Assessment of Urban Heat Island through Remote Sensing in Nagpur Urban Area Using Landsat 7 ETM+ Satellite Images

Meenal Surawar, Rajashree Kotharkar

Abstract—Urban Heat Island (UHI) is found more pronounced as a prominent urban environmental concern in developing cities. To study the UHI effect in the Indian context, the Nagpur urban area has been explored in this paper using Landsat 7 ETM+ satellite images through Remote Sensing and GIS techniques. This paper intends to study the effect of LU/LC pattern on daytime Land Surface Temperature (LST) variation, contributing UHI formation within the Nagpur Urban area. Supervised LU/LC area classification was carried to study urban Change detection using ENVI 5. Change detection has been studied by carrying Normalized Difference Vegetation Index (NDVI) to understand the proportion of vegetative cover with respect to built-up ratio. Detection of spectral radiance from the thermal band of satellite images was processed to calibrate LST. Specific representative areas on the basis of urban built-up and vegetation classification were selected for observation of point LST. The entire Nagpur urban area shows that, as building density increases with decrease in vegetation cover, LST increases, thereby causing the UHI effect. UHI intensity has gradually increased by 0.7°C from 2000 to 2006; however, a drastic increase has been observed with difference of 1.8°C during the period 2006 to 2013. Within the Nagpur urban area, the UHI effect was formed due to increase in building density and decrease in vegetative cover.

Keywords—Land use, land cover, land surface temperature, remote sensing, urban heat island.

I. INTRODUCTION

URBAN development leads to radical land cover changes as urban areas expand into surrounding forests, grasslands, and natural cover gets replaced by roads, buildings, parks, and gardens. Increase in built-up cover reduces vegetation cover and adds heat absorbing surfaces such as pavings, buildings and rooftops [1], [2]. Permeable and moist land surfaces get converted into dry and impermeable building cover. These hard urban surfaces absorb and store more heat thereby raising temperature in urban areas [3], [4]. Such developmental changes make urban area warmer than its rural surroundings and leads to UHI effect [5], [6].

In 1810, Luke Howard investigated and described for the first time about the UHI phenomenon. He stated that *'An Urban Heat Island (UHI) refers to any area, populated or not, which is consistently hotter than the surrounding area.'* UHI

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is also refers to the elevated temperatures in built-up areas compared to more rural surroundings. *Wherein 'UHI Effect is the atmospheric temperature rise experienced by any urbanized area'.* UHI intensity is defined as the difference between the rural temperature and the warmest urban zone [7], [8]. Under clear sky conditions, UHI varies through the day as well as night-time. At night, stored heat gets released slowly from the urban surfaces as compared to rural surfaces [9], [10].

Extensive work has been done in the western context related to UHI studies in the context of Surface UHI. Most of these studies have observed LST acts as a key characteristic in identifying UHI effect. Air temperature of the lowest layer of the urban atmosphere gets modulated due to LST thereby influencing the urban climate and causing discomfort to the city dwellers [7]. LST distribution pattern could be studied in relationship with various Land Use/Land Cover (LU/LC) surface types within an urban environment and its adjacent surroundings. Non-permeable materials restrict the water run-off and evaporative cooling processes on the urban surface [11], [12]. To extract the point LST and to understand the urban landform, NDVI is one of the most widely applied vegetation indices through remote sensing studies [8], [13], [14]. Spectral emissivity has been estimated by utilizing NDVI values [15], [16]. The emissivity of a material is the relative ability of its surface to emit energy by radiation and ranges from 0 to 1. Griend and Owe state that the emissivity value for NDVI ranges from 0.157 to 0.727 [15].

To address urban-rural features, LU/LC was classified on the basis of water bodies, open areas, green cover ratio, built up area and building density [17], [18]. LU/LC change in cities has significant impact on local climate including temperature, precipitation, humidity and wind. These impacts need to be well documented and understood for proper development of a city. Change detection is one of the processes to study the transformations occurring within an urban area. Urban change detection is widely studied through LU/LC classification [19], [20]. The influence of vegetation is adversely impacting the air temperature distribution, especially the night-time air temperature [11], [21]. The relation between the spatial distribution of vegetation density and LU/LC is closely related to the UHI development [22], [23]. Stone and Norman conclude that UHI effect was produced in residential areas with low density housing and higher spatial distribution [24].

In Indian context, few studies have been carried out using

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observational approach through field surveys to study the relation between UHI intensity and LU/LC pattern. It was revealed that in tropical cities UHI varies gradually within the city and is directly related to land-cover [25]. Ansar infers that intra urban temperature differences are due to the different building density and surface features in Thiruvananthpuram [26]. Devi carried a LU/LC study in Visakhapatnam and infers that Central Business District (CBD) areas were highly under the influence of UHI [27]. In Chennai city, reduction in green spaces and increase in built-up areas leads to increase in urban air temperatures [28]. Using Remote Sensing (RS) and Geographical Information Systems (GIS) technique, it was observed that temperature variations correlated well with the building density patterns in Nagpur urban areas [29]. Studies conducted through satellite images derived LST measurements in urban areas and found UHI prominent in high building density localities in Indian Context [14], [30], [31].

II. STUDY AREA

Nagpur is a tropical city and lies at the center of India from latitude 21° 41' N to 20° 35' N and longitude 78° 15' E to 79° 45' E and a height of 312.4 m above mean sea level. As per the Census, 2001 and 2011, Nagpur city is spread over an area of 217.65 km^2 and experienced increase in population during 2001-2011. In 2001, the city had a population of 2.1 million and by 2011 it had increased to 2.4 million. It has a hot and dry climate in summer and a cool and dry climate in winter with dry conditions prevailing for the entire year, with the exception of the monsoon season (June to September). Here, the city has climate variation during three important seasons as summer, winter and monsoon. Summer reaches the pinnacle in the month of May. The maximum temperature remains more than 42 °C and it may reach to 48 °C. The monsoon months of June to September receive an annual rainfall of 1,205 mm (47.44 in).

III. STUDY DATA

In this study, daytime Landsat 7 ETM+ images (Table I) were selected to retrieve the brightness temperature and LU/LC features. Since Nagpur has severe summer from March to June, available images during these periods were acquired from the USGS free website. Multi temporal images of Landsat 7 ETM+ images have UTM map projections with WGS84 datum and zone as 44N. Landsat Images have seven spectral bands, of which the panchromatic grid cell size is 15 m, while the sixth band grid cell size is 30 m. This sixth band provides the thermal surface reflectance feature as it records emitted energy in the thermal infrared part of the spectrum.

TABLE I
LANDSAT7 ETM+ DATA USED FOR THE STUDY

Sr. no.	Time	Resolution	Date of acquisition	Sun elevation
1	5:00:45	30 m	17th April, 2000	63.17979228
2	4:58:32	30 m	4th May, 2006	65.27213684
3	5:04:31	30 m	5th April, 2013	61.01139554

IV. METHODOLOGY

To analyse the changes in LST and LU/LC in the study region, multi temporal Landsat-7 ETM+ images of 2000, 2006 and 2013 were co-registered in the same co-ordinate system (i.e. UTM/ WGS84/ 44N). Geo-referencing to a common UTM co-ordinate system was done through spectral angular mapper algorithm. Each ETM+ file consisting of independent single-band image was converted to multi band image using layer stacking tool in ENVI 5. The image subset tool was used to clip the study area.

Supervised LU/ C area classification for 2000 to 2013 was categorized to study change detection using ENVI-5. This classification helped for delineating various temperature zones within urban areas. Classification was based on initial data procured from topo-sheets, photo-interpreted maps and field surveys (ground truthing) to assign training area of different features to be classified. Using these feature signatures, each pixel with similar characteristics were grouped and assigned to respective class. To fit a common land typology, each rectified image was independently classified. Following the classification, resulting land cover maps were overlaid and compared on a pixel-by-pixel basis (Fig. 1).

LU/LC area classification was widely studied on the basis of vegetation cover and built-up ratio in percentage [29], [32]-[34]. Due to diverse urban settings, the Nagpur urban area level classification was categorized as urban built up areas, forest/agriculture, water bodies and open land. Further urban built up areas were subdivided into densely built-up, high built-up, medium built-up and low/sparse built-up areas (Table I). Most of the urban densely built-up covers buildings for residential and commercial purpose; it has been classified as the 100% built-up category. Here, the 100% built-up is showing the occupied building structures with narrow lanes, where there is no space for any new development to take place. Built up structures in these areas were not planned and mostly are old structures. Densely built-up clusters are seen in these areas. Urban high built-up areas are lesser dense than the above class in the city with very few open spaces. It has been classified as 20% vegetation-80% built-up category. They are one/two stored residential or commercial structures and may be intermixed with new higher stored buildings. Urban medium built-up areas are well planned colonies with three/four multistory residential and commercial buildings. These are well planned colonies with open spaces and classified as 40% vegetation-60% built-up or 60% vegetation-40% built-up category. Urban low built-up areas are residential areas interspersed with plenty of green or open spaces and classified as 80% vegetation-20% built-up category. These are mostly the gated residential colonies and few university campuses with very less buildings without any commercial intermixing activities within them.

Forest/agriculture areas include green coverage ranging from medium dense forests to cultivated lands, parks and gardens. There are a few dense forests areas in Nagpur. They are the Seminary Hills, Telankhedi Lake and Ambazari Lake stretch, marked with dense lush vegetation. There are some land pockets of agricultural university for conducting various

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researches, field trials in addition to seed multiplication programme which are characterized majorly by short grass and shrub vegetation. Water bodies are the lakes within an urban area such as Ambazari Lake and Phutala Lake. They were categorized to analyze the impact of water bodies on UHI formation. Areas under open land shows no significant built up structures or any type of extensive natural or cultivated green coverage. LU/LC classification was done on the basis of ascending order of vegetation pattern and descending order of building density in percentage. While making LU/LC classification, care has been taken to include observation points from residential, commercial, recreational, institutional, administrative and industrial type along with gardens and water bodies.
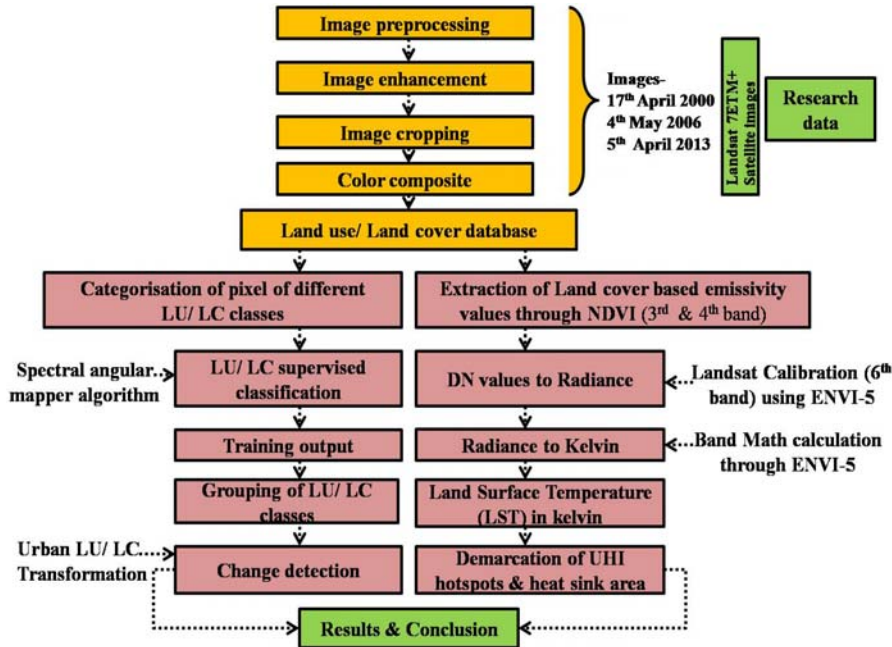

Fig. 1 Study Methodology

After supervised classification, images were further verified for their accuracy where some open areas resembled as built up category. Mixed pixels mostly create confusion while using remotely sensed data in the classification process [35]. Thus, pixels belonging to any particular area were identified region by region to the real value using spatial pixel editor tools. This confusion in urban areas arises due to different shades of paved areas, building roof tops, cement roads, etc. Shadow areas are influenced strongly due to the characteristics of the generating features and their immediate surrounding pixels [32]. It was described that computation of LST from the ETM + thermal infrared band conducted using Normalised Difference Vegetation Index (NDVI) [32]. The present study explores NDVI of pure vegetation and bare pixels obtained from the surface reflectance in near infrared band (NIR) and red band to calculate vegetation cover using ENVI 5 (Fig. 1). The ratio between the near infrared band (i.e. band 4) and the red band (i.e. band 3) gives the vegetative information. NDVI was calculated using (1) and spectral emissivity was estimated by utilizing NDVI values as stated in (2) and Table II [15], [36].

$$NDVI = \frac{NIR-R}{NIR+R} \qquad (1)$$

$$\varepsilon = 1.0094 + 0.0047 In(NDVI) \qquad (2)$$

TABLE II
ESTIMATION OF EMISSIVITY USING NDVI

SR. No	NDVI	Land Surface emissivity (ε)
1	NDVI < -0.185	0.995
2	$-0.185 \leq NDVI \leq 0.157$	0.970
3	$0.157 \leq NDVI \leq 0.727$	$1.0094 + 0.0047 In(NDVI)$
4	NDVI > 0.727	0.990

Retrieval of LST from Landsat-7 ETM+ approaches are described in Landsat-7 user handbook by National Aeronautics and Space Administration (Table III). In the first step the DN values were converted from thermal to radiance through Band Math expression in ENVI 5. In the second step, the radiance values were further converted into Kelvin to get the exact spatial temperature distribution through Landsat calibration method. The DN value for the thermal bands has been converted to radiance values and inverse of the Planck function was used to derive temperature values (Fig. 1). Equation (3) was used to calculate temperature from radiance as per calibration constants and (4) was used as the ENVI 5 formula in Band Math calculations [37], [38].

$$T = \frac{K2}{In\left(\left(\frac{K1*b2}{b1}\right)+1\right)} \qquad (3)$$

where: T = Effective satellite temperature in degrees Kelvin, b1= Band 6 of Landsat7 ETM+ (the cell value as spectral

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radiance), b2= Spectral emissivity (NDVI band-calculated from (1)), K1 & K2= Calibration constants.

TABLE III
CALIBRATION CONSTANT [39]

CALIBRATION CONSTANTS	LANDSAT TM	LANDSAT ETM+
K1	607.76	666.09
K2	1260.56	1282.71

$$T = \frac{1282.71}{alog\left(\left(\frac{666.09 * b2}{b1}\right) + 1\right)} \qquad (4)$$

Daytime LST were measured for the individual thermal image and then compared between different time periods. Different representative areas were classified as per urban built-up and vegetative areas for observation of point LST. UHI intensity from 2000 to 2013 was compared to understand the UHI transformation within the Nagpur Urban area.

V. RESULTS AND DISCUSSIONS

The study throws light on certain major aspects related to transformation in LU/LC. In 2000, LU/LC areas of forest/agriculture and open land were 56.61% and 17.39%, respectively, with 24.97% total built-up area. In 2006, forest/agriculture decreased to 36.18%; while open land and total built-up area increased to 29.49% and 33.29%, respectively. Areas under water bodies slightly increased from 0.99 % to 1.01 % during 2000-2006. During 2000-2006, urban built-up has been increased with the difference of 8.32% of the total area, whereas forest/agricultural area have been reduced with a difference of 20.43% and open land area increased by 12.10%. While in 2013, forest/ agriculture and open land were 31.14% and 21.93%, respectively, with 45.71% total built-up area. Areas under water bodies slightly increased from 1.01% to 1.18%. During 2006-2013, urban built-up area has been drastically increased with the difference of 12.42% of the total area, whereas forest/agricultural area have been reduced with a difference of 5.04% than previous and open land area reduced by 7.56 % (Fig. 2).

TABLE IV
CLASSIFICATION BASED ON URBAN BUILT-UP AND VEGETATION

| Class. No.	Class distribution	Class features	LC areas in years %		LC Change Detection %	LC areas in years %		LC Change Detection %
			2000	2006	2000-2006	2006	2013	2006-2013
1	Urban densely built-up	100% built-up	2.82	6.78	3.96	6.78	7.01	0.23
2	Urban high built-up	20% veg-80% built-up	7.68	10.66	2.98	10.66	10.34	-0.32
3	Urban medium built-up	40% veg-60% built-up	1.99	4.51	2.52	4.51	9.89	5.38
4	Urban low built-up	60% veg-40% built-up/ 80% veg-20% built-up	12.48	11.34	-1.14	11.34	21.11	9.77
	Total urban built-up		**24.97**	**33.29**	**8.32**	**33.29**	**48.35**	**15.06**
5	Forest/ agriculture	100% veg	**56.61**	**36.18**	**-20.43**	**36.18**	**31.14**	**-5.04**
6	Water bodies		**0.99**	**1.01**	**0.02**	**1.01**	**1.18**	**0.17**
7	Open land		**17.39**	**29.49**	**12.1**	**29.49**	**21.93**	**-7.56**
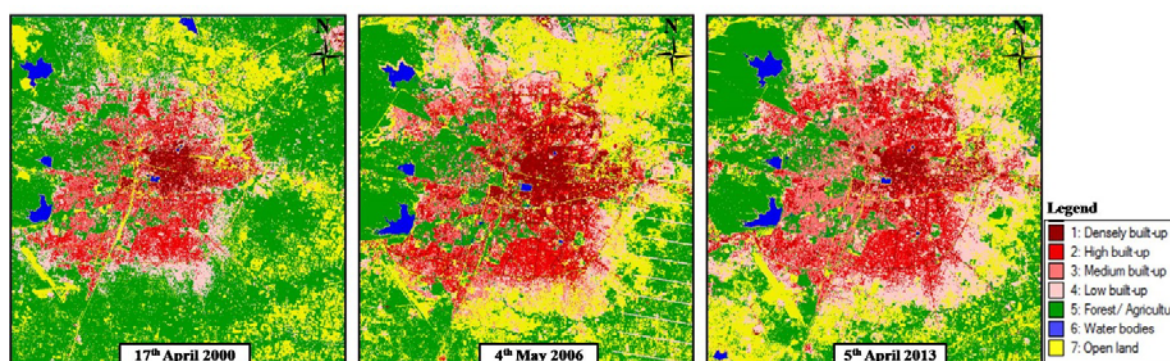
Fig. 2 LU/ LC map through supervised classification of Nagpur urban area

Within urban built-up it has been observed that there was an increase in urban densely built-up and high built-up classes during 2000-2006 as compared to 2006-2013. While urban medium and low built-up classes show drastic rise during 2006-2013 than during 2000-2006 (Figs. 2 and 3, Table IV). It was observed that as the built-up area increases, the forest/agricultural areas decrease with the decrease in open land areas.

Daytime LST results for the Nagpur urban area are shown in Fig. 4. Specific observational points from eight representative LU/LC areas were identified for 2000, 2006 and 2013. LST maps to study the variation in the thermal behaviour of the urban environment of Nagpur City (Fig. 5. and Table V).

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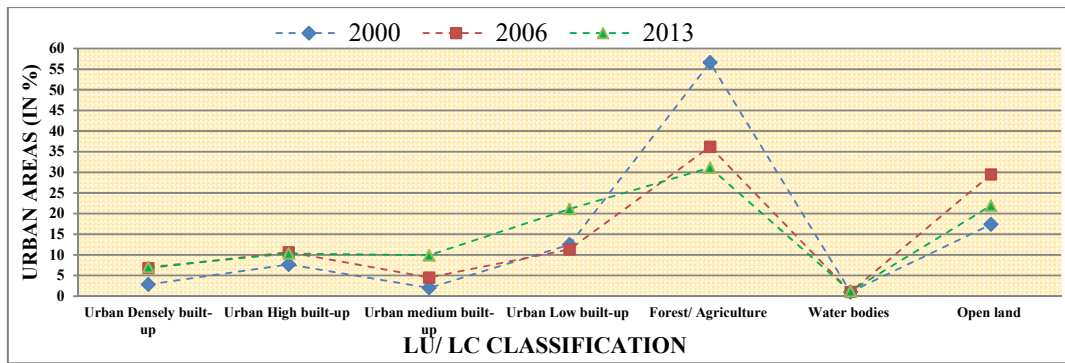Vol:11, No:7, 2017

Fig. 3 Change detection statistics through supervised classification
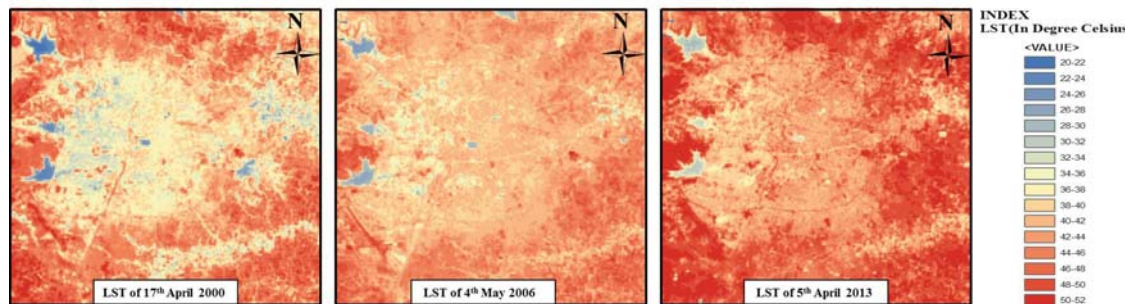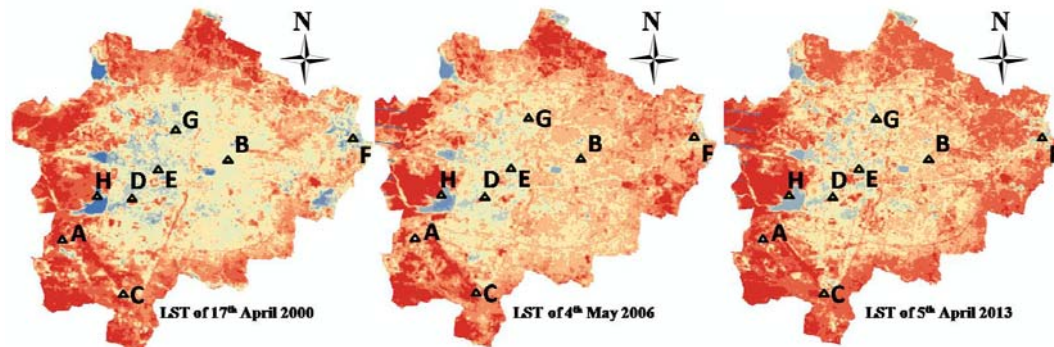

Fig. 4 LST of Nagpur

Fig. 5 LST variation of representative points

TABLE V
LST VARIATION OF REPRESENTATIVE POINTS AS PER LU/ LC FEATURES

Observation points	Observation area	LU/LC features	Classification based on urban built-up and Vegetation (in %)	Point Land LST in ^{0}C		
				17th April' 2000	4th May' 2006	5th April' 2013
A	Hingana area	Open land		40.3	41.3	42.6
B	Mahal area	Urban densely built-up	100% built-up	42.1	44.8	49.4
C	Swawalambi Nagar	Urban high built-up	20% veg-80% built-up	39.4	41.7	44.4
D	Shivaji Nagar	Urban medium built-up	40% veg-60% built-up	34.8	38.5	38.7
E	Civil lines	Urban medium built-up	60% veg-40% built-up	35.72	37.12	38.96
F	Kamptee cantonment	Urban low built-up	80% veg-20% built-up	31.4	33.4	36.2
G	Seminary hills	Forest/agriculture	100%veg	30.9	33.4	33.8
H	Ambazari lake	Water bodies		28.5	28	28.5
	Day time SUHI Intensity during the respective period			**10.7**	**11.4**	**13.2**
	Difference in SUHI Intensities during the respective period			**0.7**	**1.8**	

Densely built-up class exhibits highest temperature, while temperature reduces with decrease in built-up density. The temperature gradually decreased from the highest values observed in urban densely built-up class (such as B), to the moderate values in high and medium built-up density areas (C, D and E), to the lowest in low built-up density areas (such as

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F).

While the least values were observed in non-urban areas (G & H) (LST ranges from 20°C to 52°C, with the highest in red and lowest in blue).

Mean UHI intensity has gradually increased by 0.7°C from 2000 to 2006, whereas during 2006 – 2013 drastic increase of 1.8°C is observed (Table V). Forest/agriculture area decreased by 20.43 % and 5.04 % during 2000-2006 and 2006-2013, respectively (discussed in Section V, Figs. 2, 3 and Table IV). LST of forest area shows increase by 2.5°C and 0.4°C during 2000-2006 and 2006 – 2013, respectively. This shows that as forest/agriculture area decreases, LST rises and increases in the UHI intensity due to decrease in vegetation cover. Highest LST was observed in Mahal, a densely built up area also a CBD of Nagpur city, falling under the densely built-up class. Open land, which increased by 12.1% during 2000-2006, decreased by 7.56% during 2006- 2013 (Table IV). Open land (i.e. Hingana) shows an increase in LST by 1.0°C during 2000-2006 and by 1.3°C during 2006- 2013 (Table V). This means that as the open area increases, LST increases, and if these open areas were further replaced by buildings or hardcover, again the LST increases.

Researchers studied the UHI intensity impact through LU/LC classification in terms of percentage variation [29], [32]-[34]. Similar type of percentage variation has been studied in this paper. In urban built up category, urban densely built-up with 100% class, the urban medium built-up with 60% veg-40% built-up class and urban low built-up with 80% veg-20% built-up classes shows a gradual increase in the LST during 2000-2006, and 2006-2013. Classes with 100 % built-up shows 3.96% increase in area during the period 2000–2006, while very small increase of 0.23% was recorded during 2006–2013 (Table IV). This must be due to the congestion in building density in these 100% class category. They are mostly the old core areas having no space to occupy the new urban developments. The urban medium built up (40% veg-60% built-up and 60% veg-40% built-up) and the urban low built-up (80% veg-20% built-up) classes were also showing a rise in their respective LST (Fig. 5 and Table V).

VI. LST STATISTICAL CORRELATION ANALYSIS

Statistical Correlation was carried to measure the nature and strength of a linear association to be analysed between daytime LST and LU/LC classification composition acquired from Landsat images to compare the green land and built-up land (Table VI). LU/LC (Vegetation in %) was the independent variable, while LST is the dependent variable. The correlation coefficient of LST in relation with LU/LC (Vegetation) are -0.960**, -0.980** & -0.930** during 2000, 2006 and 2013, respectively. These negative values indicate the impact of vegetation is inversely proportional to the LST values. That means vegetation pattern could reduce the LST impact in the city.

The relation between Vegetation and LST is statistically significant at $p<0.01$ level. The study infers the existence of negative correlation between Vegetation and LST (r = -0.960**, -0.980** & -0.930** in 2000, 2006 and 2013,

respectively). This negative correlation indicates that when Vegetation in % increases, LST tends to decrease (Table VI). Study infers that Vegetation cover is one of the powerful determinant causing rises in LST in the Nagpur urban area. As and when there is decrease in the vegetation cover (as observed from 2000 to 2013), the Nagpur urban area has witnessed higher LST throughout the changing time period.

TABLE VI
CORRELATION MATRIX TO STUDY LST THROUGH CHANGE DETECTION

		Vegetation	LST2000	LST2006	LST2013
Vegetation	Pearson Correlation	1	-0.960**	-0.980**	-0.931**
	Sig. (2-tailed)		0.002	0.001	0.007
	N	6	6	6	6
LST2000	Pearson Correlation	-0.960**	1	0.986**	0.979**
	Sig. (2-tailed)	0.002		0.000	0.001
	N	6	6	6	6
LST2006	Pearson Correlation	-0.980**	0.986**	1	0.950**
	Sig. (2-tailed)	0.001	0.000		0.004
	N	6	6	6	6
LST2013	Pearson Correlation	-0.931**	0.979**	0.950**	1
	Sig. (2-tailed)	0.007	0.001	0.004	
	N	6	6	6	6

During both observation periods, higher LST has been observed in mixed use area i.e. residential cum commercial area, which falls under urban densely built-up and medium built-up class. Sparsely vegetated areas showed higher temperatures similar to the highest recorded areas. Classes with medium built-up areas showed less LST than densely built-up class. Sparse built-up with dense vegetation is observed to have lowest LST. Areas coming under forest/agricultural field, as complete vegetation, also exhibit the least LST than densely built-up class. Water bodies and open land shows minimum LST. Urban developments in the urban-fringe area of Nagpur city which are under medium built-up, less vegetation and mostly open land exhibits higher LST. Thus, it is observed that as the building density in urban areas increases, LST also increases. Hence, the entire urban area shows that as building density increases with decrease in vegetation cover, LST increase gradually, thereby causing the UHI effect.

VII. CONCLUSIONS

LU/LC distribution within Nagpur urban area was studied by processing supervised classification through change detection analysis. Through the NDVI values, retrieval of LST was conducted to understand the urban environmental behavior as per the change detection during 2000 to 2013. A comparative study of point LST from different zones of LU/LC categories was conducted. It was observed that vegetation cover decreased from 2000 to 2013. UHI effect was found to be increased with increase in building density and decreased with increased vegetation cover. Areas which are having higher temperature fall under the densely built-up areas and medium built-up with less vegetation. Sparsely vegetative areas having more hard surfaces, absorb heat during the

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daytime and release it at night. This might be the reason why there are LST variations in the different LU/LC areas. These areas were delineated as urban hot spots within the Nagpur urban area. Sparse built-up with dense vegetation areas and those near water bodies exhibits lowest LST. These observed areas were delineated as urban heat sink spots. Lowest LST was mostly in the green areas with less building density, while highest LST was found in the core areas. This was mostly in the commercial areas i.e. the CBD areas having high building density. Higher LST might be due to congested i.e. high building density with uneven geometry of layout.

The study reveals that green cover and building density plays an important role in the formation of UHI. The study concludes that there is a continuous increase in more built-up areas around the core city as medium built-up class with a significant expansion in low built-up class; and contrary, a reduction in the green areas and forest areas that help in reducing the UHI effect. This study methodology could help rapidly growing cities to understand the LU/LC pattern with thermal characteristics using satellite imagery. This would further guide in monitoring the temperature trend within any urban areas to identify the UHI effect.

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