Critical review of the Climate Change Impact on urban areas by assessment of Heat Island effect. Case of Pune, India

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Abstract

Urbanization is led by haphazard development, resulting into harsh climate change impacts. Climate change mitigation is bolstered by effective urban green space planning. This indirect relationship between Climate Change and urban green coverage, related with the heat island formation, has necessitated this research. The paper sets a goal to identify and measure the city level parameters of climate change. The objective is to analyze, if planned development of urban areas relates to the mitigation factors, or if the currently evolved urban pattern relates to the Urban heat island and the ecological function in direct relation with climate change adaptation. The assessment of this relationship between urbanization and climate change impacts, which is governed by Urban Green coverage is quantified using multi criteria evaluation.

A study of Pune city is carried out for land cover change detection for the past 15 years and heat island generation due to urbanization, using Landsat 7 (ETM+) and Landsat 8 (OLI/TIRS) imagery and climatic data. The outcome is quantified for climate change for Pune City. This paper also reviews the policies of World health organization against the requisites for urbanization in India and concludes on the necessary inclusions in policy implementation.

Keywords: *Urbanization, Climate Change, Urban Green coverage, Ecological balance, Environmental policies, Spatio-temporal analysis.*

Introduction

The intergovernmental Panel on Climate Change (IPCC) has over and again indicated that 'observed warming has been, and transient greenhouse-induced warming is expected to be, greater over land than over the oceans'. These effects have been observed more prominently over the last 50 years as one of the adverse outcomes of urbanization, which has led to new technologies and materials for development. These impervious materials possess varied thermal properties that can considerably impact the generation of extreme land surface temperatures.

Urban Heat Islands (UHIs) develop as heat is emitted from a range of built-up surfaces, under favorable meteorological conditions (i.e. direction and velocity of wind, low water vapor content, etc.). An urban heat island effect is defined as the abrupt rise of the isothermic curve at the boundary of a highly urbanized area which modifies its thermal characteristics compared to those of the adjacent areas. UHI effects are thus seen more prominently in the afterhours of the day, by a rise in temperature ranging from 5-15 degrees.

Urban heat islands have a direct impact on human health and urban energy consumption patterns. Over the past 35 years, more than 20,000 people have died of heat-related causes in Indian megacities. Statistics show over 793 (2011), 1247 (2012), 1216 (2013) and over 2500 (2015) reported deaths due to such heat waves in urban parts of India. Studies also indicate global urban population (which is over 50% of the total population) per capita energy usage for operating cooling systems, to be over 3 times than the rural dwellers. This over consumption of resources has caused serious concerns for energy as well as the environment sector. This papers studies the urban heat island effect in Indian context. Understanding of how patterns of land development and land use spatial distribution affect the formation of urban heat islands can inform urban design and planning practices and lead to successful mitigation of temperature extremes.

Land Surface Temperature

Innovative technologies were used to quantify important factors of anthropogenic heat such as urban pattern- urban land use, and the thermal properties of buildings which, individually or in combination, can affect urban heat island formation. The use of heat-absorbing construction materials (e.g., stone, metal, and concrete) and building of roads, pavements, footpaths, parking lots and terraces in urban areas and the corresponding reduction of natural vegetation and water bodies result in higher temperatures in urban areas which may seem to be localized effect but in long-term it may contribute to the global heat. The most important anthropogenic influences on climate are the emission of greenhouse gases and changes in land use. The urban green coverage, such as forests or parks, can the ameliorate UHI effect by preventing incoming solar radiation from heating the surrounding buildings and surfaces, cooling the air by evapotranspiration, and reducing wind speed.

Ambient atmospheric temperature is directly proportional to land surface temperature. Land surface temperature (LST) is a good indicator of both the energy equilibrium of the earth’s surface and greenhouse effects. It’s a key variable controlling fundamental biospheric and geospheric interactions between the earth’s surface and its atmosphere. Our study is based on estimating LST for Pune city, using remote sensing technology. LST in remote sensing terms can be defined as the average surface temperature of the ground under the pixel scale mixed with different fractions of surface types. LST can be viewed as the canopy surface temperature of the vegetation, for dense vegetated ground.

A thermal sensor picks up radiant energy emitted from a surface target heated through; radiation (heating of surface material), convection (atmospheric circulation) or conduction (through the ground). Earth radiant energy is a function of temperature (ground surface kinetic temperature, which depends on thermal properties of the material) and emissivity (property of materials controlling radiant energy flux, which depends on colour, roughness & surface state of object).

LST estimations are governed by three physical laws- Planck’s law (describes the amount of energy per wavelength dependent on object temperature); Wien’s displacement law (wavelength is inversely proportional to the temperature of an object); and Stefan Boltzman Law (defines the relationship between surface temperature and the total radiant temperature). It was thus possible to estimate the ambient temperature by spatially acquired LST estimates by processing the thermal data. The analysis of such spatio-temporal data may lead us to a better understanding of climate change phenomenon via heat island effect in Urban areas.

Description of Study Area

Pune a historically and strategically prominent city with a biodiverse climate (being near to Western Ghat region), has been experiencing atmospheric turbulence, hinting towards climate change phenomenon. Due to rise in population and urbanization, the effects could be related with a number of heat island effect studies done in India and abroad. The administrative boundary of Pune Municipal Corporation (PMC) is geographically located between latitude 18°37’30" North - 18°24’30" North, and 73°45’30" East - 73°58’30" East longitude; lies at an altitude between 550-1000m (1,840 ft) above sea level and covering an area of 243.80 sq.km; supports a population of 31,15,454 (Census 2011) and is the 9th largest city in India. Central Pune is at the confluence of the Mula and Mutha Rivers. Cantonment Area has been included for ease of study.

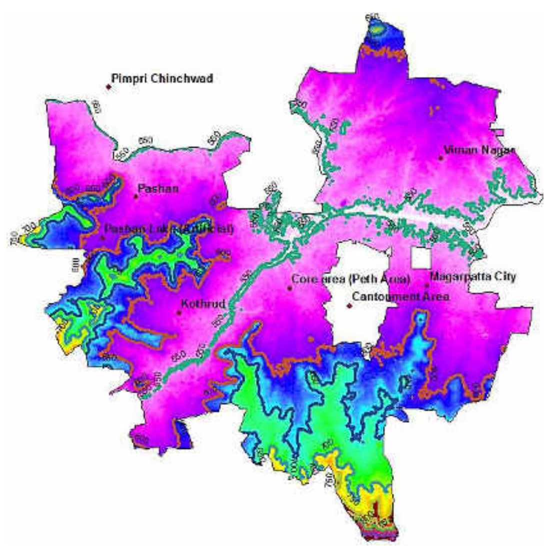

Figure 1. PMC Study Area (Contour Map)

Pune experiences three distinct seasons: summer, monsoon and winter. Typical summer months are from March to May, with maximum temperatures ranging from 35 to 39°C (95 to 102°F). While May is the warmest month in most of the Deccan Plateau, the warmest month in Pune is April. Pune experiences winter from November to February. During summer, maximum temperature in the city can go up to 48°C, while in the winter, temperature can go as low as 5 to 6°C. Average rainfall is about 62.5 cm. In short, the weather seems balanced i.e. clear and sub-tropical. Local materials, stone structures were highly used in heritage buildings and houses, which form a large part of the core Pune city.

Due to high urbanization and population growth, the built area in Pune has seen diurnal disturbances in temperature. The cause is estimated to be urban Heat Island effect. Our study analysis this assumption on the basis of data from remote sensing technology for estimating the climate change impact at city level (PMC area).

Methodology for Research

Few studies have been done regarding temperature disturbances of Pune. A study (Thapliyal and Kulshreshtha, 1991) on temperature trends in Pune indicates a slight warming within the limits of 1 SD between 1901 and 1990, using manual surveying. Gadgil and Dhorde, 2005 studied temporal variations in temperature over Pune city, during the period 1901- 2000 and showed significant decrease in annual average and annual average maximum temperatures which can be ascribed to a significant increase in the amount of suspended particulate matter (SPM) in its ambient temperature. Our goal is to quantify this climate change to some extent using satellite imagery for a way forward.

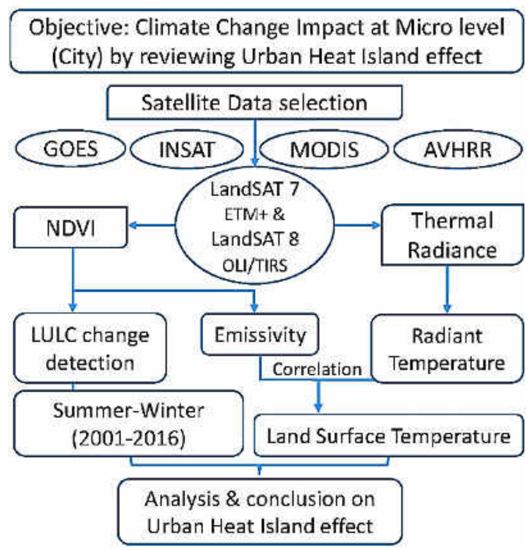

Figure 2: Methodology of Research

This study is based upon satellite data -Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) Collection 1 Level-1 data, acquired from U.S. Geological Survey's Earth Resources Observation and Science (EROS). Normalized Difference Vegetation Index (NDVI) and LST estimations were done using ArcGIS© software (Ver.10.2.2). Images were acquired for Summer (April) and Winter (January) for near zero cloud cover (<6%) and acquisition time of evening (3pm to 7pm) for accurate Heat Island effect analysis of PMC administrative area.

Satellite Data Acquisition

Land Surface Temperature (LST) estimation can be done through thermal sensor which captures thermal infrared radiation (3 to 35 µm), within a proper atmospheric window of 8 to 14 µm wavelength. LST satellite products (sensors) such as ASTER, MODIS, LANDSAT, SEVIRI, KALPANA, INSAT, FY-2C are available and are specified Table 1.

Sensor	Spatial Resolution	Temporal Resolution
GOES	4 km	One cycle per day
MODIS	1km, 5km, 0.05 degree	Daily 8 days, monthly
LandSAT 7 ETM+	Resampled to 30m	16 days
LandSAT 8	30 m (OLI), 100m (TIRS)	16 days
ASTER	90m	16 days
AVHRR	1.099km	24 days
SVISSR	1.25km	4 years
VHRR (INSAT 3D)	4 km ground resolution	26 minutes
VHRR (Kalpana)	2 km	35 days

Table 1: Available thermal sensors and their specifications

The best possible satellite imagery currently available for free download for our specifications in India is LandSAT 7 ETM+; also, the results were compared with LandSAT 8 (OLI/TIRS) imagery for its accuracy. It made sense to compromise on spatial resolution while acquiring thermal data for better signal to noise ratio (SNR).

The imagery of LandSAT 8 is available for free download since 1 January, 2017. The image quality (9) and thermal band accuracy, produce motivating results. LandSAT 8 (OLI/TIRS) imagery is available after March 2013, LandSAT 7 ETM+ imagery is available after August 1999.

Satellite Data Processing for Change Detection

Satellite imagery for 2001 & 2016- summer (April) and winter (January), as per Pune's season's, is acquired for analyzing the increase in Urban Green Cover and interrelating the heat island effect with climate change factors. The Near Infrared (NIR) band (0.722- 0.898 µm) and Red band (0.631 – 0.692 µm) are analyzed for NDVI (Normalized Difference Vegetation Index) analysis. Float function is used for spatial NDVI analysis in ArcGIS;

$$\mathbf{NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})}$$

where R_{NIR} and R_{RED} are the reflectance's for aforesaid NIR and Red bands for LandSAT 7 (2001) & LandSAT 8 (2016) imagery.

Land Surface Temperature Estimation [8]

Radiant (brightness) temperature can be estimated on the basis of DN values for pixels of thermal bands of LandSAT imagery.

For **LandSAT 7 ETM+ imagery**, effective at satellite temperature was obtained using following equation;

$$\mathbf{L\lambda = ((L_{MAX}\lambda - L_{MIN}\lambda) / (QCAL_{MAX} - QCAL_{MIN})) * (QCAL - QCAL_{MIN}) + L_{MIN}\lambda}$$

Where, $L\lambda$ = Spectral Radiance of the sensor
$L_{MAX}\lambda$ = Spectral radiance scaled to $QCAL_{MAX}$
$L_{MIN}\lambda$= Spectral radiance scaled to $QCAL_{MIN}$
$QCAL_{MIN}$= Min. quantized calibrated pixel value
$QCAL_{MAX}$= Max. quantized calibrated pixel value

For **LandSAT 8,** TIRS and OLI band data are converted to top of atmosphere (TOA) spectral radiance using the radiance rescaling factors specific to each band provided in the metadata file;

$$\mathbf{L\lambda = M_L QCAL + A_L}$$

Where, $L\lambda$ is the TOA spectral radiance (Watts/(m²·sr·µm), QCAL is the pixel value (DN), and M_L and A_L are rescaling coefficients (as given in the metadata file).

Land Surface emissivity is then calculated for both LandSAT (7/8) imagery, using NDVI and proportion of emissivity (Pv);

$$\textit{(Land Surface Emissivity)}\ \mathbf{\varepsilon = 0.004 * \{(NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})\}^2 + 0.986}$$

Correlating emissivity by calibration constants, effective Land Surface temperature is now computed;

$$\textit{(Land Surface temperature in } ^oC)\ \mathbf{T_S = \{L\lambda / [1 + \omega * (L\lambda / \rho) * \ln \varepsilon]\} - 273.15}$$

Where,
***ρ** = Planck's constant * (velocity of light / Boltzmann constant) = 14380*
***Lλ** = at satellite temperature; **ω** = wavelength of emitted radiance (11.5 µm)*
273.15 - Conversion factor from Kelvin to Celsius.

Emissivity and NDVI values for common land cover are as specified in table 2 below. Change detection for these NDVI values for land cover changes and Land Surface temperature relating to the ambient temperature, in the imagery are computed spatially for concluding on the specto-temporal variations in temperatures in summer and winter for 2001 & 2016 LandSAT (7/8) imagery.

Land Use	NDVI	Emissivity
Water Bodies	-0.070	0.989
Barren Land	0.027	0.896
Built Area	0.107	0.957
Sparse Vegetation	0.320	0.957
Dense Vegetation	0.425	0.967

Table 2: Generic emissivity and NDVI values

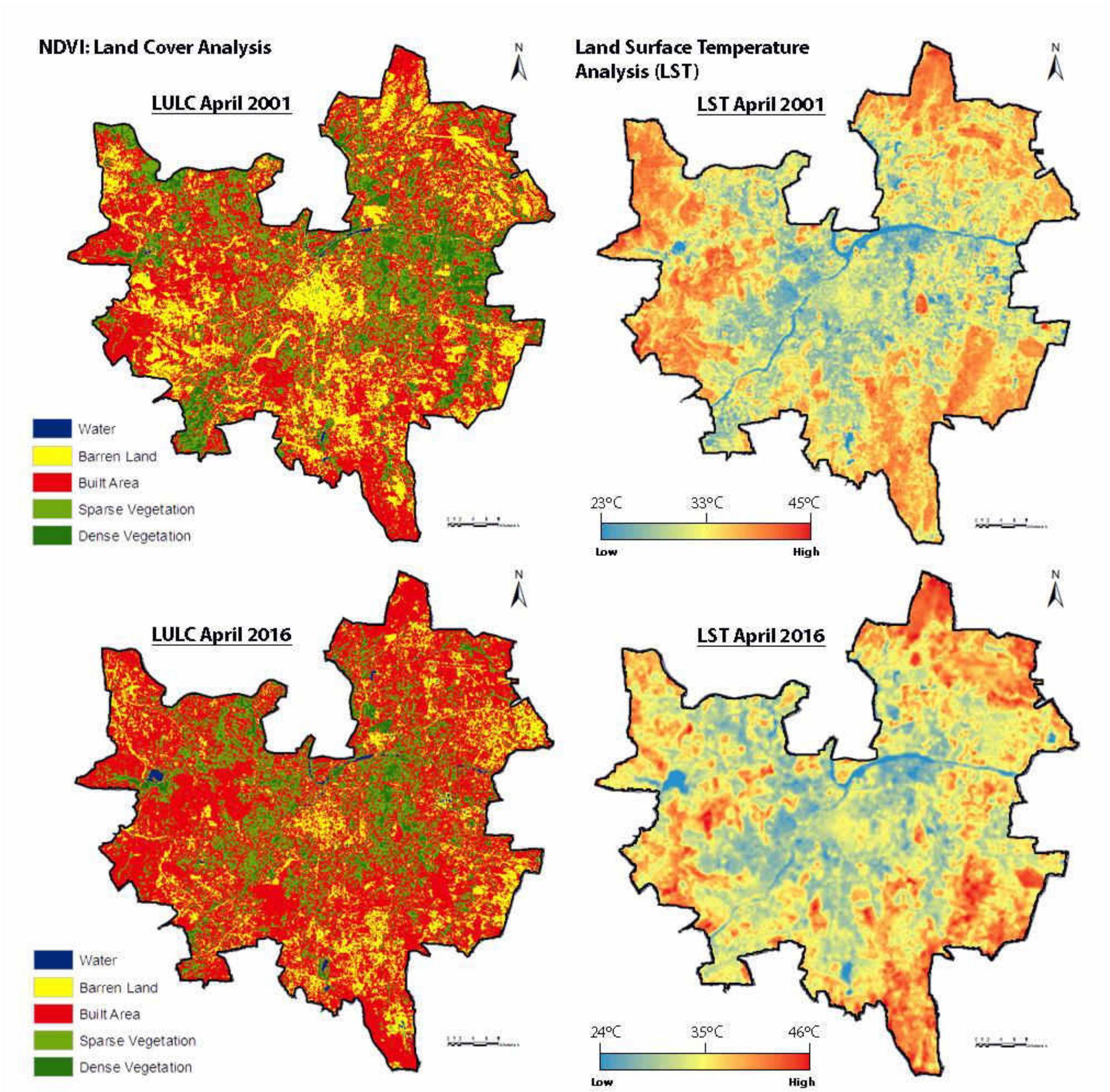

Figure 3: NDVI and Land Surface Temperature- Summer correlations for April 2001 and 2016 [8]

Correlation analysis for accuracy assessment

Normalized Difference Vegetation Index (NDVI) is inversely proportional to Land Surface Temperature (LST). This relationship is clear from the spatio-temporal analysis of satellite imagery of Pune. Since we have analyzed NDVI and LST for both Summer and Winter seasons of 2001 and 2016, we are able to correlate the results for obtaining the trends in their correlation, using Regression Analysis. In both the seasons the LST values decreases with increasing NDVI values. However, the coefficient of determination (R2) is more for summer

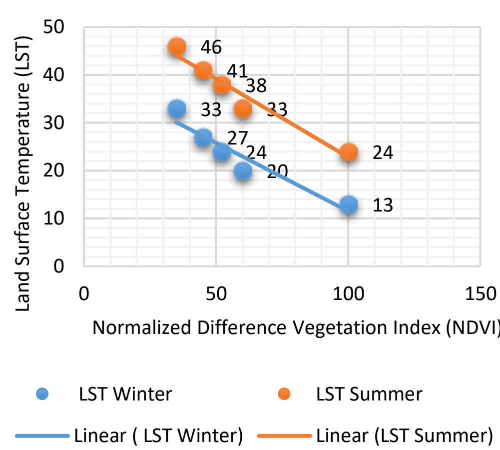

Figure 4: Seasonal trends (NDVI-LST) Summer & Winter for Pune (2016)

season (0.9509) in comparison to that of winter season (0.9071). This depicts that the correlation between LST and NDVI is stronger for summer which further indicates that reduced green spaces in summer would affect the rise in LST to a greater extent as compared to that of winter season. The allied reason for LST to be more dominant and leading to UHI effect in summer is the already high atmospheric temperature. The difference in slope for trends (Figure 3) quantify the prominence of this cooling effect for PMC area. The cooling effect reduces as a logarithmic function to distance from the green space. This spatial autocorrelation seems to extend up to 4 km in direct proportion with the area and green index of the open space and water bodies.

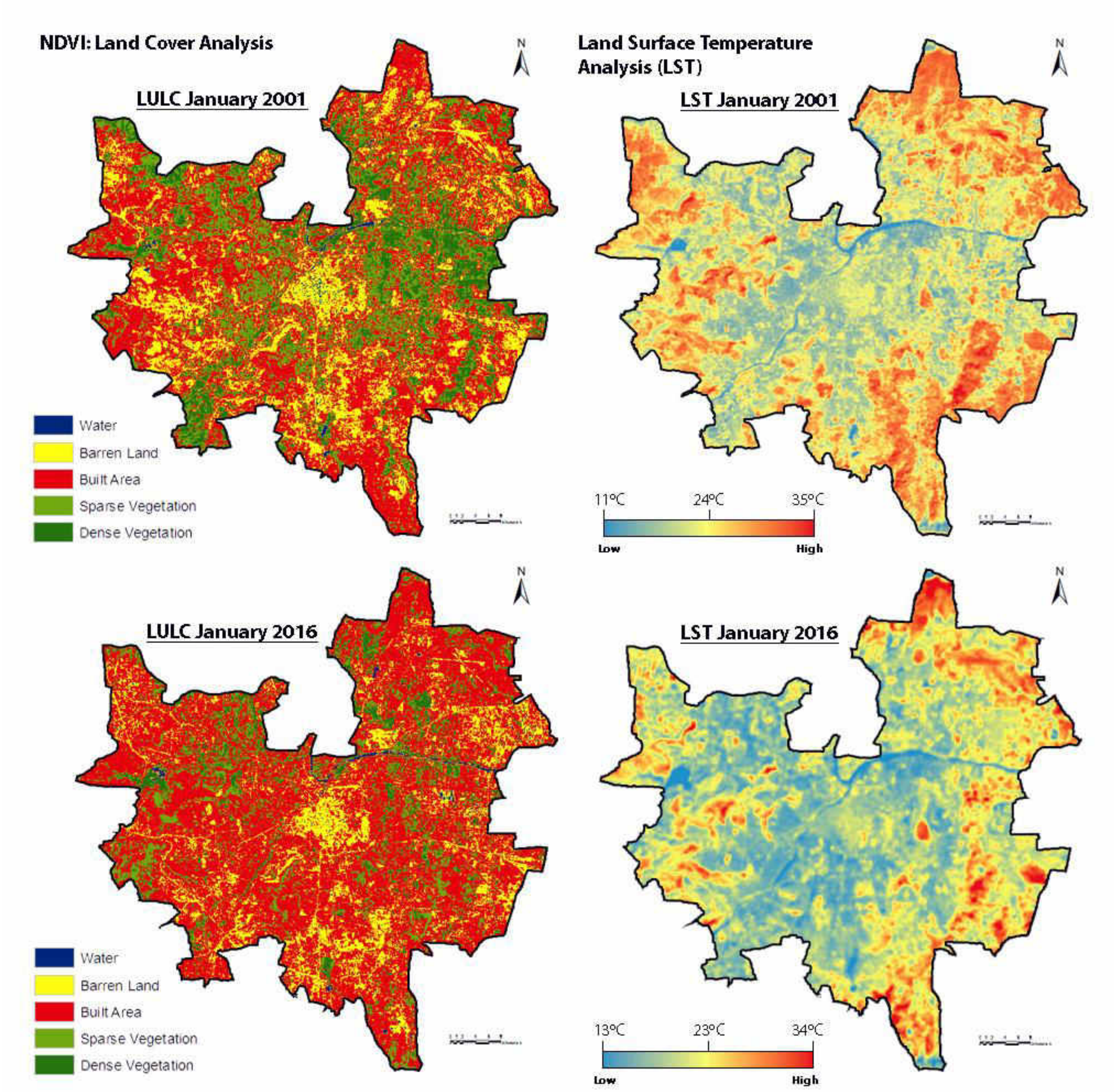

Figure 5: NDVI and Land Surface Temperature- Winter correlations for January 2001 and 2016 [8]

Change Detection analysis for the NDVI and LST Maps

NDVI change detection give specific results regarding increase or simultaneous decrease in the classified land covers viz. Water Bodies, Barren Land, Built Area, Sparse Vegetation, and Dense Vegetation or

Agriculture land. The change detection results indicate that the built up area has changed considerably in relation with the green cover and vegetation. Open spaces too have reduced along with water bodies.

Land Cover	2001		2016		Change	
	Area (km sq)	%	Area (km sq)	%	Area (km sq)	%
Water	2.00	0.62	1.70	0.52	-0.32	-0.10
Barren land	100.80	31.30	105.00	32.60	4.19	1.30
Built Up	97.60	30.30	108.90	33.80	11.28	3.50
Sparse Vegetation	65.70	20.40	57.60	17.88	-8.12	-2.52
Dense Vegetation	56.00	17.38	49.00	15.20	-7.02	-2.18
Total area	322.20	100.00	322.20	100.00		

Table 3: Change detection in Land Cover Areas (2001-2016)

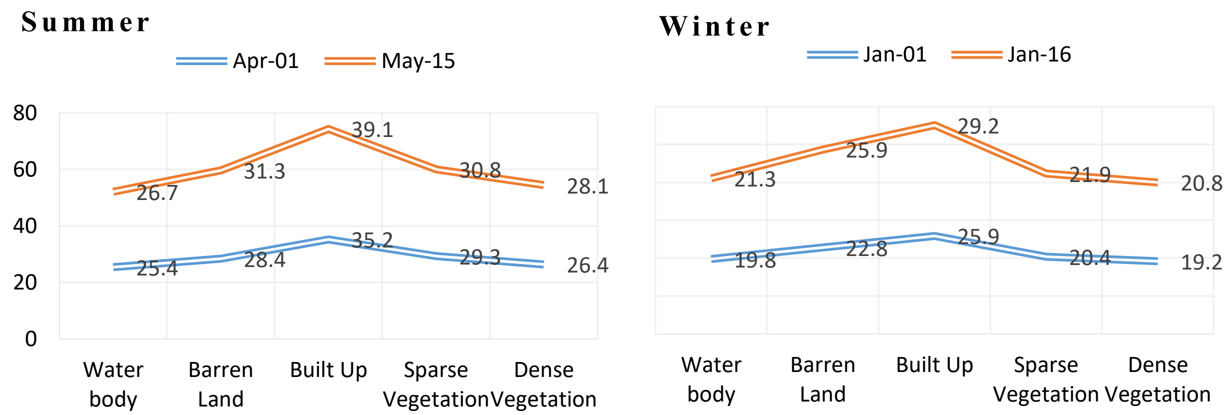

Figure 6: Temperature change over specific land covers (mean) in Summer and Winter (2001-2016)

Climate Change Analysis for LST over common land cover

The average change in the LST from 2001 to 2016 for summer and winter seasons is shown in the graphs. From the table it is clear that the rise in average LST is observed majorly over barren land and built up. Thus we can conclude that over a period of 15 years the rise in Land Surface Temperature is higher in areas where there is more built-up and barren land which ultimately relates to the reduced green cover in these areas.

LULC Classes	Average Change in LST (2001 – 2016)	
	Summer (°C)	Winter (°C)
Water Bodies	1.3	1.6
Barren Land	2.9	3.1
Built Areas	3.9	3.4
Sparse Vegetation	1.45	1.5
Dense Vegetation	1.74	1.6

Table 4: Temperature differences for LULC (2001-2016)

Conclusion and Inferences

LST in summer varies prominently as compared to winter as the dense cover decreases. Green cover is more in winter due to earlier monsoon rains. While the green cover decreases more in Summer. Thus, heat Island effect seems more prominent in Summer.

It can be construed from the LST and NDVI maps that temperature ranges higher in areas with barren land and built areas. In the core areas of Pune, the temperature is interestingly low, which does not relate Pune area with most of the western cases for Urban Heat Island effect. We have compared LandSAT 7 results with LandSAT 8 data and found the same results for various yearly data. As the outskirts or border areas of the city show elevated temperatures than the core areas of the city, should it be concluded that we have no heat island effect? This is due to the Vernacular City Pattern- which plays an important role in dissipating heat by obstructing and circulating winds. Also, the built materials used in the core city are stone and other

natural materials, instead of concrete, asphalt. These built materials have thermal properties which absorb and radiate very less heat, thus contributing towards dissipating the heat islands.
Western cities have dense and high rise structure for its core areas, whereas the Indian cities have a considerably low rise pattern in its core and high rise concrete pattern in its newly developed areas in its fringe areas. We can see that the LST is high in these areas. Also, the rivers Mula – Mutha pass from the core areas of the city, which lower their temperature and increase the green cover even further. We can also see such behavior near lake areas in Pune.
Thus, Heat Island effect does exist here, but in smaller range of areas; or when we consider a district wide area- the rural underdeveloped areas with a lot of green cover as well. It can be seen from temperature graphs for summer and winter for specific land covers, that the mean temperature is increasing over time. More prominently for built areas than green and water bodies; a proof of Climate Change.

Policy recommendations

World Health Organization (WHO) has set a minimum limit standard for Urban Green Spaces per capita for healthy living, i.e. $9.5m^2$/person (Kuchelmeister, 1998). Our Indian bylaws- National building code, State Modal Acts (Maharashtra Regional Town Planning Act, 1966), and City Development Control Regulations (PMC_DCR) state mandates on open space as a percent of the whole area for development, totally ignoring the per capita criteria for the city. This has led to grave situations in cities like Delhi and Mumbai with less than 2 m^2 per capita availability of open space. Pune currently has over 4 m^2/capita of open space, owing to its natural topographic features and green cover, but only in specific areas of the city. An effort to control and maintain these open spaces and green cover at ward level is the need of the hour.

The vertical profile of the city- height of the buildings, and of biosphere- greenhouse gases absorbing and storing heat, resulting into rise in ambient temperature- has not been considered and be treated as a limitation to this study. But, Pune's nearness to Western Ghats Region (biodiversity) and altitude has a definite role in cooling effect for its climate considerations.

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