RESEARCHERID
THOMSON REUTERS

*[Sakthivel *,* 5(11): November 2018] ISSN 2348 – 8034
DOI- 10.5281/zenodo.1493908 Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

URBAN HEAT ISLAND (UHI) ANALYSIS USING GEO-SPATIAL TECHNOLOGY IN PUNE CITY, MAHARASHTRA

Dr. M. Sakthivel*[1], Dr. M. H. Kalubarme[2], Gaikwad Vishal Vilas[3] & Panhalkar Bilal Dastagir[3]
[*1]Associate Professor, Dept. of Geography, University of Madras, Chennai.
[2] Project Director, BISAG, Gandhinagar.
[3]Student, M.Tech., (Geo-informatics), Dept. of Geography, University of Madras, Chennai

ABSTRACT
Urban Heat Island (UHI) refers to the phenomena of higher surface temperature occurring in urban areas as compared to the surrounding areas. Spatio-temporal changes in UHI can be quantified through Land Surface Temperature (LST) derived from Remote Sensing digital data. Pune city has observed rapid urbanization over the last decade. Due to rising population pressure the city has expanded considerably in a real extent and has also observed substantial land use/land cover (LULC) changes. The major objectives of this paper is to determine changes in the LST and UHI phenomena for Pune city over the period from 1998, 2008 and 2018 and analyze the spatial distribution and temporal variation of LST in context of changes in LULC. In this study, multi-temporal Landsat data covering Pune City for the summer seasons of 1998, 2008 and 2018 were downloaded from USGS website: https://earthexplorer.usgs.gov/. Results reveal that Pune city has witnessed considerable growth in built up area over the last decade, which had clear impact on variation in LST. There has been an average rise of 2.990 C in overall summer temperature. LST change is inversely related to change in vegetation cover and positively related to extent of built up area. The study concludes that UHI of Pune city has intensified and extended over new areas.

Key Words: *Land Surface Temperature (LST), Urban Heat Island (UHI), Land Surface Emissivity (LSE), Normalized Difference Vegetation Index (NDVI), Land Use / Land Cover (LULC).*

I. INTRODUCTION

Global warming has drawn attention of researchers worldwide because the global mean surface temperature has recorded an increase since the late 19th century. As more than 50% of the human population lives in cities, urbanization has been an important contributor in the process of global warming. Temperature changes consequent upon the transformations of physical landscape associated with urbanization have led to many environmental problems. One such consequence is Urban Heat Island (UHI). Extensive urbanized surfaces modify the energy and water balance processes and influence the dynamics of air movement. The interactions of urban surfaces with the atmosphere are governed by surface heat fluxes, the distribution of which is drastically modified by urbanization. The main contributing factors are changes in physical characteristics of the surface (albedo, thermal capacity, heat conductivity) owing to replacement of vegetation by asphalt and concrete; decrease of surface moisture available for evapo-transpiration; changes in irradiative fluxes and in near surface flow, owing to complicated geometry of streets and tall buildings, and anthropogenic heat (Dousset and Gourmelon, 2003). The integrated application of remote sensing, geographic information system (GIS) and quantitative analytical modeling can provide scientific and effective methods for monitoring and studying urban land surface thermal environment.

1.1 Land surface temperature (LST) using Remote Sensing data

Land surface temperature (LST) is a key factor in physical processing of land surface at a regional and global scale, and it generalizes the results of the interaction between land surface and atmosphere, exchange of matter and energy (Wan and Dozier, 1996). In the general assessment model of sustainable development and LST change, the change of LST is regarded as an important criterion upon which the evaluation of environmental quality and social and economic development policy can be based. Findings of Kim & Baik (2002) reveal that average maximum UHI is weakest in summer and strong in autumn and winter. The UHI intensity was found to be inversely correlated with the rural temperature, while the spatial extent was found to be independent of both heat island magnitude and rural temperature by Streutker (2002). Hawkins et al., 2004 studied the effect of rural variability in calculating the urban heat island effect. Xiao et al., 2008 identify quantification of statistical relationship between LST and land use land cover parameters as a relatively neglected field of research in the field of thermal remote sensing.

1.2 Relationship of Land surface temperature (LST) and Land Use

It was found that LST is positively correlated with built up area and population density, while negative association exists between LST and percentage of forest, farmland and water bodies. Positive relationship between LST and fraction of impervious surface, and negative association between LST and fraction of green vegetation cover has been corroborated by the findings of Weng et al., 2007, Buyantuyev and Wu (2010) studied diurnal and seasonal characteristics of the surface UHI in relation to land cover properties and observe that vegetation is the most significant explanatory variable of daytime surface temperature. They further observe that agricultural activities have an obvious influence on the interpretation of land use land cover types. Li et al., 2014 have studied LST variations for over a decade (2008-2009) using multi-temporal Landsat data and find that high LST regions correspond with residential and industrial areas with low vegetation coverage. Low population density is associated with lower LST values. Nevertheless, seasonal analysis of relationship between LST and percent impervious surface and NDVI done by Yuan and Bauer (2007) reveals that relationship between NDVI and LST varies seasonally. They suggest percent impervious surface cover as a more reliable metric for quantitative analysis of LST over different seasons for urbanized areas. Studies have established that UHI intensity is related to patterns of land use/cover changes, e.g., the composition of vegetation, water and built-up and their changes over a specific period. Various vegetation indices obtained from remote sensing images can be used in the assessment of vegetation cover qualitatively and quantitatively (Tian & Xiangjun, 1998). Qualitative and quantitative studies on the relationship between land use/cover pattern and LST are imperative for effective urban land use planning.

1.3 Urban Heat Island (UHI) Studies using Remote Sensing

Remote sensing observations provide useful information on urban heat island intensities and hotspots as supplement or proxy to in-situ surface based measurements. A case study has been undertaken to assess and compare the UHI and hotspots based on in-situ measurements and remote sensing observations as the later method can be used as a proxy in absence of in-situ measurements both spatially and temporally. Capital of India, megacity Delhi has grown by leaps and bounds during past 2 - 3 decades and strongly represents tropical climatic conditions where such studies and field campaigns are practically non-existent. Thus, a field campaign was undertaken during summer, 2008 named DELHI-I (Delhi Experiments to Learn Heat Island Intensity-I) in this megacity. Urban heat island effects were found to be most dominant in areas of dense built up infrastructure and at commercial centers. The heat island intensity (UHI) was observed to be higher in magnitude both during afternoon hours and night hours (maximum up to 8.3˚C) similar to some recent studies. The three high ranking urban heat island locations in the city are within commercial and/or densely populated areas. The results of this field campaign when compared with MODIS-Terra data of land surface temperature revealed that UHI hotspots are comparable only during night time (Manju Mohan et al., 2012).

A study was carried out to identify and study the urban hot spots using the LANDSAT–5 TM in the Pune City. A typical residential building, one from each of the administrative zones, was chosen for studying the energy performance and end-use energy distribution. Results of this study helped to develop a decision making tool for selection of appropriate building material for a particular isotherm. Also various building parameters have been selected to study their impact on the building operational energy. A multivariable regression equation has been generated in linear and exponential terms to study mathematically the impact of each parameter. This equation may be used as a tool by the designers and planners while incorporating energy efficiency in to a new building or for retrofitting an existing building. One of these major problems is the Urban Heat Island phenomena (UHI) which has increased the temperature by four to five degrees and has also severely affected air quality.

1.4 Major objectives

i) To determine changes in the LST and UHI phenomena for Pune city during 1998, 2008, and 2018 using Lansat digital data

RESEARCHERID
THOMSON REUTERS
*[Sakthivel *,* 5(11): November 2018] ISSN 2348 – 8034
DOI- 10.5281/zenodo.1493908 Impact Factor- 5.070

ii) To analyze temporal changes of land use / land cover of Pune city during 1998, 2008, 2018 and its impact on LST and UHI
iii) To analyze the spatial distribution and temporal variation of surface temperature.

II. METHODS AND MATERIAL

2.1 Study Area

Pune city lies on the western margin of the Deccan plateau, at an altitude of 560 m (1,840 ft) above sea level. It is on the leeward side of the Sahyadri mountain range. It is a hilly city, with Hill rising to 800 m (2,600 ft) above sea level. It is situated at approximately 18° 37" North latitude and 73°55" East longitude. Pune has a hot semi-arid climate (type BSh) bordering with tropical wet and dry (type Aw) with average temperatures ranging between 19 and 33°C (66 and 91 °F). Pune experiences three seasons: summer, monsoon, and winter. Typical summer months are from mid-March to mid-June, with maximum temperatures sometimes reaching 42 °C (108 °F). The city has a population of 3,124,458; while 5,057,709 people reside in the Pune Urban Agglomeration as of the 2011 census. The number of people migrating to Pune rose from 43,900 in 2001 to 88,200 in 2005.

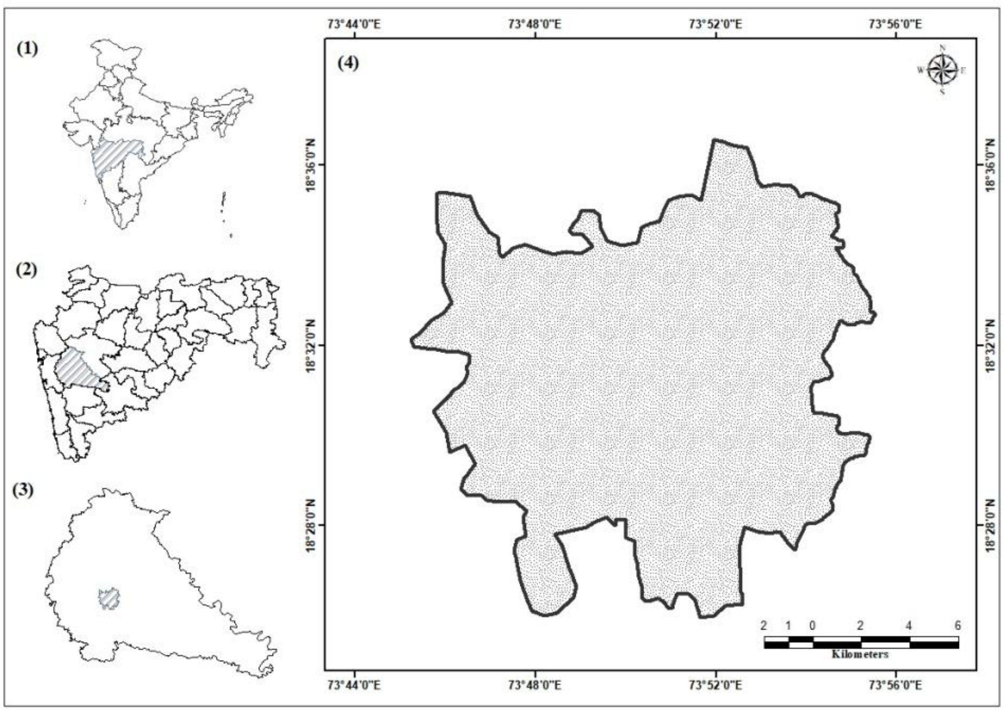

Figure-1: Location map Pune City in Maharashtra State

2.2 Data Used

A set of cloud free imagery of summer season, Landsat-5 Thematic Mapper (TM) digital data acquired during 1998, 2008 and Landsat-8 Operational Land Imager (OLI) & Thermal Infrared Sensor (TIRS) acquired during 2018 have been used. Band 6 (Thermal band) used for Landsat-5 and bands 10 and 11 (Thermal band) used for Landsat-8 image for LST analysis. The details of Landsat data are given in **Table-1**.

*[Sakthivel *,* 5(11): November 2018] ISSN 2348 – 8034
DOI- 10.5281/zenodo.1493908 Impact Factor- 5.070

Table-1: Landsat Satellite data used in UHI Analysis of Pune City

Sr. No.	Satellite	Sensor	Spatial Resolution (m)
1	Landsat-5	TM	30
2	Landsat-5	TM	30
3	Landsat-8	OLI	30

2.3 Supervised Classification

The Landsat-5 TM digital data of the years 1998, 2008 and Landsat-8 (OLI & TIRS) of the year 2018 was classified using Supervised classification using Gaussian Mixture Model (QGIS, Version 2.18) has been performed on combination of Band-4 (NIR), Band-3 (Red), Band-2 (Green) and Band-1 (Blue) for Landsat-5 (TM) satellite image and for Landsat-8 (OLI & TIRS) satellite image used Band-2 (Blue), Band-3 (Green), Band-4 (Red) and Band- 5 (NIR). The supervised classified images were used to generate aggregated Land use / land cover maps of the study area during 1998, 2008 and 2018 years. Images have been classified into four classes- built-up, vegetation, water bodies and barren land. The land use land cover maps indicate that the percentage of area under different land use classes as obtained from the supervised classification. The maps brought out a striking pattern of changes in the study area. It was observed that the built up area has significantly increased in the core and also in area away from the centre.

2.4 Accuracy Assessment of Supervised Classification

Accuracy assessment of each classified image was performed using 80 reference pixels identified through stratified random sampling. Table-2 presents the results of accuracy assessment of the classified maps. Subsequently, classified images have been compared visually as well as quantitatively to detect and measure the patterns and magnitude of changes in selected land cover categories which have occurred in 2018 as compared to 1998.

Table- 2: Accuracy Assessment of Land Use / Land Cover (LULC) Classification

LULC Class	1998		2008		2018	
	PA	UA	PA	UA	PA	UA
Water Bodies	86.67	94.12	86.67	100.00	83.33	100
Vegetation	90.00	75.00	90.00	93.10	80.00	93.10
Built-Up Area	100.00	85.00	100.00	73.17	100.00	73.17
Barren Land	70.00	89.47	70.00	87.50	86.67	87.50
	OA = 85		OA = 86.67		OA = 87.5	
	K = 0.81		K = 0.82		K = 0.83	

(K) = Kappa Coefficient, OA = Overall accuracy, UA = User's Accuracy

High classification accuracy has been achieved for all the selected classes in the classified maps. Overall accuracy (OA) for all the years is more than 85 percent along with fairly high Kappa (K) statistics of approximately more than 81 percent which indicates high reliability of classification results. Further the class wise accuracies for both years particularly User's Accuracy (UA) for individual classes is more than 73 percent for almost all classes of interest during different years.

2.5 Procedure Adopted for Land Surface Temperature Calculation

2.5.1Conversion of Top of Atmosphere (TOA) Radiance:

Using the radiance rescaling factor, Thermal Infra-Red Digital Numbers (DN) can be converted to TOA spectral radiance.

[Sakthivel *, 5(11): November 2018] ISSN 2348 – 8034
DOI- 10.5281/zenodo.1493908 Impact Factor- 5.070

$$L\lambda = \{(Lmax – Lmin) / (QCalMax - QCalMin)\} * (QCal - QCalMin) + Lmin$$

Where:

Lλ = TOA spectral radiance
LMax = Spectral radiance that is scaled to QCalMax
LMin = Spectral radiance that is scaled to QCalMin
QCalMax = Maximum quantized calibrated pixel value in DN
QCalMin = Minimum quantized calibrated pixel value in DN
Qcal = Quantized and calibrated standard product pixel values (DN)

2.5.2 Conversion of Top of Atmosphere (TOA) Brightness Temperature:

Spectral radiance data can be converted to top of atmosphere brightness temperature using the thermal constant values in metadata file.

$$BT = K2 / \ln (k1 / L\lambda + 1) - 272.15$$

Where:

BT = Top of atmosphere brightness temperature (°C)
Lλ = TOA spectral radiance (Watts/(m^2 * sr * μm))
K1 = K1 Constant Band (No.)
K2 = K2 Constant Band (No.)

2.5.3 Normalized Differential Vegetation Index (NDVI):

The Normalized Differential Vegetation Index (NDVI) is a standardized vegetation index which calculated using Near Infra-red and Red bands.

$$NDVI = (NIR – RED) / (NIR + RED)$$

Where:

RED = DN values from the RED band
NIR = DN values from Near-Infrared band

2.5.3 Land Surface Emissivity (LSE) estimation

Land surface emissivity (LSE) is an important surface parameter and can be derived from the emitted radiance measured from space. Besides radiometric calibration and cloud detection, two main problems need to be resolved to obtain LSE values from space measurements. These problems are often referred to as land surface temperature (LST) and emissivity separation from radiance at ground level and as atmospheric corrections in the literature. Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from NDVI values. The proportion of vegetation (PV) is computed as follows:

$$PV = [(NDVI – NDVI\ min) / (NDVI\ max + NDVI\ min)]^2$$

Where:

PV = Proportion of Vegetation
NDVI = NDVI Values from the Image
NDVImin = Minimum NDVI
NDVI max = Maximum NDVI

Using the computed values of proportion of vegetation (PV) the E = Land Surface Emissivity is computed as follows:

ISSN 2348 – 8034
Impact Factor- 5.070

$$E = 0.004 * PV + 0.986$$

Where:

E = Land Surface Emissivity
PV = Proportion of Vegetation

2.6 Land Surface Temperature (LST):

The Land Surface Temperature (LST) is the irradiative skin temperature of the land surface, as measured in the direction of the remote sensor. It is estimated from Top-of-Atmosphere brightness temperatures from the infrared spectral channels of a constellation of geostationary satellites. Its estimation further depends on the albedo, the vegetation cover and the soil moisture. LST is a mixture of vegetation and bare soil temperatures. Because both respond rapidly to changes in incoming solar radiation due to cloud cover and aerosol load modifications and diurnal variation of illumination, the LST displays quick variations too. In turn, the LST influences the partition of energy between ground and vegetation, and determines the surface air temperature.

$$LST = (BT / 1) + W * (BT / 14380) * \ln(E)$$

Where:

BT = Top of atmosphere brightness temperature (°C)
W = Wavelength of emitted radiance
E = Land Surface Emissivity

III. RESULTS AND DISCUSSION

3.1 Vegetation abundance from NDVI Images

NDVI images have been generated for 1998, 2008 and 2018 years to estimate the vegetation abundance, using Red and NIR bands of Landsat-5 and Landsat-8. The high NDV values indicate more abundance of vegetation as compared to areas with low NDVI values (Figure-2). The vegetation abundance computed from the NDVI images was used to generate the land surface emissivity (LSE) of different land use land cover classes in Pune City.

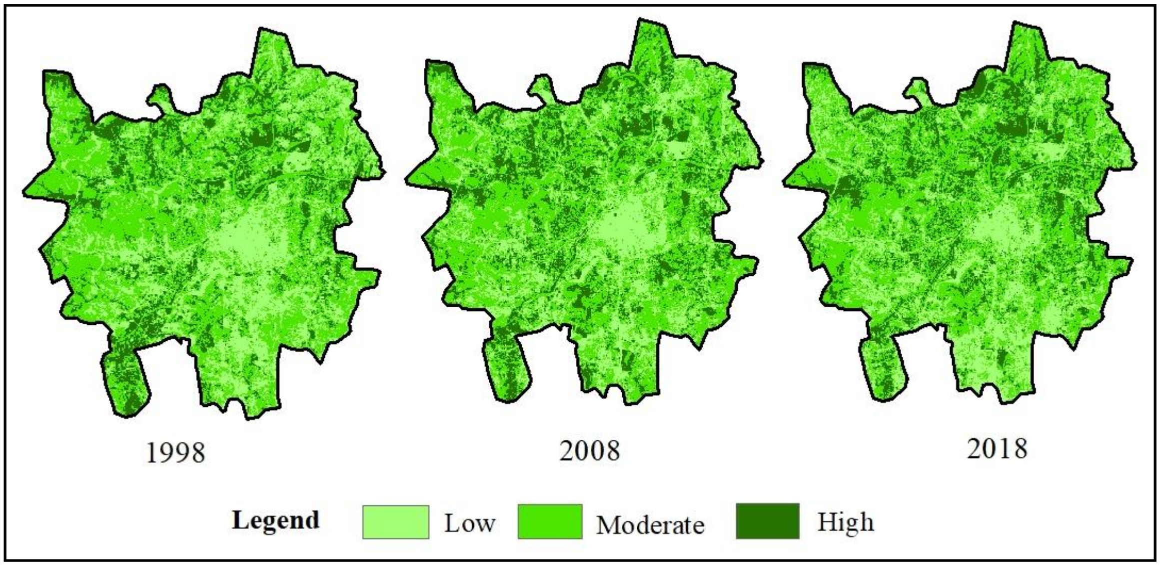

Figure-2: NDVI map of different Land Use classes in Pune City for 1998, 2008 and 2018

Table-2: Area Statistics of Different Vegetation Density computed using NDVI images of different years

	1998		2008		2018	
Class Names	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
No Vegetation	4907.61	22.63	5529.31	25.50	5686.45	26.59
Low vegetation	9822.69	45.30	8843.06	40.79	7386.83	34.55
Moderate Vegetation	4720.32	21.77	4904.37	22.62	5489.37	25.67
High Vegetation	2231.19	10.29	2405.07	11.09	2819.16	13.18
Total	**21681.8**	**100**	**21681.8**	**100**	**21381.8**	**100**

To determine the density of green on a patch of land, researchers must observe the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. As can be seen through a prism, many different wavelengths make up the spectrum of sunlight. When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected, respectively.

3.2 Land Use/ Land Cover Analysis using Supervised Classification

The land use land cover maps for the year 1998, 2008 and 2018 were generated from the supervised classification of Landsat digital data covering Pune City **(Figure-3**). The area under each Land use/ Land Cover class was estimated and given in **Table-3**. The results indicate that the percentage of area under different land use classes have drastically changed during last 20 years from 1998 to 2018. The total built-up area has increased from 29.1 % during 1998 to 42.5 % during 2018, an increase of 13.4 % over the period of 20-years. It was observed that the built up area has significantly increased in the core and also in area away from the centre. In 1998 built up area was 29.9 % (6315.48 ha) which has increased to 34.36 % (1140.3 ha) an increase of 5.26 % to during 2008 (7455.78 ha). The built-up area has increased to 42.52 % (9227.15 ha) during 2018 an increase of 8.16 % as compared to area during 2008 (7455.78 ha).

ISSN 2348 – 8034
Impact Factor- 5.070

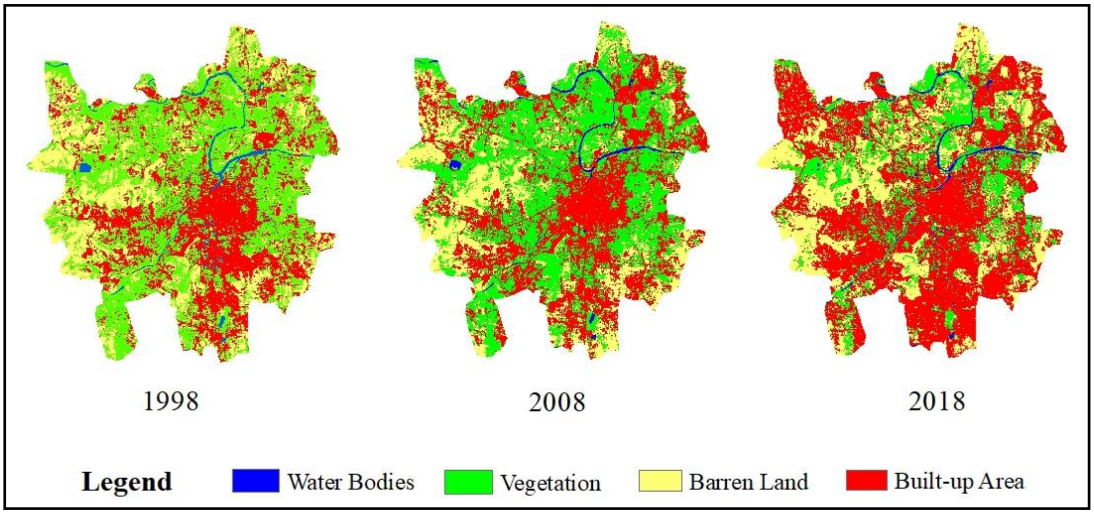

Figure 3-: Land use / Land Cover Maps of Pune City : 1998, 2008, 2018

Table-3: Area under Land Use Classes (%) Changes (%) obtained from the supervised classification of Landsat data for different years

Class	1998	2008	Change	2008	2018	Change	1998	2018	Change
Water Bodies	2.02	1.27	-0.75	1.27	1.86	0.59	2.02	1.86	-0.16
Vegetation	44.95	40.5	-4.45	40.5	37.61	-2.89	44.95	37.61	-7.34
Barren Land	23.93	23.88	-0.05	23.88	18.01	-5.87	23.93	18.01	-5.92
Build-Up Area	29.1	34.36	5.26	34.36	42.52	8.16	29.1	42.52	13.42

3.3 Spatial Patterns of LST in Pune City

Figure-4 shows the spatial distribution of day-time summer LST in the Pune City in year 1998, 2008 and 2018. During 1998 LST ranged from 18.83^{0}C to 29.60^{0}C across the city. However, during 2008, the LST has slightly increased and it ranged from 22.38^0 C to 33.66^0 C. It also showed slight increase in LST during 2018 and it ranged from 17.57 ^{0}C to 34.62 ^{0}C. Highest temperatures were observed in south-east, north-east and center parts of the city in 2008 and 2018 as compared to 1998.

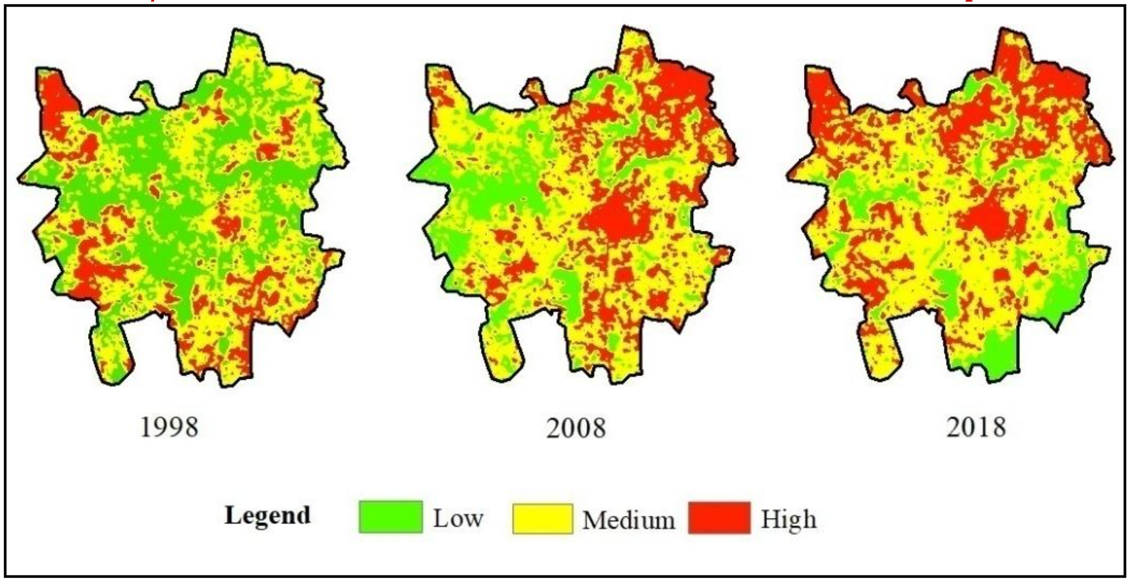

Figure-4: Land Surface Temperature of Pune City: 1998, 2008, 2018

The LST of other land use classes like Vegetation, water bodies and barren lands were very less as compared to comparatively built-up area. These classes also show slight increase in temperatures during 2008 and 2018 as compared to 1998. Rapid spatial expansion and densification of built up area coupled with destruction of vegetation cover has resulted into a significant average rise of 2.99 ^{0}C temperature across the Pune City.

Table-4: Land Surface Temperature (^{0}C) during 1998, 2008 and 2018

Classes	1998 (Avg.)	2008 (Avg.)	2018 (Avg.)
Water Bodies	10.41	11.84	12.17
Vegetation	20.75	23.60	24.27
Barren Land	22.01	25.03	25.74
Built Up Area	27.00	30.70	31.58

3.4 Relationship between LST and Land Use/Land Cover

Results reveal that highest LST corresponds to built-up areas and barren land. Water bodies record lowest LST values followed by vegetation classes. The statistics underlines significant negative relationship between LST and abundance of vegetation cover. Highest increase in temperature is primarily associated with newly built up areas. Positive changes have also occurred in areas where marked densification of built up area has taken place as in north-east part of the city.

Northern part of the region has observed conversion of densely vegetated and vacant land to built up as well as considerable densification of built up area has been observed. The regions also records substantial rise in LST. Central part of the region shows drastic decline in dense vegetation. The area also records some pockets of intense heating. Extreme north east part shows change of densely vegetated area into vacant land which also corresponds to transition of area from lower to higher LST category.

IV. CONCLUSIONS

Pune city is undergoing urbanization at a faster pace and need to accommodate ever increasing population has accelerated indiscriminate destruction of urban greenery and agricultural land during the past decade. Rapid spatial expansion and densification of built up area coupled with destruction of vegetation cover has resulted into a significant average rise of 2.99 ^{0}C temperature across the city which can potentially pose a serious threat to the urban micro-climate. Urban Heat Island effect has not only intensified but has also spread to newer areas. There is a dire need for continuous monitoring of city's land use land cover dynamics and to devise rational, scientific and sustainable urban land use plans. The study also shows the potential utility of remote sensing and GIS technology for effective and timely monitoring of spatial patterns and trends of physical growth of the city, to understand the associated changes in urban environment, to identify problem areas and to devise sustainable urban land use plans and policies so as to check the phenomenon of intensification of UHI.

V. ACKNOWLEDGEMENTS

The authors like to express their sincere thanks to Director, Bhaskarcharya Institute for Space Applications and Geo-informatics (BISAG), Department of Science & Technology, Government of Gujarat, Gandhinagar 382007, for his keen interest and encouragement in executing this project.

The authors are also very much thankful to Associate Prof. Dr. M. Sakthivel, Dept. of Geography, University of Madras, Chennai.

REFERENCES

1. *Landsat data downloaded https://earthexplorer.usgs.gov.*
2. *SOI. Survey of India/toposheet/N43-6/poona:http://naksha.soi.gov*
3. *Buyantuyev A. and Wu, J., 2010. Urban heat islands and landscape heterogeneity: linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns. Landscape Ecology, 25, pp. 17-33.*
4. *Weng, Q., 2009. Thermal infrared remote sensing for urban climate and environmental studies: methods, application and trends. ISPRS Journal of Photogrammetry and Remote Sensing, 64, pp. 335-344.*
5. *Oke, T. R., 1987. Boundary Layer Climates (2nd edition). Methuen, London, pp. 435.*
6. *Schott, J. R. and Volchok, W. J., 1985. Thematic Dapper thermal infrared calibration. Photogrammetric Engineering and Remote Sensing, 51(9), pp. 1351-1357.*
7. *Streutker, D. R., 2003. Satellite-measured growth of the urban heat island of Houston, Texas. Remote Sensing of Environment, 85, pp. 282-289.*
8. *Manju Mohan, Yukihiro Kikegawa, B. R. Gurjar, Shweta Bhati, Anurag Kandya, Koichi Ogawa, 2012. Urban Heat Island Assessment for a Tropical Urban Airshed in India. Atmospheric and Climate Sciences, Vol. 2 No. 2 (2012), Article ID: 18813 , 12 pages DOI:10.4236/acs.2012.22014*
9. *Ram Joshi, Hardik Raval, Maharshi Pathak, Sumit Prajapati, Ajay Patel, Vijay Singh, and Manik H. Kalubarme, 2015. Urban Heat Island Characterization and Isotherm Mapping Using Geo-Informatics Technology in Ahmedabad City, Gujarat State, India. International Journal of Geosciences, 2015, 6, 274-285.*