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ORIGINAL RESEARCH PAPER

Microclimate land surface temperatures across urban land use/ land cover forms

S.B. Ali*, S. Patnaik, O. Madguni

Department of Ecosystem and Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, 462003, India

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ABSTRACT: Urbanization brings biophysical changes in the composition of the landscape. Such change has an impact on the thermal environment locally. The urban mosaic of land use and land cover is thus characteristically composed of local climate zones. The spatial variation in the land surface temperature across specific zone is studied for Bhopal city. The objective of the study was to understand how the surface temperature varies with the spatial characteristics of the landscape. The green spaces had the lowest surface temperature that reaches to about 30.5 °C in parks with dense tree cover and highest mean normalized difference vegetation index value of about 0.5. The surface temperature was 36.1 °C for built up/barren areas. The study documents the correlation that exists between surface vegetation and surface temperature across the landscape of Bhopal city. The extent of tree cover and land surface temperature exhibited a strong negative correlation. A decrease in vegetation cover and successive increase in urban built up area were found to be related with high surface temperature. This implies that land surface temperature is an effective tool and may help city planners to make appropriate strategies for improving the tree resources of the urban landscape.

KEYWORDS: *Land surface temperature; Land use/cover; Microclimate; Normalized difference vegetation index; Urbanization.*

INTRODUCTION

Cities are growing at a fast pace and the enhanced urbanization is leading to expansion of cities, which change the properties and composition of the landscape. The United Nation's present estimates of world's urban population is 50% which is projected to increase to 66 per cent in the 2050 (United Nations, 2014). This urban population growth is expressed by a spatial upsurge in the urban built-up pattern (Zeug and Eckert, 2010; Tajbakhsh *et al.,* 2016). All these changes are bringing alterations in the spatial characteristics of the landscape. Replacement of vegetation and soil with impervious surfaces composed of concrete and asphalt has resulted in altered surface temperatures (Obiakor *et al.,* 2012; Ahmed *et al.,* 2013). The relatively higher surface temperature of urban areas in comparison to that of rural areas is termed as the Urban Heat Island (UHI) (Voogt and Oke 2003). The UHI has detrimental effects on human health (Tan *et al.,* 2010) and on ecosystem functioning (Imhoff *et al.,* 2010). UHI is categorized into three types, Canopy Layer Heat Island (CLHI), Boundary Layer Heat Island (BLHI) and Surface Urban Heat Island (SUHI) (Weng, 2009). While CLHI and BLHI are atmospheric phenomena, SUHI is the temperature gradient between the rural and urban areas (Yuan and Bauer, 2007). The heat island is further intensified during the day due to anthropogenic heat release, street canyon geometry which affects the wind speed and flow, reduced evapotranspiration

*Corresponding Author Email: *sarahali30308@gmail.com*
Tel.: +91 947 986 7033 Fax: +91 755 277 2878
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due to impervious covers (Oke, 1982). It is generally seen that the Land Surface Temperatures (LST) are inversely proportional to the vegetation or tree cover of the area (Lambin and Ehrlich 1996; Weng *et al.,* 2004; Weng and Lu, 2008; Raynolds *et al.,* 2008). Therefore, LST is generally seen as a tool to assess the urban green spaces and their cooling intensities (Rosenzweig *et al.,* 2009; Stathopoulou and Cartalis, 2007; Cao *et al.,* 2010; Bowler *et al.,* 2010). Besides vegetation, the moisture content of barren soil, thermal features of construction material used in buildings and roads, the land form configurations, and ultimately the urban canopy also affect LST in urban areas. (Goward, 1981). Urbanization has brought changes to land cover patterns, which has in turn brought undesirable environmental changes (Feyisa *et al.,* 2014). With most of the UHI cases and from developed countries, there is there is a need to know about the characteristics and impacts of UHI in developing countries (Xiao *et al.,* 2002). As most of the developing countries are located in the tropics, these are expected to experience severe consequences of urbanization in the form of heat island effects, undesirable changes in microclimate and consequent prevalence of physiological thermal discomfort (Burkart *et al.,* 2011). Apart from the climatological aspect, elevated ambient temperatures have evidently led to mortality (Basu, 2009). Thus, measures for ameliorating the micro-UHI (e.g., urban greening initiatives) may decrease the effects of high ambient temperatures on human health (Smargiassi *et al.,* 2009). Both remote sensing and field-based studies have shown that spatial network of urban parks and other outdoor green spaces can considerably decrease the average surface and ambient air temperature of cities (Schiano-Phan *et al.,* 2015).

Some of the selected studies explain the urbanization and impacts and most of such studies focused on developed countries. Land use changes due to urbanization, leading to heat island formation, is being brought to light through various studies from across the world in varied climatic zones. Variability in LSTs has been examined across different land use / land cover (LU/LC) types (Mallick *et al.,* 2008). In another study by Hu and Jia (2010) in Guangzhou, a decadal fall in Green Vegetation Fraction (GVF) was by 0.16 from 1990-2007 and mean LST increased by 2.48 ˚C during the same period (Hu and Jia, 2010).

The spatial (Weng *et al.,* 2007) and temporal (Singh *et al.,* 2014; Hussain *et al.,* 2014) variation in LST have been studied across urban Land Cover types. The impact of the variation in and size of the impervious surfaces in the city have positively correlated with the LST (Xiao *et al.,* 2007). Likewise, the relationship of landscape patterns and LST has also been assessed (Liu and Weng, 2008). A comparative analysis of two metropolitan cities of Delhi and Mumbai show that due to low tree cover and urban development, the UHI in Mumbai was significant as compared to Delhi (Grover and Singh, 2015). The decadal spatiotemporal footprints of urbanization were studied using biophysical parameters, the land surface temperature (LST) and normalized difference vegetation index (NDVI) for Surat city of Gujarat. The results indicated that the city expansion and transformation of vegetation to built-up lead to 5.5±2.6 °C increase in LST (Sharma *et al.,* 2013). UHI was identified in different zones of the Ahmedabad city using the satellite and field data. It was indicated that LST was higher near industrial areas and densely built residential and commercial areas of the city (Joshi *et al.,* 2015).

Application of remotely sensed data found to be effective in documenting the relationship exists between the tree cover and the LST. This relationship has been determined by exploration of NDVI and LST values in urban areas (Amanollahi *et al.,* 2012). The study of the impacts of tree loss in central Massachusetts revealed that a tree canopy loss of 10% lead to 0.7 °C rise in LST, whereas a 10% increase in exposed impervious surface area having no overlying tree canopy caused 1.66 °C elevation in LST (Rogan *et al.,* 2013). A temporal analysis of surface temperature and vegetation index showed that most changes due to urbanization were evident through the transition of low temperature-high vegetation fraction pixels to high temperature-sparse vegetation fraction pixels (Amiri *et al.,* 2009).

Vegetation helps in mitigating heat stress on a regional, local and microclimatic change in urban areas (Ali-Toudert and Mayer 2007; Onishi *et al.,* 2010; Li *et al.,* 2011; Farina, 2011; Chen *et al.,* 2013; Zhibin *et al.,* 2015). But successfully incorporating green vegetated areas into the existing urban units is a challenging task. Therefore, temperature reduction by existing categories of green spaces has been studied and it was suggested that green areas in private urban space should be encouraged over small parks in the area (Rotem-Mindali *et al.,* 2015). A Recent study from Munich, Germany indicated that there is non-linear cooling effect of urban vegetated areas as LST within vegetated space was in fact also impacted by the variable thermal properties of nearby urbanized spaces (Alavipanah *et al.,* 2015). In India's context, a study was carried out in Pune city to identify the role of different land covers to attain improved microclimatic conditions in the city (Nesarikar-Patki and Raykar-Alange 2013). The results highlighted the influence of construction boom (32.68% increase in built-up from 1999 to 2006) on the LST (1 ºC to 4 ºC rise in surface temperature).

In all the studies mentioned above, various methods and mathematical processes have been formulated to retrieve LST from the remotely sensed data (Sobrino *et al.,* 2004). The methods utilize the thermal infrared wavelength band. Based on these established methods, the present study firstly aims to assess the LST across various land cover types at macroscale, generating the spatial distribution of UHI in Bhopal. Secondly, assessment of the microscale impacts of urban forms (parks and residential colonies types) on LST. While studies assessing the LST and UHI have been carried out for metropolitan (Tier-I) cities in India like Delhi and Mumbai (Singh and Grover, 2014, 2015), not much has been analyzed for emerging (Tier-II) cities like Bhopal (Ranade, 2015). In this light, Bhopal city is taken as the subject of interest to assess how the surface temperature varies with the spatial characteristics of the urban landscape. The study area, Bhopal, is a city from a developing country. Like any other developing country it has diverse neighborhoods (Henderson, 2010; Dutt *et al.,* 2016) which enables assessment on small spatial scales. The environmental issues arising due to urbanization are faced alike by all developing countries. The problems which once emerged at the local level, have become global problems today (Yigitcanlar and Dizdaroglu, 2015). Therefore, assessment of microclimate is needed at different spatial scales, the magnitude and results of which could be in direct line of interest for urban planning in other developing cities. From the climate point of view, Bhopal lies in the tropical dry climate zone, thus the results of this study may be applicable to other developing cities with tropical dry climate globally. The study is carried out the satellite imagery of Bhopal city within the limits of municipal corporation boundary in 2014.

MATERIALS AND METHODS

Study area

Bhopal, the capital city of Madhya Pradesh state (Fig. 1), situated on the Malwa Plateau (geographical coordinates of 23° 16' 0" N, 77° 24' 0" E.) at an average elevation of 576 m. above mean sea level, and faces hot dry summers and mild winters. Bhopal has uneven elevation and has a number of small hillocks and large water bodies and forest areas in contiguity to the urban areas.

The land use in Bhopal is categorized into seven classes as Residential, Commercial, Industrial, Public, Public utilities, Recreational and Transport (Bhopal City Development Plan, 2005). The Bhopal city landscape has rolling topography and diverse green cover. Percentage of tree cover in Bhopal is 13.20% of the geographical area (Forest Survey of India, 2011). The Bhopal city can be divided into three characteristic regions i.e. Old city, New Bhopal and BHEL (Bharat Heavy Electricals Limited) campus with varied levels of vegetation. Old Bhopal has haphazard growth process and has less vegetation as compared to other two regions. Planned development in New Bhopal has traced green spaces in the form of National park, Regional parks, City Parks, Community Parks and Local Residential Amenity Open Spaces along with avenue of road side plantation. Similarly, BHEL campus also has abundance of greenery due to limited population and less interference from outside its jurisdiction boundary.

The municipal boundary of Bhopal is taken as the limit of the study area. LST and NDVI maps are prepared from Landsat 8 imagery for the summer day of 2014 for the reason that climatic heat stress in the urban open space mainly occurs during the summer period (Orosa *et al.,* 2014).

Land use and cover types of Bhopal landscape were examined for macro-scale variation in LST. Among the different urban land uses, different locations were selected to examine the surface temperature at microscale;

a) Urban parks: public parks with dense (>70%), moderate (50-70%) tree canopies; park with water body, park with grass lawns, and city forest plantations.

b) Built up areas:

1) Green residential area with dense canopied trees on streets and private gardens.

2) Old city's compact low rise built up area with no vegetation.

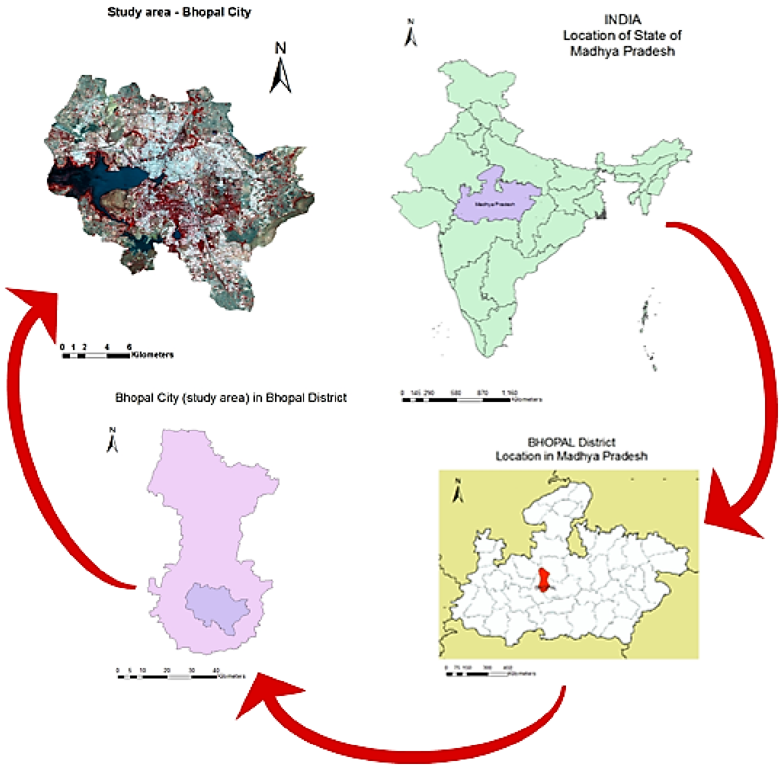

Fig. 1: Location of the study area

3) City Airport: Dominance of large low-rise buildings with no trees in proximity. Concrete and metal construction materials, and paved land.

The LST was generated for the Bhopal city for the year 2014. Landsat data of summer month June is focused for two reasons – firstly, UHI is more significant during summer season (Zeng *et al.,* 2010) and its associated heat health risks (Lindley *et al.,* 2006); secondly, studies have revealed that the cooling effect of urban green spaces to be higher in summer season (Ren *et al.,* 2013). Thus, the present study can help identify the pronounced effect of vegetation on the surface temperature of Bhopal in the summer season. The relationship between LST and NDVI was explored across each Land Use/Cover LU/LC type, with emphasis on selected locations of vegetation and built up areas in the city.

Land use/ cover (LU/LC) mapping

In ERDAS, Maximum likelihood supervised classification. Class signatures were made prior to supervised classification in Erdas Imagine. Following are the six classes: Water body, Marshy land, Settlement, Vegetation, Barren land, Agriculture land.

LST retrieval for Bhopal using Landsat 8 TIRS data

To analyze the surface temperature variations the following steps of Mono Window Algorithm (Chakraborty *et al.,* 2015; Wang *et.al.,* 2015) were followed to retrieve the LST in Landsat 8 TIRS imagery data (Table 1) using ArcGIS 9.2 (USGS, 2015). This method utilizes surface brightness temperature which is obtained from the surface radiance by means of Plank's Law.

The thermal band data is rescaled to generate TOA (top of atmosphere) radiance by applying calculation factors from the metadata file as Eq. 1.

$$L = (M_{*}Q) + A \qquad (1)$$

Where, L is TOA radiance in watt/(m^2*srad*µm), M is radiance multiplicative factor for the thermal band, A is the radiance additive factor for the thermal band, Q is the quantized pixel value.

Table 1: Properties of Landsat satellite image used.

Satellite	Sensors	Date of data acquirement	Path and row	Spatial resolution	Clouds
Landsat 8	TIRS/OLI	10 June 2014	145/044	30m	Nil

The second step is the conversion of spectral radiance to brightness temperature using the thermal constants from the metadata file according to the Eq. 2.

$$T = K2/ln\,(K_1/L)+1 \quad (2)$$

Where, T is brightness temperature in Kelvin, L is TOA radiance, K_1 and K_2 are thermal conversion constants provided in the metadata of Landsat 8.

The temperature obtained was transformed from Kelvin to Celsius using the factor 273.15 as Eq. 3.

$$T\,°C = T - 273.15 \quad (3)$$

Estimation of NDVI

The NDVI from Landsat 8 satellite image was generated using red (4th) and near-infrared (5th) bands using the equation (Equation 4) in ArcGIS software. This vegetation index is widely used for representing the expanse and health of vegetation. The value of NDVI is unit less and ranges from -1 to +1, where higher positive values represent vegetation against the negative values representing the non-vegetation areas as Eq. 4.

$$NDVI = \frac{(\text{Band5} - \text{Band4})}{(\text{Band5} + \text{Band4})} \quad (4)$$

Using LU/LC map, the Land Use classes were vectorized individually in QGIS 2.8.1. These vectors were then used to mask and clip LST and NDVI images. In ArcGIS, Band Collection Statistics (Table 2) was performed on the Land Use Class Polygons of LST and NDVI maps to get the Mean LST and Mean NDVI values and the correlation coefficients. In this study, the Pearson's correlation is a measure of linear correlation between biophysical variables which may indicate the effect size of LST reduction by NDVI. Similarly, selected land uses cases of green spaces and built up areas were also clipped from the images and studied.

Field measurements were undertaken to measure the tree cover in the selected locations using Densiometer (Lemmon, 1956). The spherical densiometer is simply a convex mirror with grid-overlay (96 vertices) that is used to measure tree/forest canopy closure. The tool was held level at predefined coordinates (10x10m plots) in the study locations of the city. The vertices that reflected canopy openings were counted and multiplied by 1.04 and subtracted from 100% to give canopy closure. Such readings in 4 cardinal directions are then averaged to give tree cover (overstory density) of that point.

RESULTS AND DISCUSSION

The Landsat 8 TIRS data was acquired for the summer season of June 2014 to analyse the variation in thermal responses of different land cover forms in Bhopal city. Band combinations of channels 3, 4 and 5 were used to generate maximum information in LULC classification (Fig. 2).

The analysis from imagery (Fig. 3) reveals that built, barren, agriculture areas had higher

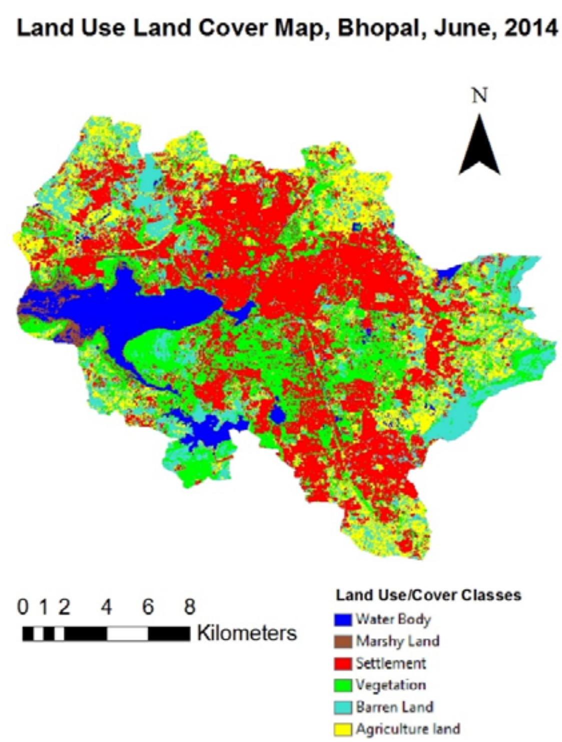

Fig. 2: LULC map of Bhopal

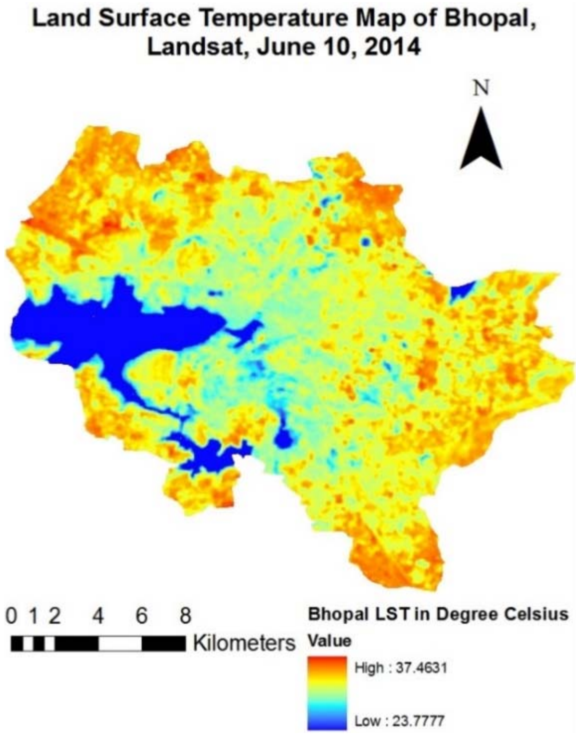

Fig. 3: Land surface temperature (LST) map of Bhopal

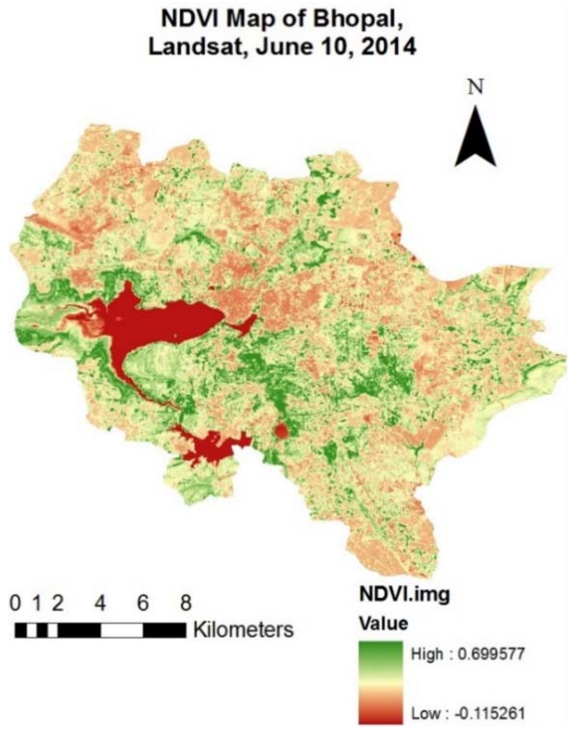

Fig. 4: Normalized difference vegetation index (NDVI) maps of Bhopal

surface temperature (33.2 ºC, 34.9 ºC and 35.3 ºC respectively) than areas with vegetation cover (32.7 ºC) and water bodies exhibiting lowest surface temperature (25.2 ºC). The high LST of built area is for the reason that impervious surfaces like buildings and roads capture and retain larger fraction of the sun's heat relative to what natural vegetation does (Alavipanah *et al.,* 2015). Open barren land has low evapotranspiration as compared to vegetated land (Sinha *et al.,* 2015). The comparatively low difference in mean LST of built and vegetation land cover can be due to the effect of the shadow of buildings (Uysal and Polat, 2015; Stamou and Patias, 2014). The mean NDVI value of Bhopal city (Fig. 4) is 0.136 (standard deviation 0.245) with maximum mean NDVI for vegetation cover (0.31). Besides vegetation influencing the variation in NDVI value, other land and atmospheric factors like topography, slope and solar radiation also affects the retrieved index values (Bian and Wlash, 1993).

The relationship between LST and NDVI was examined for each LU/LC type through correlation analysis. Table 2 illustrates the Pearson's correlation between the two variables for each of the land use class. The highest correlation is found in vegetation (-0.55056), followed by crop (-0.39921) and barren land (-0.31269). The built up area (-0.06725) exhibited the lowest correlation. The positive correlation exists for water bodies (0.385). Since vegetation index shows strong negative correlation with LST, it can be established that higher is vegetation abundance on land, lower will be the LST.

Similarly, for the relationship between LST and NDVI was studied for selected locations in the city through correlation analysis. NDVI is attributed to the tree cover in all the locations (Table 3). This was established by a strong Pearson's Correlation Coefficient (0.78) that exists between NDVI and percentage Tree Cover of all locations. It was found that *location A*, i.e., the park in close proximity to water body has the lowest LST. In *location B*, the park that constitutes the highest tree cover zone of the city, a strong negative correlation (-0.79) exists between its low LST and high NDVI. *Location C* is a dense tree canopy park with a water body (small lake) inside, where the low correlation (-0.10) between NDVI

Table 2: Descriptive band statistics of LST and NDVI across Land Use/Cover type

Land use/ cover type	Mean LST in ºC (Standard deviation)	Mean NDVI (Standard deviation)	Correlation between LST and NDVI
Built	33.23 (0.98)	0.19 (0.06)	-0.06725
Vegetation	32.75 (1.46)	0.31 (0.09)	-0.55056
Barren	34.93 (0.78)	0.20 (0.05)	-0.31269
Agriculture land	35.32 (0.71)	0.18 (0.04)	-0.39921
Water	25.24 (1.40)	0.03 (0.13)	0.385

Table 3: Selected locations of vegetation and built land uses from Bhopal city

	Locations in Bhopal City	Tree cover (%)	Mean LST (ºC)	Mean NDVI	Correlation coefficient (Mean LST and Mean NDVI)
A	Park near lake *(Kamla Park)*	58.00	30.5	0.38	-0.54
B	Dense tree canopy park *(Ekant Park)*	92.00	30.9	0.48	-0.79
C	Park with water body *(Jawahar Bal Udyan JBU park)*	76.00	31.4	0.39	-0.10
D	Remnant forest patch (Near Vidhan Sabha)	54.00	33.1	0.35	-0.70
E	Park with grass lawns *(Mayur park)*	30.00	32.1	0.45	-0.09
F	Grass lawns and palm trees *(Nishat park)*	27.00	32.3	0.43	-0.07
G	Remnant evergreen Forest *(Forest patch near JBU)*	85.00	32.9	0.42	-0.53
H	Green Residential Colony *(Char Imli Colony)*	69.00	32.1	0.40	-0.20
I	Old City- Densely Built up *(Aishbagh)*	0.00	33.7	0.10	0.11
J	Airport	0.00	36.1	0.09	0.50

and LST can be attributed to the presence of water body. This is followed by *location E* and *location F,* characterized by grass lawns and open tree canopy, which exhibit low correlation (-0.07). *Location D* and *location G* are contrasting forest patches in terms of tree canopy density and exhibit a strong negative correlation (-0.70 and -0.53 respectively) between NDVI and LST, supporting that Tree Cover brings down the surface temperature. Another case of the location which was studied was the residential areas of the city. *Location H*, a green residential area characterized by dense canopied trees on streets and private gardens exhibited a moderate negative correlation (-0.2). This was enough to support that trees bring down the surface temperature (by 1.6 °C) when compared with the results of *Location I*, densely built old city (0.11 correlation between LST and NDVI). For identifying the impact of sole concrete built up, airport building was investigated. It exhibited highest surface temperature (36.1 °C) of all locations.

Comparative analysis of LST in parks and in green residential colonies shows that green residential colonies and open parks with low tree cover had similar mean LST. This suggests that green areas within private urban gardens and street trees in green residential colonies should be encouraged. Similar results were seen in Tel-Aviv by Rotem-Mindali *et al.* (2015). Thus in the course of urbanization and seeking efforts to mitigate UHI, new residential colonies should be planned and developed with green spaces and pockets within the colonies, rather than laying out new small to medium sized parks in cities that lack space for large parks. These results generate a picture of existing conditions of city morphology and variety of green spaces in the city. It is established that NDVI is an indicator of LST across the LU/LC classes in the city. Studies have quantified relationship between surface temperature and biophysical parameters using correlation analysis between NDVI and LST for different land use and cover types (Dewan and Corner, 2014). The correlation analysis in the case of Bhopal city not only depict the importance of urban vegetation in reducing temperature but also highlights the contribution of large and small water bodies on ameliorating microclimate. Similar studies have also recognized the impact of both vegetation and water in mitigating the variation in the thermal environment (Sun and Chen, 2012). Thus for improving the micro and macro-climatic conditions in the city, the two natural resources in the city– water and vegetation have to be strategically utilized and managed by the city planners. The network of these two natural resources forms the Green Infrastructure which provides ingredients for solving urban problems like UHI effect (Radhi *et al.,* 2013). A well-established class of green infrastructure is green roof (roofs with vegetation growing on a substrate). They help in regulating temperature of building and reducing urban heat-island effects (Oberndorfer *et al.,* 2007) due to small sensible heat flux of green surfaces (Takebayashi and Moriyama, 2007). Other methods of greening that are prevalent in green residential colonies of Bhopal city are private house gardens and street plantations. These urban greening methods reduce the mean LST of the residential colony (Table 3) by 1.6 ºC as compared to a highly dense built up colony that lacks vegetation. Incorporation of these features in the planning of cities will lead to its sustainable growth and development. Cities like Bhopal need to have an effective framework of green infrastructure in order to achieve maximum ecosystem services and to attain smart development.

CONCLUSION

Urbanization is leading to changes in the signature surface properties. This is best estimated by drawing out a broad picture of LU/LC in the city. These classes of land cover vary in their surface spectral emissivity properties which are utilized to retrieve a digital image using remote sensing technology. The estimation of LST and NDVI of Bhopal has been used to assess the effects of urbanizing activities on the thermal environment of Bhopal. LST, NDVI, and LU/LC together provide the spatial pattern of urban thermal environments. Surface temperature and vegetation index across the land cover classes was determined and it was estimated that dense vegetation areas have the lower surface temperature than the highly built up areas. Band collection statistics shows that green spaces like parks have higher mean NDVI and low mean surface temperature. With micro thermal details of the individual type of park with comparison to built-up area, it would help the planning departments to establish and maintain the optimum type of Green Space along the urbanization activities. It thus highlights a scenario for the city planners to implement firm urban norms to develop and increase the tree cover in the city. The principle of 'the right tree in the right place' should be adopted in order to produce a city landscape which helps regulate the micro-environments in the city. Other measures of green infrastructure like green roofs and green walls which have proved beneficial in other countries may be incorporated in the development plan of the city.

CONFLICT OF INTEREST

The authors state that there is no conflict of interests concerning the publication of this manuscript.

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ABBREVIATIONS

%	Percent
°C	Degree celsius
μm	Micrometer
A	Additive factor for radiance
BHEL	Bharat heavy electrical limited
CLHI	Canopy layer heat island
E	East

Eq.	Equation
GIS	Geographic information system
GVF	Green vegetation fraction
K_1	Thermal conversion constant 1
K_2	Thermal conversion constant 2
L	TOA radiance
ln	Natural log
LST	Land surface temperature
LU/LC	Land use/ land cover
m	Meter
M	Multiplicative factor for radiance
m^2	Meter square
N	North
NDVI	Normalized difference vegetation index
Q	Quantized pixel value
QGIS	Quantum Geographic information system
srad	Steradian
SUHI	Surface urban heat island
T	Brightness temperature in Kelvin
T °C	Temperature in degree celsius
TIRS	Thermal infrared sensor
TOA	Top of atmosphere
UHI	Urban heat island
USGS	United States Geological Survey

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AUTHOR (S) BIOSKETCHES

Ali, S.B., Ph.D. Candidtae, Department of Ecosystem and Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, 462003, India. Email: *sarahali30308@gmail.com*

Patnaik, S., Ph.D., Professor, Department of Ecosystem and Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, 462003, India. Email: *spatnaik@iifm.ac.in*

Madguni, O., Ph.D., Assistant Professor, Department of Ecosystem and Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, 462003, India. Email: *prakash@iifm.ac.in*

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