SPATIO-TEMPORAL ANALYSIS OF URBAN HEAT ISLAND IN PUNE CITY, INDIA

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Abstract

The main purpose of the study is to use remote sensing to investigate temporal changes in land surface temperature (LST) and Normalized Vegetation Index (NDVI) in Pune. Urbanization causes shifting urban geometry, which can substantially impact local microclimates and the planning of new urban settlements. As a result of urbanisation, there is planned as well as unplanned development and has shifts in land-use patterns. Pune has a hot semi-arid climate that borders a tropical wet and dry climate (Aw). Temperatures in the urban heat islands metropolitan area climb by several degrees when compared to the surrounding area. The study was carried out in Pune city for year 2001 and year 2021 to recognise land cover change and the heat island formed as a result of it. The imagery data from Landsat 7 (ETM+) and Landsat 8 (OLI/TIRS) was used and processed. The research was carried out to examine the relationship between creating Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) maps. The study outcome for years 2001 and 2021, the acquired data revealed an increase in surface temperature of 2.91 degree Celsius. The study will help architects, planners and government officials to take adaptive and mitigate measures on the Urban Heat Island in due course of time.

Keywords: Urban Heat Island, Urbanization, Land Surface Temperature, Normalized Difference Vegetation Index

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1. Introduction

The natural environment and surroundings have been degraded and destroyed as a result of the rising population and unwanted expansion. Rapid population expansion necessitates the construction of additional homes, schools, hospitals, transit systems, and other services. Additionally, more and more land is being used for urban land uses. According to a United Nations study, the world's population will hit 8 billion on November 15, 2022, and India will overtake China as the world's most populated country in 2023 (World Population Prospects 2022: Summary of Results, 2022). Thus create pressure on natural resources and alternating geographical and land use pattern (Guldman, April 2014). Urban expansion is putting pressure on cultivated land (Gaodi X, 2010). The vegetation that surrounds urban centres is recognised to deliver advantageous ecosystem services, including those that regulate climate, filter water, and clean the air. The city's land use and land cover (LULC) have changed significantly as a result of the city's rapid urbanisation, significantly altering and rise in the local thermal climate (Kumar, 2023). Oke (1982) and J. K. Voogt (2003) termed Urban Heat Island (UHI) as the difference in surface temperature between urban and rural areas. Due to human heat release, roadway canyon design that impacts wind speed and flow, and decreased evapotranspiration due to impermeable coverings, the heat island is further amplified throughout the day (Oke, January 1982). In general, it is believed that the relationship between the local plant cover and land surface temperatures (LST) is inverse (Yunfei Li, 27 May 2020; Gabriele Lobaccaro & Juan A Acero, 2015;Matthew Maimaitiyiming et al., 2014).

Some of the chosen papers describe urbanisation and its effects; the majority of these research concentrated on industrialised nations. Studies from throughout the world in a variety of climatic zones are shedding light on the land use changes brought on by urbanisation, which result in the establishment of heat islands. Wenze Yue et al., analysis spatial pattern of urban thermal environment in Shanghai. Alexandre Rosa dos Santos, et al, (2017) has describe Spatial and temporal distribution of urban heat islands in connection between the Green Areas and LST's. Various research from across the world in various climatic zones have shed light on the changes in land use brought on by urbanisation that result in the establishment of heat islands. Different forms of land use and land cover (LU/LC) have been explored for variation in LSTs (Mallick, J., & Kant, Y. , 2008). Nikhil Mehare et. al. (2021) Studied on the various aspects of urban built form, geometry and its impact on microclimate formation to UHI (Nikhil P. Mehare & Mahendra Joshi, 2021)

Application of remotely sensed data was useful in establishing a connection between tree cover and the LST. Examining NDVI and LST values in urban areas has revealed this link (Omkar Parishwad and Vinita Shankar, 2017; John Paravantis et al., 2015). Sarah B Ali (2017) studies derided that as per the urban locations, vegetation reduces the effects of heat stress on regional, local, and microclimate changes (S.B. Ali et al., 2017).
The NDVI is used to investigate the relationship between thermal behaviour and the quantity of plant cover. Finally, the regression approach is employed to determine the relationship among LST and NDVI. It is established that the relationships within NDVI and LST is negative, as is the regression coefficient from NDVI to LST (Sara Afrasiabi Gorgani et al, 2013).

Study Area

Pune, one of India's eight megacities, is the second-largest and fastest-growing city in Maharashtra. Pune has developed into a well-known location for industrial businesses, as well as the nation's information technology and educational hub. As per 2011, Pune metropolitan area is 243.84 sq. km. in size and home to about 3 million people. Pune city is located between latitudes 18° 25'N and 18° 37'N and longitudes 73° 44'E and 73° 57'E and has a population divided into 76 general electoral wards (PMC, 2012). By 2021, it's predicted to increase to about 540 million. The city is referred to as the Oxford of the East and the cultural centre of Maharashtra. One of Maharashtra's most popular tourist destinations is Pune. The districts of Thane to the north-west, Raigad to the west, Satara to the south, Solapur to the south-east, and Ahmednagar to the north and north-east surround the city. A rural area becomes a city through the physical, socioeconomic, and spatiotemporal process of urbanisation. Pune's urban expansion is influenced by existing transportation routes, current and future industrial projects in and around Pune, and the growth of the central business district (CBD). Pune's growth has been focused on areas that are nearer to employment hubs and places that offer quick access to these hubs (PMC, 2012).

Research objective

The research objective is to the correlation that between surface Normalised Differential Vegetation Index (NDVI) and Land Surface temperature (LST) of Pune city.

2. Methodology for Research

There haven't been many research done on Pune's weather variations. There was a slight warming in Pune between 1901 and 1990, according to studies (Thapliyal and Kulshreshtha, 1991) that used manual sampling (Omkar Parishwad and Vinita Shankar, 2017). In their study of temperature variations over Pune City from 1901 to 2000, (Gadgil, 2005) found a marked decrease in annual average and annual average maximum temperatures, which they attribute to a marked rise in the amount of suspended particulate matter (SPM) in the ambient temperature. In order to move forward, our objective is to partially measure this climate shift using satellite imagery. This research is based on satellite data from the U.S. Geological Survey's Earth Resources Observation and Science program, specifically Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) Collection 1 Level-1 data (EROS). ArcGIS software (Ver.10.5) was used to calculate the Normalized Difference Vegetation Index (NDVI) and LST estimates. For an exact study of the Heat Island impact on the Pune Municipal Corporation administrative region, the images chosen having less than 10% cloud cover. The thermal bands utilised for LST analysis in Landsat-7 and Landsat-8 image are band 6 and band 10, respectively. Refer Table-1 for the details used Landsat data.

Table 1: List of Landsat spatial data for Pune Municipal Corporation (PMC).

Data	Path/row	Format	Day of acquisition (Year- Month- Day)	Spatial Resolution
Landsat7 Level 1 ETM	147/47	Raster	2001-04-25	30meter
Landsat 8 OLI/TIRS C1 Level-1	147/47	Raster	2021-04-24	30meter

Normalized Difference Vegetation Index (NDVI)
The NDVI is one of the most often used land-use indicators for displaying vegetation density (Sara Afrasiabi Gorgani et al, 2013;Guldman, April 2014; (Omkar Parishwad and Vinita Shankar, 2017). By measuring the difference between near-infrared light, which vegetation strongly reflects, and red light, which vegetation absorbs, the Normalised Difference Vegetation Index (NDVI) measures vegetation? NDVI usually falls between -1 and +1. For instance, it's quite likely to be water when you have negative numbers. On the other side, there is a good chance that it is thick green foliage if the NDVI score is near to +1. However, When the NDVI is almost negative, there are no green leaves and the land could even be urbanised. NDVI is calculated by using Equation 1.

Land surface temperature (LST) for Landset 8
Flowing are the steps to calculate for calculating Land surface Temperature (Jovanovska, 2016)
Calculation of TOA (Top of Atmospheric) spectral radiance. (BT – BRIGHTNESS TEMPERATURE) ….refer Equation 3

TOA (L) = M_L * Q_{cal} + A_L ………………………………………………………………………………Equation 1

where:
M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number).
Q_{cal} = corresponds to band 10.
A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)
TOA= 0.0003342*"Band 10" +0.1
Therefore, the equation must be solved using the Raster Calculator tool in ArcMap
TOA to Brightness Temperature (BT) conversion (Jovanovska, 2016) refer Equation 4

BT = (K_2 / (ln (K_1 / L) + 1)) − 273.15…………………………………….……Equation 2

where:
K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number).
K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number).
K1_CONSTANT_BAND_10 = 774.8853
K2_CONSTANT_BAND_10 = 1321.0789
L = TOA
Therefore, to obtain the results in Celsius, the radiant temperature is adjusted by adding the absolute zero (approx. -273.15°C).
BT = (1321.0789/Ln ((774.8853/ "%TOA%") +1))-273.15
Calculate the NDVI (Jovanovska, 2016) refer Equation 4 and 5
NDVI =(PIR-R)/(PIR+R)
Where R= Red band
PIR= near infra-red
The float function is used to calculate Landset 7 image in ArcGIS software are given as: Landset 7,
NDVI = Float(Band 4 – Band 3) / Float(Band 4 + Band 3)…………….Equation 3
The float function is used to calculate Landset 8 image in ArcGIS software are given
NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)……………………………..……Equation 4
Note that the calculation of the NDVI is important because, subsequently, the proportion of vegetation (P_v), which is highly related to the NDVI, and

emissivity (ε), which is related to the P_v, must be calculated.

Calculate the proportion of vegetation P_v (Jovanovska, 2016)

P_v = Square ((NDVI – $NDVI_{min}$) / ($NDVI_{max}$ – $NDVI_{min}$))……………………….……Equation 5

Where:

PV= Proportion of vegetation

NDVI = DN values from NDVI Image

NDVImin= Minimum DN value from NDVI Image

NDVImax= Maximum DN values from NDVI Image

Calculate Emissivity ε (Jovanovska, 2016)

ε = 0.004 * P_v + 0.986………………………………………………………………………….Equation 6

Simply apply the formula in the raster calculator, the value of 0.986 corresponds to a correction value of the equation.

Calculate the Land Surface Temperature (Jovanovska, 2016)

LST = (BT/(1+(0.00115*BT/1.4388) *Ln(ε))) ……………………….Equation 7

Finally apply the LST equation to obtain the surface temperature map.

Land Surace Temperature (1)

LST= (BT/1) +W*(BT*14380) *LnE

Where:

BT= Top of atmosphere brightness temperature (deg C)

W= wavelength of emitted radiance

E= Land surface Emissivity

Following are the Land Surface Temperature maps of Pune Municipal Corporation (PMC)

3. Results and observation

Calculation of NDVI:

The calculated value for NDVI ranges from -0.1067 to 0.73 (refer Figure no.1) and from -0.1142 to 0.63 (refer Figure no. 2) in year 2001 and 2021 respectively. The higher value of NDVI is found higher at city centre as compared to peripheral area which is urban cooling effect can be observed. Due to Pune's rapid urbanisation and the negative effects of the rural-to-urban transition on the surrounding vegetation, urban land use has changed recently and has a propensity to continue expanding into suburban regions.

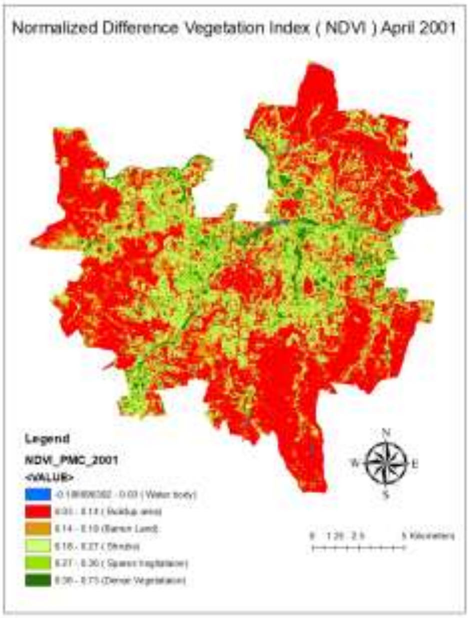

Figure 1: Pune Municipal Corporation NDVI 2001
Source: Author

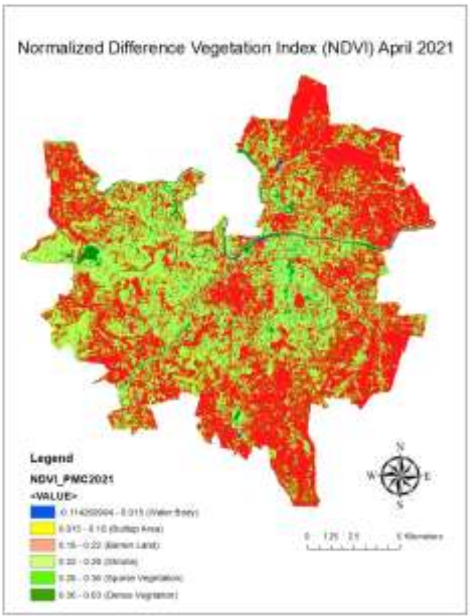

Figure 2: Pune Municipal Corporation NDVI 2021
Source: Author

Classification of NDVI:

The pixels of the photos were manually examined for NDVI values, and a range of values were adjusted for each type of land cover, with the intended outcomes for water body, built-up area, barren land, shrubs, spares vegetation and dense vegetation (Table 2)

Table 2: Classification of NDVI range and change in Land Use Land Cover from 2001 to 2021.

Name	2001	Area in Sq. Km.	2021	Area in Sq. Km.	Change in Sq. Km
Water Body	-0.1067 to 0.03	0.2961	-0.1142 to 0.015	0.86	0.563
Built-up Area	0.03 to 0.14	132.4044	0.015 to 0.18	158.07	25.6683
Barren Land	0.14 to 0.18	46.2456	0.18 to 0.22	43.18	-3.0641
Shrubs	0.18 to 0.27	53.8731	0.22 to 0.28	40.64	-13.2337
Sparse Vegetation	0.27 to 0.36	23.9562	0.28 to 0.36	19.52	-4.4343
Dense Vegetation	0.36 to 0.73	12.0951	0.36 to 0.63	6.73	-5.4614

Urban land use land cover (LULC) change of Pune Municipal Corporation area form 2001-2021.

The Landsat digital data for Pune Municipal Corporation was supervised classified to produce the land use and cover maps for the years 2001 to 2021. ArcGIS software was used to classify the NDVI image in 6 land use land cover category. Refer the table no.2 for land use land cover (LULC) classification. The findings show a significant shift in the amount of land covered by various land use classes during the past 20 years, from 2001 to 2021. Over the period of last 20 years, increase trend in water body and built-up area 0.563 Sq. K to 25.6683 Sq. Km. Increasing water body area is the result of decreasing percolation area due to increase in built-up areas. The decreasing trend in other land use classification is observed in the same period (refer table 2)

Land Surface Temperature spatial analysis Pune Municipal Corporation

The overall difference of 2.53 degree Celsius increase in minimum temperature range from 25.37 degree Celsius to 27.90 degree Celsius and the overall difference of 3.29 degree Celsius increase in maximum temperature range 47.02 degree Celsius to 50.31 degree Celsius between year 2001 and year 2021 respectively is observed in Figure no. 3 and Figure no. 4.

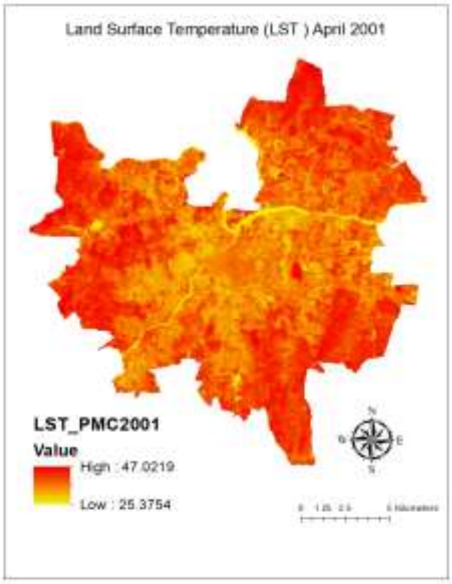

Figure 3: Pune Municipal Corporation LST 2001
Source: Author

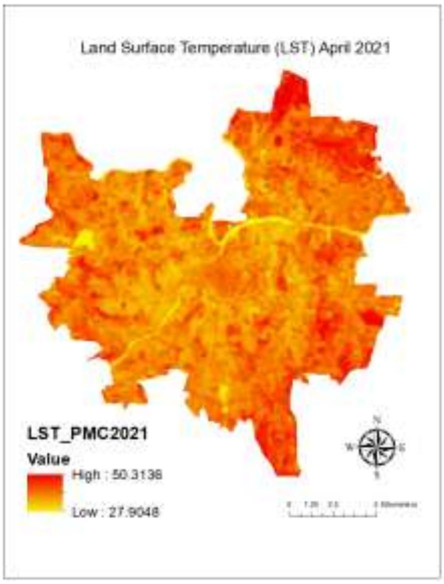

Figure 4: Pune Municipal Corporation LST 2021
Source: Author

The mean LST calculated for all classes like water body, built-up area, barren land, Shrubs, Sparse vegetation and dense vegetation is shown in Figure no. 5. The overall average temperature rise of 2.91

degree Celsius is observed across in Pune Municipal Corporation area between years 2001 and 2021.

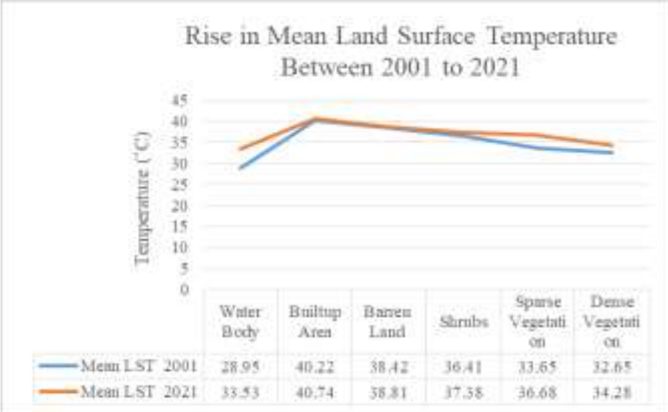

Figure 5 Rise in mean Land Surface Temperature (LST) between year 2001 and year 2021.
Source: Author

Urban Heat Island and

The results show that built-up regions and arid plains have the greatest LST. Lowest LST levels are seen in water bodies, followed by vegetation classes. The findings highlight a strong inverse link between LST and plant cover abundance. The locations with the greatest temperature rise are often those that have recently been developed. Positive developments have also taken place in locations where there has been a noticeable densification of built-up area, such as in the city's northeast. In the region's north, there has been a noticeable densification of the built-up area as well as the conversion of heavily vegetated and unoccupied ground to buildings. The regions also saw a significant increase in LST. The region's dense vegetation has drastically decreased in the centre. Additionally, there are several hot spots in the vicinity. A shift from a heavily vegetated region to barren terrain can be seen in the far northeast, which also marks a change in LST category from lower to higher.

4. Conclusion

The NDVI-based categorization was taken into consideration to analyse the change in land cover of the region at a geographical and temporal scale based on Landsat satellite data sources. The LST and NDVI maps suggest that temperature variations are higher in regions with built-up areas and arid land. Interesting low temperatures may be seen in Pune's central areas, which contrasts with the majority of Western urban heat island examples.

The transition of the natural surface, which often involves a loss in vegetation land and an increase in impermeable cover area, is being accelerated in recent years by fast urbanisation and growing population pressure. The findings of this study serve as a crucial analytical step for Pune Municipal Corporation, which has plans for future land management and usage.

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