA USED

Cloud Free Landsat satellite data of 2002 and 2017 for the study area were downloaded from USGS Earth Explorer website. All the data were pre-processed and projected to the Universal Transverse Mercator (UTM) projection system. The details of the satellite data used are shown in the Table 1.

Table 1: Details of Landsat data used

Date of Image	Satellite/ Sensor	Path/ Row
11-05-2002	Landsat 7 ETM+	142/45
12-05-2017	Landsat 8 TIRS	142/45

5. Methodology

Geo-morphologically, For the present study the following methodology was adopted which involved satellite data collection, classification of the imagery, preparation of landuse/landcover maps, NDVI maps, Land Surface Temperature maps and correlation studies. Using hand held GPS field surveys were conducted in the study area and nearly 50 Ground truth points were selected. Field data and Google Earth data were used for enhancing the accuracy.

5.1. Preparation of Landuse/landcover

Using bands 1- 4 of Landsat 7 and 2 – 5 of Landsat 8 pre-processed images the landuse/landcover patterns were mapped by Visual interpretation using Arc GIS10.3. Nine classes of Landuse/landcover which were considered for the study are Agricultural land, Builtup land, Heavy industry, Industrial dust, Light industry, Mixed builtup land, Open area, Vegetation and Water bodies.

5.2. Derivation of NDVI

The NDVI is a measure of the amount of vegetation on the surface. It is related to vegetation cover because of the fact, healthy vegetation reflects very well in the near infrared part of the Electromagnetic Spectrum. Green leaves have a reflectance of 20 % or less in the 0.5 to 0.7 μm range (green to red) and about 60 % in the 0.7 to 1.3 μm range (near infrared). The value of NDVI varies between -1.0 and +1.0.

NDVI=(NIR-RED)/(NIR+RED) …………… (1)

5.3. Estimation of LST from Landsat 7 ETM+

The digital number (DN) of thermal infrared band is converted in to spectral radiance (Lλ) using the Planks equation given by the Landsat user's hand book.

$$L\lambda = \left\{\frac{LMAX-LMIN}{QCALMAX-QCALMIN}\right\}*DN-1+LMIN\text{……..(2)}$$

LMAX = the spectral radiance that is scaled to QCALMAX in W/(m2* sr *μm)
LMIN =the spectral radiance that is scaled to QCALMIN in W/(m2* sr *μm)
QCALMAX =The maximum quantized calibrated pixel value (corresponding to LMAX) in DN = 255
QCALMIN = the minimum quantized calibrated pixel value (corresponding to LMIN) in DN = 1
LMAX andLMIN are obtained from the Meta data file available with the image and are given in the Table 2.

Table 2: LMAX and LMIN values of Landsat data

Band No	Satellite/ Sensor	LMAX	LMIN
6.1	Landsat7 /ETM+ High gain	12.65	3.2
6.2	Landsat7 /ETM +Low gain	17.04	0.0

The effective at-sensor brightness temperature (TB) also known as black body temperature is obtained from the spectral radiance.

Conversion of spectral Radiance to temperature in Kelvin.
Tb=K2/ ln ((K1/L) +1 …………………… (3)
Where,
K1= Calibration constant 1
K2= Calibration constant 2
Tb= Brightness temperature
The calibration constants K1 and K2 obtained from Landsat data user's manual are given in Table 3.

Table 3: Calibration constants for thermal band

Sensor	K1	K2
Landsat 7/ ETM+	666.09	1282.71

5.4. Estimation of LSTfrom Landsat 8 TIRS

Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)band data can be converted to Top of Atmosphere (TOA) spectral radiance using the radiance rescaling factors given in Table 4.
Lλ = MLQcal + AL

Where:
Lλ = TOA spectral radiance (Watts/(m2 * srad * μm))
ML = Band-specific multiplicative rescaling factor
AL = Band-specific additive rescaling factor
Qcal = Quantized and calibrated standard product pixel values (DN)

Table 4: Rescaling Factor

Rescaling Factor	Band 10	Band 11
M_L	0.000342	0.000342
A_L	0.1	0.1

IRS band data can be converted from spectral radiance to brightness temperature using the thermal constants. K1and K2 values are given in the Table 5.

$$T=\frac{K2}{IN\left(\frac{K1}{L\lambda}\right)+1}$$

Where:
T =At-satellite brightness temperature (K)
Lλ =TOA spectral radiance (Watts/(m2 * srad * μm))
K1 = Band-specific thermal conversion constant
K2 = Band-specific thermal conversion constant

Table 5: K1 and K2 Values

Thermal Constant	Band 10	Band 11
K_1	1321.08	1201.14
K_2	777.89	480.89

Land Surface Emissivity (LSE)

To find out LST it is necessary to calculate the LSE of the region. LSE was estimated using NDVI threshold method. (Emissivity Values are given in Table 6.)

LSE = εs (1-FVC) + εv * FVC

Where,
εs and εv - soil and vegetative emissivity values of the corresponding bands.
FVC - fractional vegetation cover

Table 6: Emissivity Values

Emissivity	Band 10	Band 11
εs	0.971	0.977
εv	0.987	0.989

6. RESULT AND DISCUSSION

6.1. Landuse/Landcover maps

The Landuse/Landcover map of the study area prepared for the years 2002 and 2017 using visual interpretation technique is given in Fig.2. The total area of interest (AOI) is 22748.4 square kilometers. The details of the landcover of the study area are given in Table 7.

6.2. NDVI Image

NDVI is one of the most widely used indices for monitoring of vegetation cover. The NDVI values of the pixels varies between -1 and +1. Higher values of NDVI indicate the richer and healthy vegetation and lower LST (except water bodies). NDVI of the study area prepared are shown in the Fig.3.

6.3. LST Images

From brightness temperature (TB) and land surface emissivity the final Land Surface Temperature image was obtained by developing a model in ERDAS Imagine 10.3. The LST image is shown in Fig.4. Field photographs of the important landuses that influence the LST of the study area are given in Fig. 5.

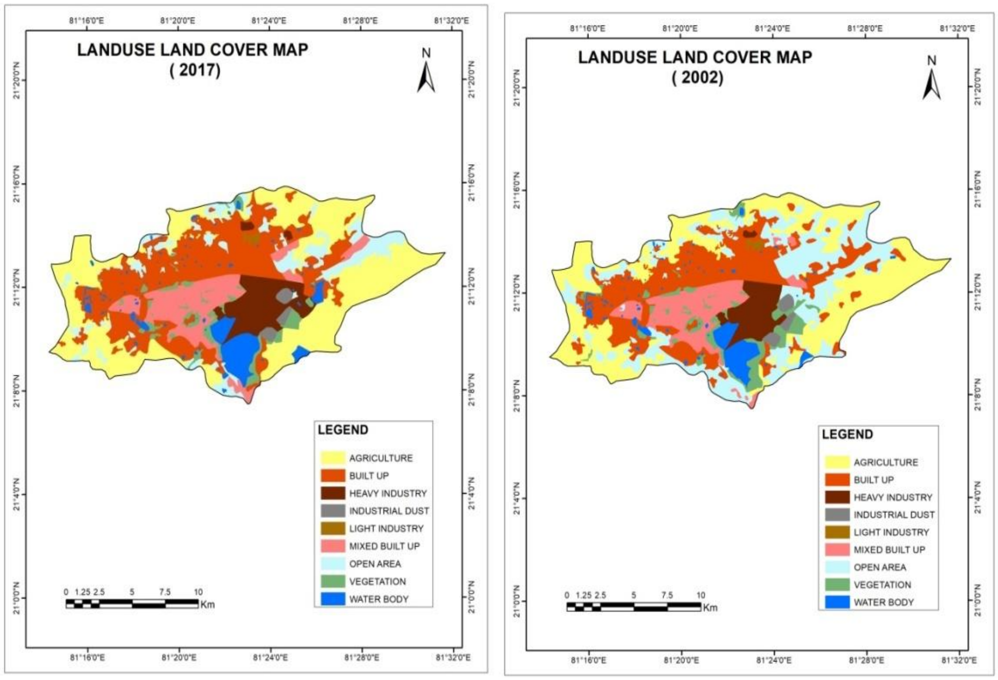

Figure 2: Land use/Land cover maps of 2002 & 2017

Table 7: Land use /land cover area 2002 and 2017

Year 2002	
Class	**Area (Ha.)**
Agricultural land	7791.296
Builtup land	6363.071
Heavy industry	1342.98
Industrial Dust	283.4621
Light industry	69.56995
Mixed builtup land	2294.808
Open Area	5625.572
Vegetation	1344.422
Water Body	1068.885

Year 2017	
Class	**Area (Ha.)**
Agricultural land	8920.343
Builtup land	7509.424
Heavy industry	1871.853
Industrial Dust	277.5612
Light industry	69.56995
Mixed builtup land	2610.89
Open Area	2488.339
Vegetation	997.2003
Water Body	1438.886

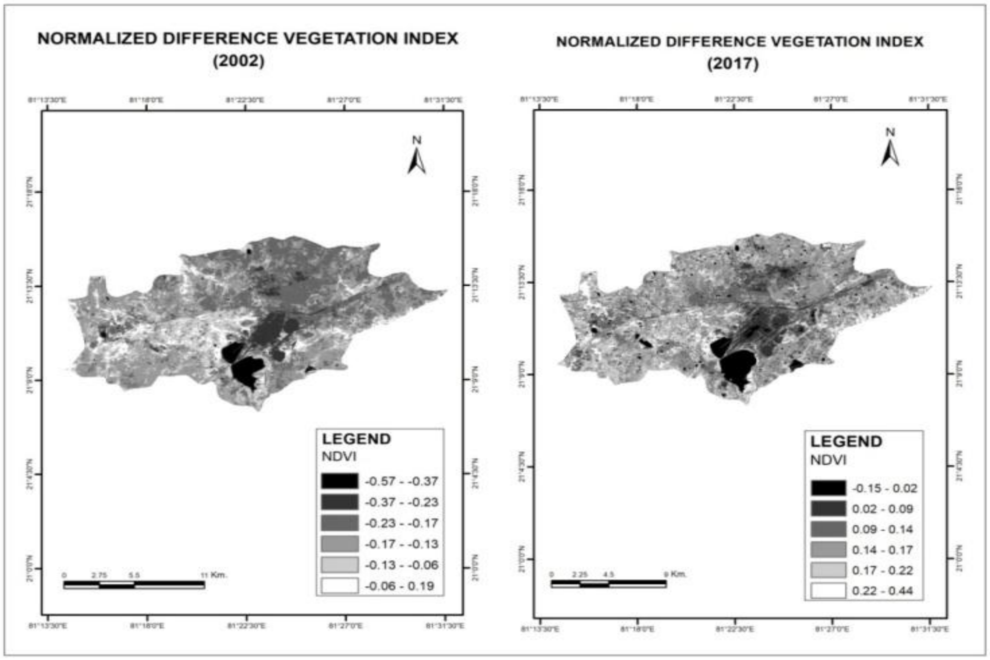

Figure 3: NDVI of the study area of the years 2002 & 2017

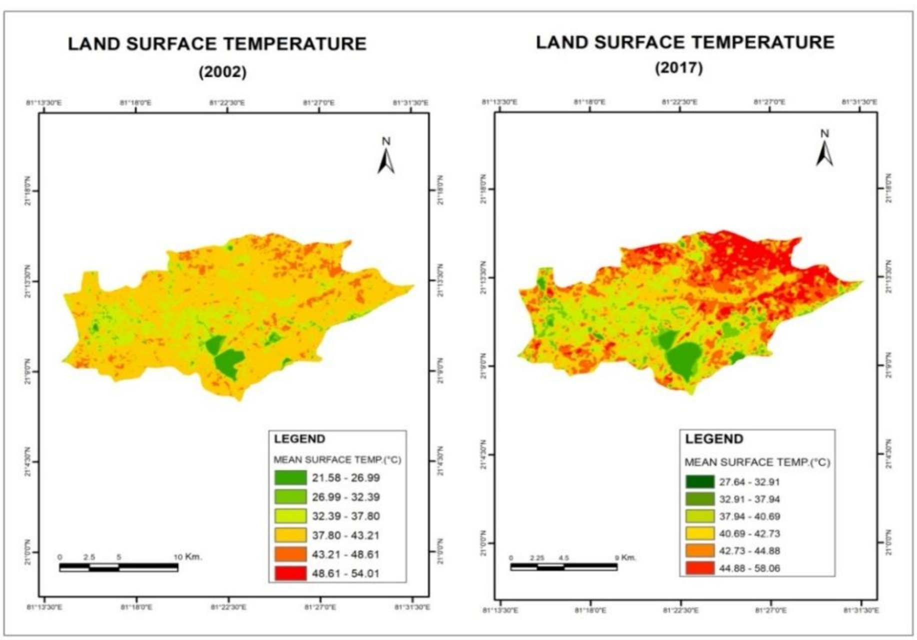

Figure 4: Land Surface Temperature image of the study area of the years 2002& 2017

Figure 5: Field Photographs of landuses influncing LST

6.4. LST and NDVI relationship

By visual interpretation it is apparent that there is inversely proportional correlation between LST and NDVI. Multiple comparisons of mean LST and NDVI values associated with each landuse type are also found to be significantly different. The result of a regressive analysis shows an inverse correlation relationship between LST and NDVI in 2002 as well as in 2017. Correlation between LST and NDVI shown in the Fig.6 and Fig. 7.

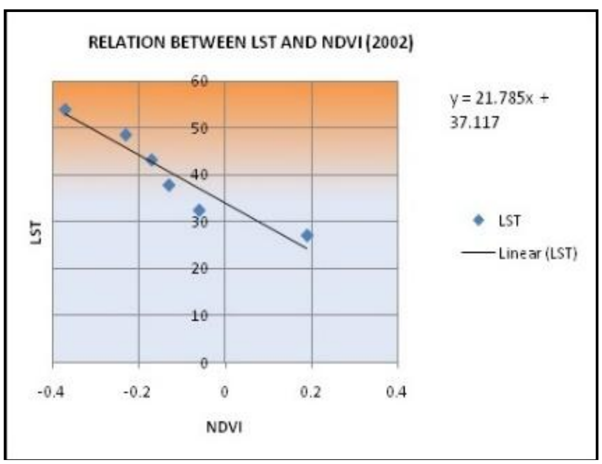

Figure 6: Correlation between LST and NDVI year 2002

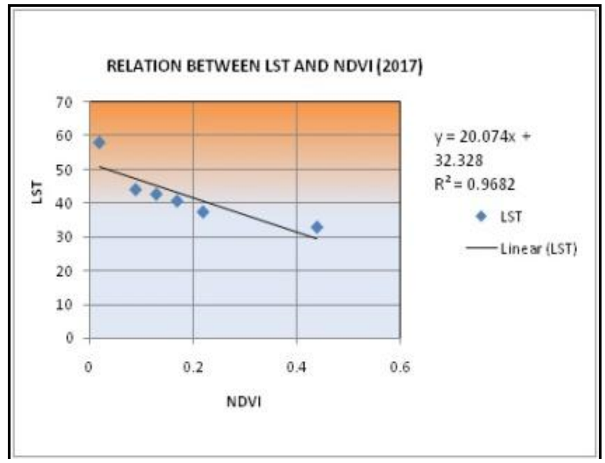

Figure 7: Correlation between LST and NDVI year 2017

6.5. LU/LC and LST relationship

From the LST image of the year 2002 it was observed that the high temperature found is about more than 40o C that exist in urban built up areas, industrial areas and open areas and low temperature found is about less than 25oC that exist in wetland areas and in the areas covered with vegetation. Two transverse cross section lines were drawn on LST images for both the years 2002 and 2017 from Northeast to the Southwest which are passing through the city and cross through almost all classes of LU/LC. Correlation between LST and LU/LC shown in the Fig. 8 and Fig. 9. Some of the land use/land cover changes in the study area that influencing the LST are shown in Fig 10.

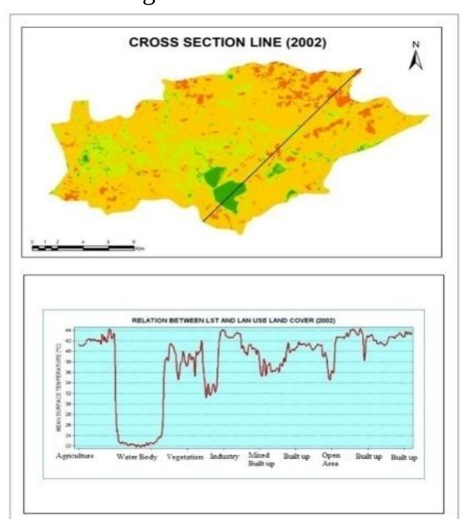

Figure 8: Cross section line on LST and correlation between LST and LULCYear 2002

From the LST image of the year 2017 it was observed that the high temperature found is about more than 45^{o} C that exist in urban builtup areas, industrial areas and open areas and low temperature found is about less than 30^{o} C that exist in wetland areas and in the areas covered with vegetation.

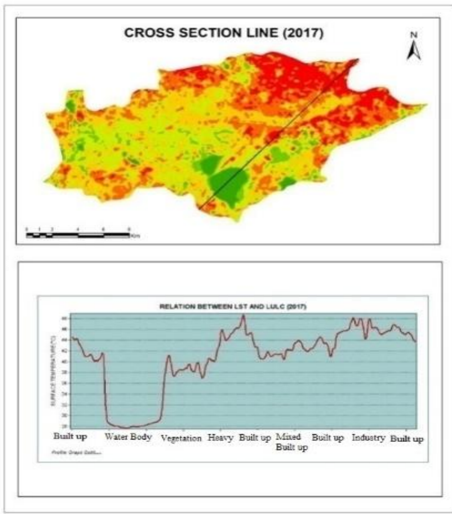

Figure 9: Cross section line on LST and correlation between LST and LULC year 2017

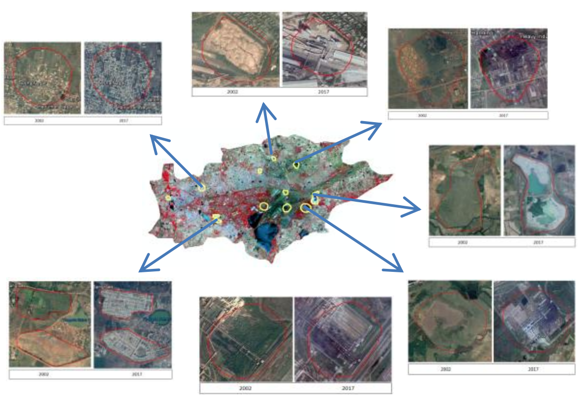

Figure10: Major LU/LC changes in the study area that influence the LST

7. CONCLUSION

Formation of Urban Heat Island in the cities like Bhilai-Durg of Chhattisgarh state is a concerning issue due to rapid urbanization and industrialization.The study explored the relationship between urban land forms and UHI by GIS spatial analysis.UHI resulting in urban area could be recognized with the superior spatial resolution of the Landsat ETM+ images. It has been found that, most of the land surface is covered with concrete, asphalt and other such impervious materials leading a variety of urban environmental issues like increase in runoff and land surface temperatures. An increase of land surface temperature has been found from 2002 to 2017. The cities are experiencing more heat than the surrounding rural areas mainly due lack of vegetation cover.

Remotely sensed data along with GIS technology has been very effective in identifying the relationship between existing landuse/landcover and land surface temperature. Surface temperature was retrieved to understand the variation of temperature from low density mixed built up area to core built up areas of the city. From the analysis of LST images it is clearly understood that LST is more in core builtup and in heavy industrial area in comparison to fringe areas.

The correlation study shows that the LST is strongly negative with NDVI. The study also revealed that which landform reflects how much LST and this can help in monitoring the dynamics of landuse resulting out of changing demands of increasing population and the associated issues like Urban Heat Island can also be addressed.

The management plan that includes use of green roof, white roof, developing garden and park on and near building premises, developing green belt around industrial areas, plantation along the urban roads and between two-lane roads can be prepared to decrease or manage LST. The findings of the study about urban landforms and UHI relationship would be helpful to alleviate urban thermal environment.

REFERENCES

[1] J. C. Jimenez-Munoz, "Land surface temperature retrieval methods from landsat-8 thermalinfrared sensor data", IEEE Geoscience Remote Sensing Letters, vol. 11(10), 2014, pp. 806 – 809.

[2] S. Karmakar, and D. Bej, "Remote Sensing and GIS for Wetland Mapping and Change Analysis; A Case Study of Shivnath Basin, Chhattisgarh, India", International Journal of Creative Research Thoughts, Vol. 9(3), 2021, pp. 2313-2323.

[3] J. Li, and H.M. Zhao, "Detecting Urban Land Use and LandCover Changes in Mississauga using Landsat TM images", Journal of Environmental Informatics, vol. 2, 2003, pp. 38-47.

[4] Javed Mallik, Y. Kant, and B. D. Bharath, "Estimation of land surface temperature over Delhi using landsat-7 ETM+", Journal of Indian Geophysics Union, Vol. 12, No.3, 2008, pp.131-140.

[5] NASA, "Landsat 8 (L8) Data Users Handbook", Sioux Falls, South Dakota: U.S. Geological Survey, 2019. https://www.usgs.gov/core-science-systems/nli/landsat/landsat-8-data-users-handbook

[6] A. Rajeshwari, and N. D. Mani, "Estimation of land surface temperature of Dindigul district using Landsat 8 data", International

Journal of Research in Engineering and Technology, vol. 03(05), 2014, pp. 122-126.

[7] Bassam Saleh, and Al Rawashdeh Samih, "Study of Urban Expansion in Jordanian Cities Using GIS and Remote Sensing", International Journal of Applied Science and Engineering, vol. 5, 2007, pp. 41-52.

[8] K. C. Seto, C. E.Woodcock, C. Song, X. Huang, and R. K. Kaufmann, "Monitoring land-use change in the Pearl River Delta using Landsat TM", International Journal of Remote Sensing, Vol. 23, No. 10, 2002, pp. 1985–2004.

[9] H. S. Sudhira, T. V. Ramachandra, and K.S. Jagadeesh, "Urban sprawl: metrics, dynamics and modelling using GIS", International Journal of Applied Earth Observation and Geoinformation, vol. 5, 2004, pp. 29-39.

[10] S. Tamilenthi, J. Punithavathi, R. Baskaranand, and K. Chandra Mohan, "Dynamics of urban sprawl, changing direction and mapping: A case study of Salem city, Tamilnadu, India, Achieves of Applied Science Research", vol. 3(1), 2011, pp. 277-286.

[11] M. Turker, and O. Asik, "Land Use Change Detection at The Rural-Urban Fringe Using Multi-Sensor Data in Ankara, Turkey", International Journal of Geoinformatics, Vol.1, No.3, 2005, pp. 27-36.

[12] K. Green, D. Kempka, and L. Lackey, "Using remote sensing to detect and monitor land-cover and land-use change", Photogrammetric Engineering and Remote Sensing, vol. 60, 1994, pp. 331–337.