EXAMINING THE EFFECT OF THE PHYSICAL CHARACTERISTICS OF THE URBAN GREEN & BLUE SPACES IN HEAT MITIGATION: A CASE STUDY OF PUNE

Alisha Chowdhury[1*], Venkata Sai Krishna Vanama[2], Valliappan AL[3]
[1] Department of Architecture & Regional Planning, Indian Institute of Technology Kharagpur, India. Email: alisha.109ac@gmail.com
[2] Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India. Email: vsaikrishna1990@gmail.com
[3] School of Planning and Architecture, Vijayawada, India. Email: valliappan.al@spav.ac.in

KEYWORDS: UHII, LST, LSI, PAR, NDVI

ABSTRACT: Urban areas are characterized by heterogeneous land uses. The city development pattern, socio-economic and anthropogenic activities result in the formation of Urban Heat Island (UHI) which are characterized by high Land Surface Temperatures (LST). Cities are experiencing a rapid increase in LST. Urban green spaces such as parks, playgrounds, lawns and blue spaces such as ponds, lakes, rivers that are present in and around the city can help in regulating the land surface temperature. These spaces also lead to the formation of the Urban Cooling Island (UCI) around them due to shading from the trees, evapotranspiration from the water bodies, wherein the temperature is comparatively cooler than surrounding temperatures. This formation of a cooling island is known as the Park Cooling Island (PCI) effect. The present research aims at identifying the effect of urban green and blue spaces on LST through a multitude of data sources and geospatial technologies. Pune city is chosen as a study area for the research. The data used in the research include secondary data from various government and semi-government organizations, Landsat 8 temporal satellite images and field data. LST was calculated from Landsat 8 thermal bands by using emissivity reference channel algorithm. Various indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), Normalized Difference Water Index (NDWI), Land Shape Index (LSI), size and the Perimeter-Area Ratio (PAR) were calculated from Landsat 8 images. The results show that there is a high spatial variability in LST, as well as urban green, blue spaces, have a stronger influence on the LST.

1 INTRODUCTION

It is widely understood that urban green spaces have a natural ability to filter pollution from the air and reduce local air and ground temperature.(Mike Bulthuis 2015) Whereas, the blue spaces are known to reduce the temperature of the microclimate (Sebastian Völker, Hendrik Baumeister, Thomas Classen, & Claudia Hornberg and Thomas Kistemann 2013) by inducing evaporative cooling. Cities and the surrounding rural areas differ substantially in their land surface temperatures, which leads to Urban Heat Island Effect (UHI). Landscaping elements play a critical role in defining microclimate of the site. Water bodies can act as natural coolers for the hot and dry climate. Where the moisture from the water body can be used to cool the Land Surface Temperature around. Tree and shrub plantation plays an important role in defining wind flow and also help achieve mutual shading on building and hard paving.(Chiam Zhi Quan 2015)

Climate, buildings, and green spaces have been explored worldwide by many researchers due to their interesting interrelationships and significant impacts on the environment. In recent years, UHI induced by urban form, anthropogenic heat from buildings and air conditioning systems have been studied extensively in cities around the world. Since the mid-twentieth century, the global surface temperature has increased by 0.7±0.18°C (Correlation of Green House Molecules with Global Surface Temperature and its Effect on Environment) during the 100 years ended in 2005. This is the result of the increase in the built surfaces in the urban areas. The temperature of the heat island during daytime increases rapidly (A.A.M. Holtslag 2015) and takes 3-5 hours to reach the maximum after sunset. These increased temperatures have implications on electricity, energy consumption and use of resources which in turn affect the environment (Steve Sorrell 2015). The most sustainable solution to these energy and environment problems is following more natural passive cooling techniques (Hanan M. Taleb 2014). Urban green spaces can directly or indirectly affect local and regional air quality by modifying the urban climates (LUCA ROZÁLIA SZÁRAZ 2014). Many studies have highlighted how the landscape in urban design and planning can improve microclimate and thermal comfort. Plant processes such as photosynthesis, evapotranspiration helps to reduce the mean radiant temperature and anthropogenic heat generated from the buildings which lead to UHI effect (Chiam Zhi Quan 2015). This in turn reduces the cooling load of the buildings. The environmental conditions of urban green spaces have a significant impact on the comfort conditions experienced inside them especially in seasons of stressful climate and the development of sustainability in cities (Liding Chen 2016). Many researchers have agreed that plants affect the urban temperature and the cooling loads of building (Chao Yuan 2011). For instance, the air temperature distribution was closely related to the distribution of greenery in the urban areas where for some large urban park, the ambient temperature was 2-3°C lower than surrounding built-up areas, and it shapes a pleasant urban environment (Alamah MISNI 2014). Furthermore, the effects of plant density, plant species, plants distribution and large space of greenery give a large impact, where greenery reduce the surface temperature and urban heat effect. Green interventions like trees, shrubs, ground covers, green roofs, bioswales or rain gardens, green walls, permeable pavement may be adopted to achieve comfort and reduce UHI in urban areas. These green interventions are to be quantified to achieve the specific greenspace factors (Dr. Jinu Louishidha Kitchley 2014).

2 STUDY AREA

Pune as shown in Figure 1is on the leeward side of the Sahyadri mountain range, which forms a barrier from the Arabian Sea. It is a hilly city, with its highest hill, Vetal Hill, rising to 800 m (2,600 ft) above sea level. Central Pune is at the confluence of the Mula and Mutha Rivers. The Pavana and Indrayani Rivers, tributaries of the Bhima River, traverse the northwestern outskirts of metropolitan Pune. The climate of Pune has changed during the past three decades, especially since the rapid expansion of the industrial belts. Pune has a hot semi-arid climate (BSh) bordering with tropical wet and dry (Aw) with average temperatures ranging between 19° to 33° C. Pune experiences three seasons viz., summer, monsoon, and winter. Typical summer months are from March to June often extending until 15 June, with maximum temperatures sometimes reaching 42° C. The warmest month in Pune is between 20 April and 20 May; although summer doesn't end until May, the city often receives heavy dusty winds in May (and humidity remains high). Even during the hottest months, the nights are usually cool due to Pune's high altitude. The highest temperature ever recorded was 43.3 °C (109.9 °F) on 30 April 1897.(Voyants Solutions Pvt. Ltd. 2012)

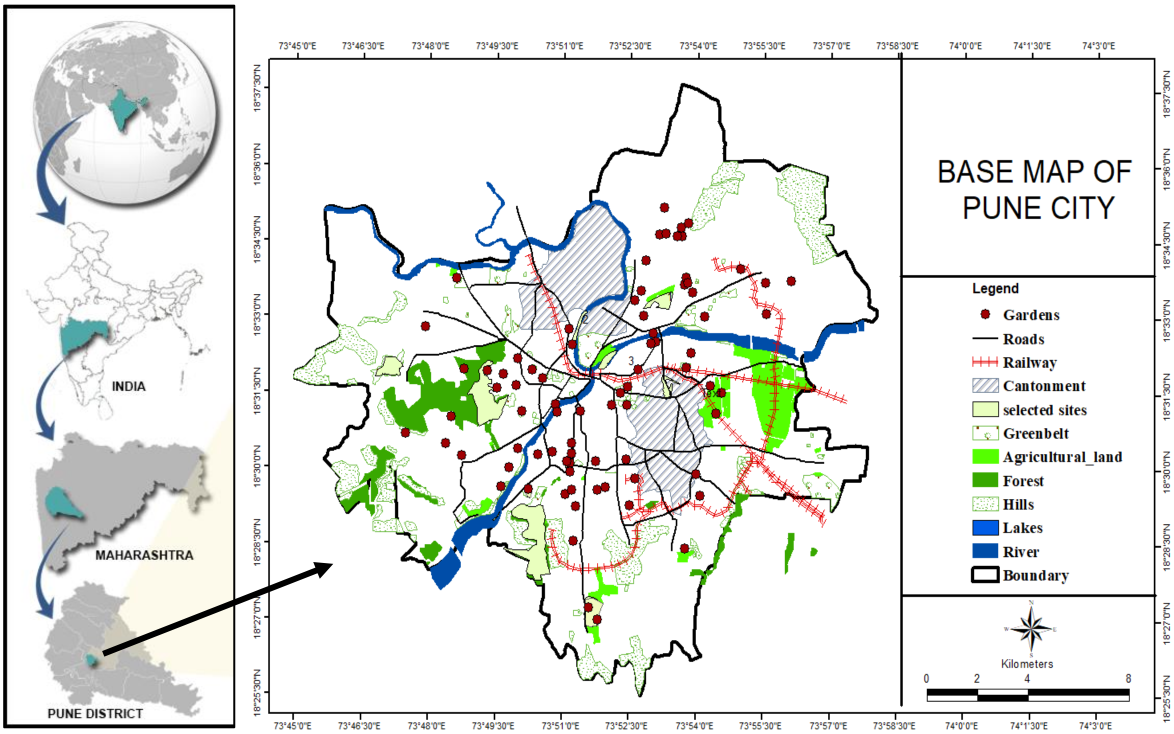

Figure 1: Location map of Pune city

2.1 Existing scenario of green cover and surface water bodies in Pune

The dendritic hydrology pattern of the city of Pune based on the monsoon is predominant giving rise to a network of seasonal streams and rivers flowing through alternating valleys and ridges. Such a setting has given rise to a moderate climate with annual rainfall of 700m. The city of Pune consists of a vast expanse of the unorganized spaces which accounts to 5443.37 Ha of the area altogether. The variety of land parcels constituting this vast stretch are agricultural lands, forests, green belts and hills which account for an area of 949.26 Ha, 1492.98 Ha, 753.17 Ha and 2247.98 Ha respectively. Pune is situated nearby 50kms to the biodiversity of Sahyadri Hills also known as the Western Ghats. As per the land use distribution of Pune city, the total area covered by hills and hill slopes is 1245 ha, i.e. 5.10% of the total land. Pune is crossed by many rivers and streams, which rise near the Sahyadris. The major rivers within the city limits include Mutha River, Mula River and Mula-Mutha River. The total length of Mutha River within the city limits is approximately 10.40 km, Mula River is 22.37 km, and Mula-Mutha River is 11.75. There are three important lakes in the city; they are Pashan Lake (62.60 Ha), Katraj Lake (7.20 Ha) and Snake Park Lake (18.60 Ha). The total area under reserved, forest and agriculture as per the land use distribution of Pune city is 2905 ha which 11.91% of the total area is. The Hills environment in the city is subject to intense pressure due to development and encroachment. The mounting concrete structures due to these developments have resulted in the loss of green covers on the hills which are resultant of the increasing climate change. There are 165 gardens in the city at present occupying an area of 195.55 Ha, and seven more gardens are proposed. The location of these existing gardens is shown in the base map with the help of green dots. As evident from the map, the parks and gardens are majorly concentrated in the central part of the city, and the periphery of the city is devoid of any organized green spaces. The vegetation pattern of the city is conducive almost for all types of tropical species indigenous and exotic both. The city has a tree cover distributed throughout the urban-scape. Approximately 380 species of trees are observed in Pune city. A tree census is being conducted by Pune Municipal Corporation. Approximately 70% of tree census was completed up to June 2011. According to the tree census, 23.33 lakh trees are present in 170 sq.km area. Katraj and Sinhagad area around Pune city has the maximum forest cover as compared to other forest areas in the city. The most commonly found tree in the city of Pune used to be the Banyan tree and the Peepal tree. As per the sources, these trees were found in abundance even along the roads. Unfortunately, these had to be cut down to make room for new construction as a part of the growing urbanization.(Pune Municipal Corporation)

3 DATASETS USED

To analyze the effect of physical characteristics of the urban green and blue spaces in heat mitigation requires the remote sensing data. Secondary data was also used for the further understanding of the existing scenario of urban green and blue spaces in the city. The secondary data included Pune base map, Pune land-use map, meteorological data, list of existing gardens in Pune, existing surface waterbodies in Pune and ongoing or upcoming projects related to the urban green and blue spaces in the city. Remote sensing datasets obtained from the United States Geological Survey (USGS) includes Landsat 8 images and SRTM 30 meter DEM of the study area. The Landsat 8 images acquired in March 2008 and 2017 are used. The spatial resolution of pan images is 15 meter whereas all other bands are having the spatial resolution of 30 meters.

4 METHODOLOGY AND ANALYSIS

The methodology of the research is divided into three parts. The first part deals with preprocessing of satellite images and the second part deals with the preparation of indices, and the last part deals with the analysis of various indices and their relation to the LST. As the multi-date images are used in the research, both the radiometric and atmospheric corrections were applied on the images which will be meaningful to compare the derived products.

4.1 Preparation of various indices

The indices are prepared for both the selected years. Normalized Difference Vegetation Index (NDVI) shown in Figure 2 was derived by using the reflectance of Near Infra-Red (NIR) and Red (R) bands which helps to identify the green spaces. NDVI was calculated by using the formula (NIR-R)/(NIR+R). The range of all the normalized indices spans from -1 to +1. Higher NDVI values represent more greenness of that area and vice-versa. This index is useful in quickly identifying the large parks, open spaces and other green areas.

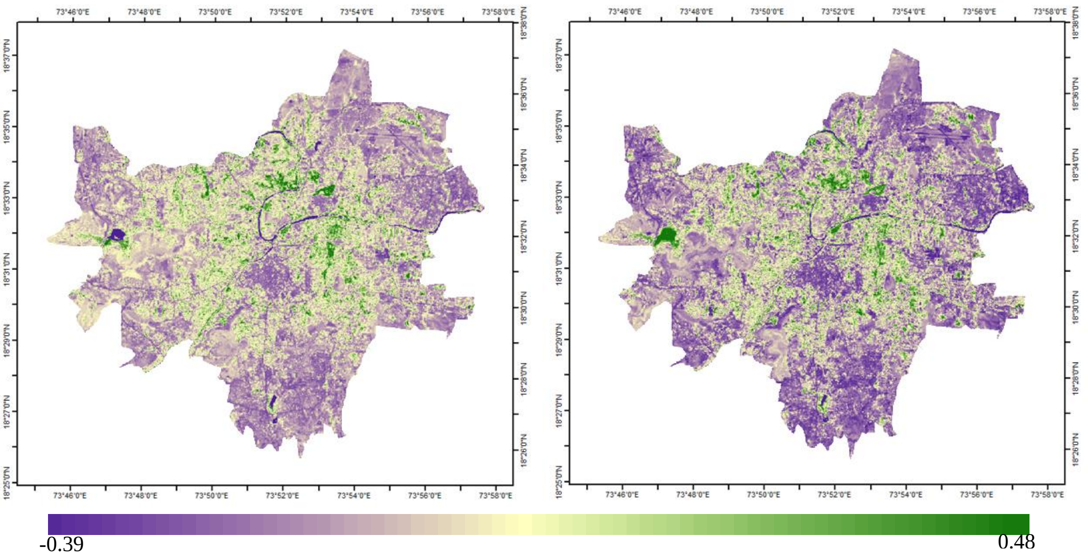

Figure 2: NDVI of 2008 (left) and 2017 (right)

Normalized Difference Water Index (NDWI) shown in Figure 3 was derived by using the reflectance of Green (G) and Near Infra-Red (NIR) bands which helps to identify the blue spaces. NDWI was calculated by using the formula (G-NIR)/(G+NIR). Higher NDWI values represent more water content of that area and vice-versa. This index is used to identify the water bodies in the city quickly.

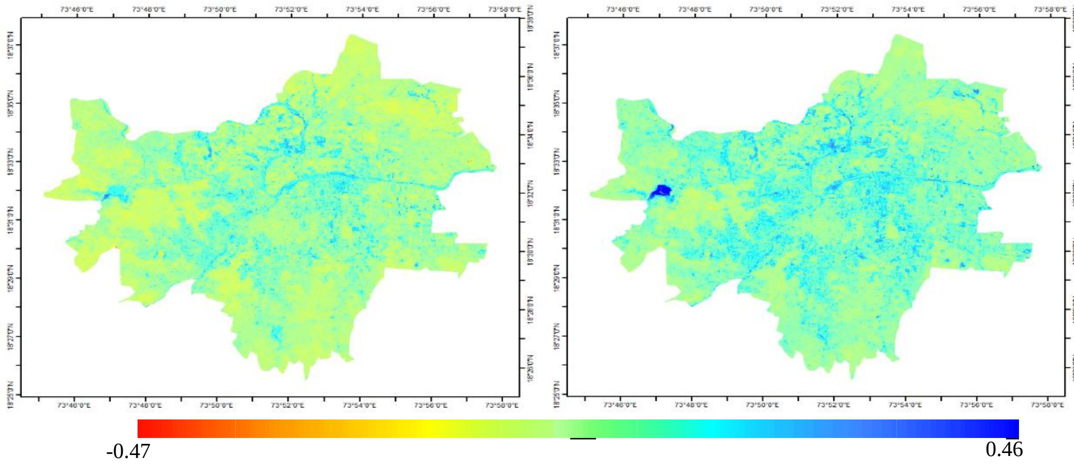

Figure 3: NDWI of 2008 (left) and 2017 (right)

Normalized Difference Built Index (NDBI) shown in Figure 4 was derived by using the reflectance of Short Wave Infra-red (SWIR) and Near Infra-Red (NIR) bands which helps to identify the built-up areas. NDWI was calculated by using the formula (SWIR-NIR)/ (SWIR+NIR). Higher NDWI values represent the high built-up area and vice-versa. This index is used to quickly identify the various types of built-up structures in the city.

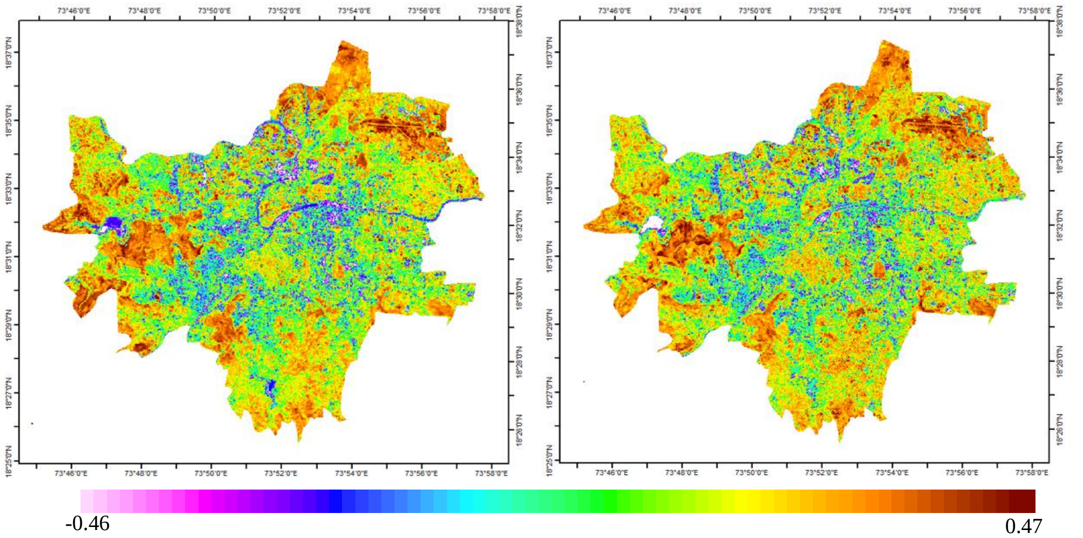

Figure 4: NDBI of 2008 (left) and 2017 (right)

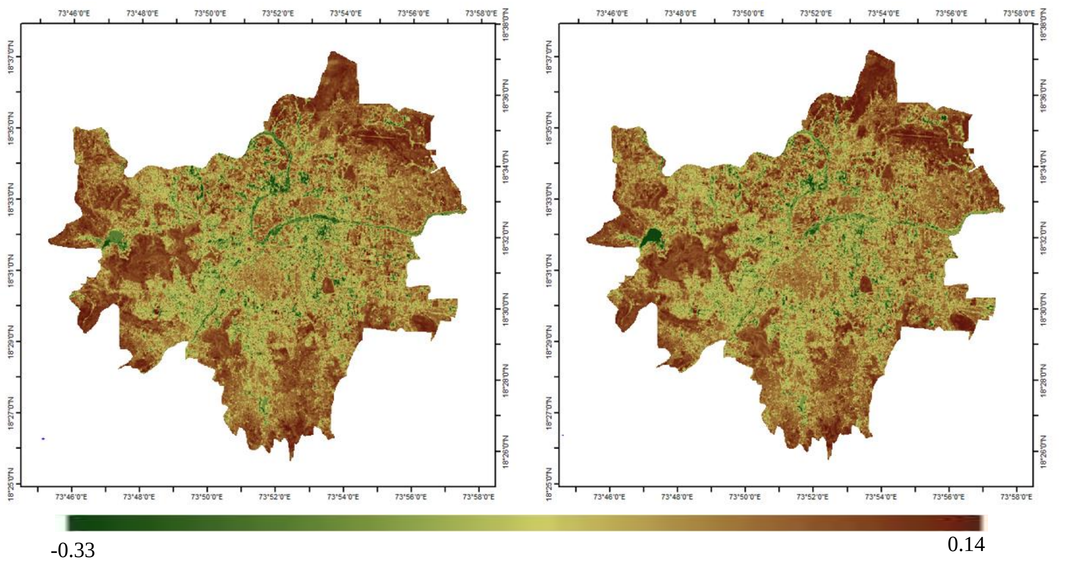

Figure 5: BSI of 2008 (left) and 2017 (right)

The Bare Soil Index (BSI) maps shown in the Figure 5 was derived by using the formula [(band6 + band4) – (band5 + band2)]/ [(band6 + band4) + (band5 + band2)]. The BSI is an index to capture soil variations. Higher BSI values represent lack of vegetation and moisture in an area. The Land Surface Temperature (LST) is calculated by emissivity reference channel algorithm. The LST derived from both the thermal bands is averaged to get the mean LST. Figure 6 shows the 2008 and 2017 LST respectively.

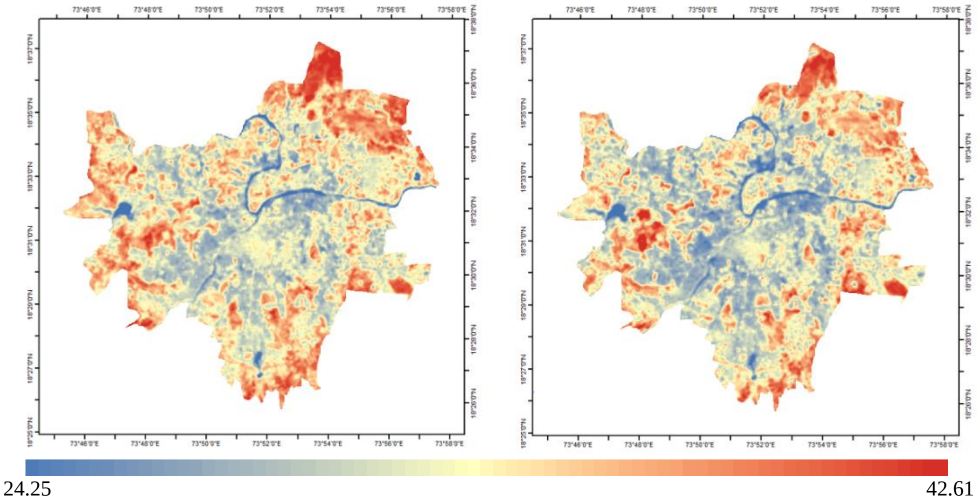

Figure 6: LST of 2008 (left) and 2017 (right)

The indices mentioned above for both the years 2008 and 2017 have been created with the same range for easier comparison and better understanding. For comparing both the 2008 and 2017 images, minimum-maximum normalization method is applied to the same range of values.

4.2 Change detection analysis:

The map is shown in Figure 7(a) reveals the patches of green areas which existed in the year 2008 but could not be seen in the year 2017. These areas account for a total of 1643.263 Ha. These areas could have been wiped clean to accommodate the new construction required for the growing urbanization.

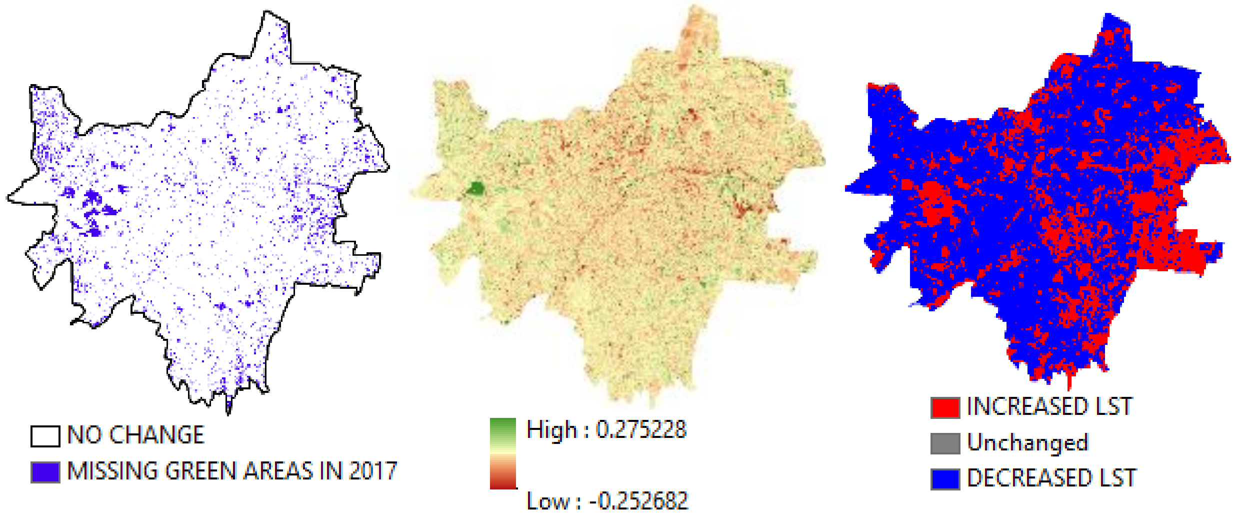

Figure 7: Change detection map of : 7(a)- NDVI (left); 7(b)- BSI (centre) and 7(c)- LST (right)

The change detection analysis was performed for the BSI maps of the years 2008 and 2017 by subtracting the BSI map of 2017 from that of 2008. Hence the positive changes, represented by green colour in the map, signifies more BSI in the year 2008. Whereas, the negative changes, represented by red colour in the map, signifies more BSI in the year 2017. The change detection map is given in Figure 7(b). The change detection of LST revealed some unexpected facts such as when on one hand the LST of the peripheral region of the city was higher in the year 2017, on the other hand, the LST of the central part of the city was found to be lower in the year 2017 as compared to that in the year 2008. The map showing the change detection analysis is given below in the Figure-7(c). The regions exhibiting a rise in the LST in the year 2017 as compared to that in the year 2008 are marked in red colour. It’s observed that these regions are mostly comprised of the peripheral region of the city. This is because these areas are wiped clean of any previously existing vegetation for expansion of the urban area. Surprisingly, a considerable portion of the city was also found to exhibit a reduced LST although the difference is very minute! These regions are marked in blue colour. The government here is very active towards the conservation of the environment. Many initiatives have been taken towards this goal, and much more are proposed. The city already consisted of 165 parks/gardens when the government proposed yet more seven parks. Moreover, the nallas (wide drains) of the city are converted into nalla gardens by purifying the foul water flowing through it naturally and landscaping the surrounding areas with beautiful flowering trees, and shrubs.

4.2.1 Site level analysis:

Site selection criteria: As observed in the literature study that spaces with smaller area did not have any significant effect in the reduction of the temperature hence, parks and gardens having an area lesser than 2 Ha was omitted from the list. From the resultant list, the five largest parks and gardens were selected out of which two of them were situated very close to each other and hence was clubbed and treated as one, i.e., the site number 8. The site numbers of the other selected parks and gardens are 6, 9 and 12. Apart from the sites mentioned above two more sites belong to the organized green space category viz., site numbers 1 and 7. These sites are golf courses and are also larger than 2 Ha. Additionally, two sites were taken from the unorganized green space category, i.e., site numbers 3, 5 and 11. These are forests. The site number 3 is a dense green forest with a high NDVI and surrounded by river on all sides. Whereas, the site numbers 5 and 11 are also forests but are deforested and hence have very low vegetation. Aside from the three rivers flowing through the city, there are only two major lakes existing in the city, which is the Pashan Lake and the Katraj Lake. The Katraj Lake is a part of a biodiversity park and hence had been selected already as site number 12. The rivers are highly polluted as compared to the lakes. So to study the effect of pollution on the cooling efficiency of the waterbodies some highly polluted areas of the rivers were selected along with the Pashan Lake which is the site number 4. The river area is selected in site number 2 and 10. Site locations are shown in Figure 8.

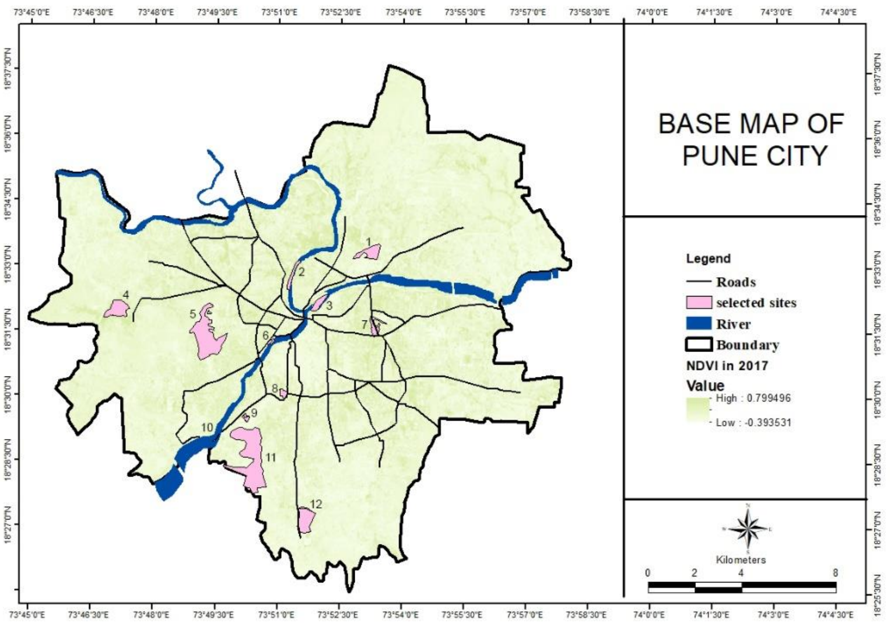

Figure 8: Spatial location of the sites

4.2.2 Statistical Analysis

The site-level analysis involved several steps. Firstly the values each of the parameters corresponding to each of the sites was tabulated as shown in table 1 below. Secondly, the LST values of each of the sites were correlated with their respective NDVIs in case of green spaces and NDWIs in case of the blue spaces. However, in case of the site number 12, the LST was correlated with both the NDVI and the NDWI as it consists of both the green and blue spaces almost equally. The results of this correlation have computed a table which has been shown in the table number 2. Next, the mode of the LST values was correlated with the area, PAR and LSI values of each of the sites. The results of this correlation have been shown in table 3. Lastly, a multivariate regression analysis was performed to check the effect of each of the variables on the LST. The result is given in table 4.

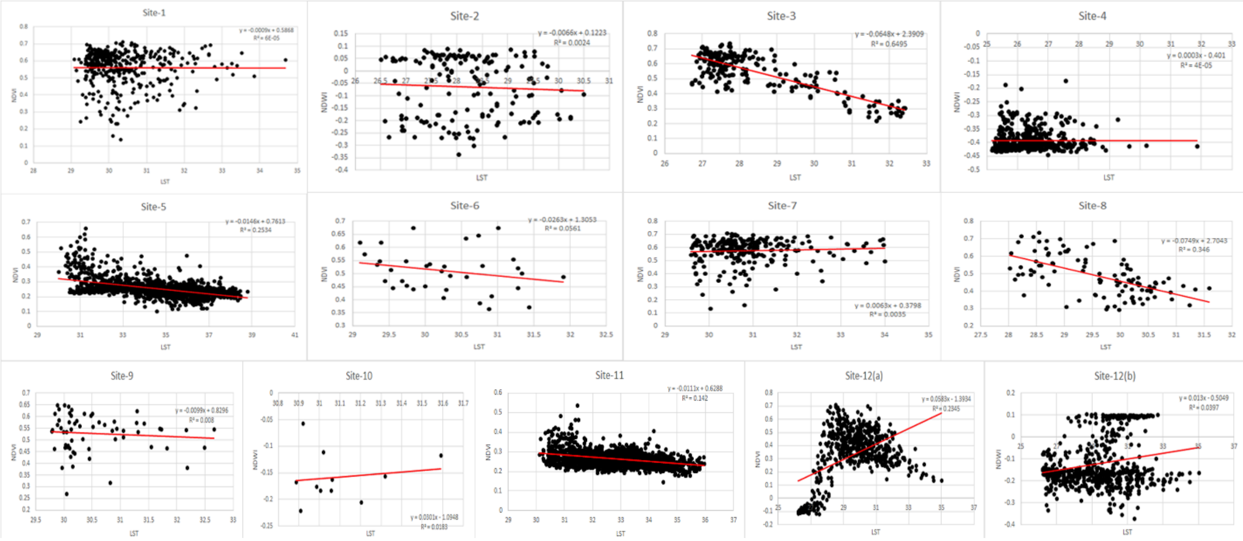

Figure 9: Correlation between the NDVI/NDWI and the LST of the corresponding sites

Table 1: Various parameters about the individual sites

Site no.	LST (ºC)	Area (Ha)	PAR	LSI
1	29.5	35.71	0.009787	1.649722
2	28.5	14.05	0.02048	2.165608
3	27.78	18.53	0.011583	1.406585
4	26.12	48.78	0.006494	1.279463
5	35.76	156.03	0.00536	1.888516
6	29.5	3.05	0.025254	1.245181
7	30.25	21.9	0.016669	2.2
8	30.5	9.28	0.014065	1.2
9	30.75	5.33	0.019139	1.247
10	31.5	1.14	0.07766	2.343615
11	33.5	224.61	0.004674	1.976
12	29.5	54.39	0.005852	1.217547

Table 2: correlation of the LSTs of each of the sites with their respective NDVIs/NDWIs

Site no.	LULC	LSI	LST (ºC)	NDVI	NDWI	PCI intensity (ºc)	PCI effect (m)	Correlation of LST with NDVI/ NDWI
1	Golf course	1.6497	29.5	0.594	-0.34	4.6	100	No correlation
2	River	2.1656	26.7	-0.07	0.05	7	100	-VE
3	Forest	1.4065	27	0.677	-0.35	7	200	-VE
4	Lake	1.2794	25.4	-0.2	-0.33	8.1	200	No correlation
5	Forest	1.8885	30.9	0.234	-0.2	_	_	-VE
6	Park	1.2451	29.3	0.454	-0.12	4.3	300	-VE
7	Golf course	2.2006	30.9	0.566	-0.26	3	100	+VE
8	Park	1.2087	28	0.578	-0.33	5.7	300	-VE
9	Park	1.2470	29.8	0.631	-0.06	5	200	-VE
I10	River	2.3436	30.9	0.119	-0.33	3.5	100	+VE
11	Forest	1.9760	31.4	0.483	-0.16	2.7	200	-VE
12	Reserve Forest	1.2175	26.2	-0.08	0.09	9.2	200	+VE

Table 3: correlation of the LSTs of the sites with the area, PAR and LSI

Correlation of LST	**Area**	**PAR**	**LSI**
	+ve	+ve	+ve

Table 4: Correlation of the LSTs of the sites with the area, PAR and LSI

	Coefficients	Standard error	P-value
Intercept	29.6	2.5	4.12E-05
NDVI	3.2	2.002	0.16
NDWI	3.7	4.03	0.39
Area	3.00E-06	1.08E-06	0.03
PAR	58.3	42.15	0.2
LSI	0.47	1.7	0.8

The equation which may be formed from the above regression analysis is given below:
LST= 26.6 + 3.2xNDVI + 3.7xNDWI + 3.0E-06xArea + 58.35xPAR + 0.47xLSI…………….(Equation-1)

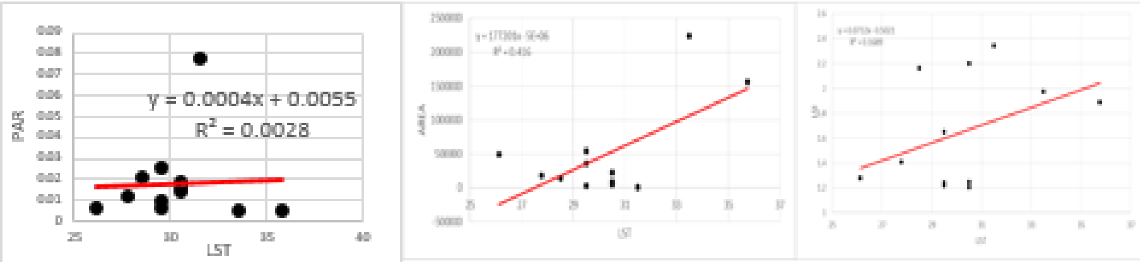

Figure 10: Correlation between LST and PAR (left), Area (centre) and LSI (right)

5 RESULTS AND DISCUSSIONS

For sites 1 and four there's no correlation between their LSTs and NDVI/ NDWI. The probable reason behind this phenomenon could be the inefficiency of site 1 to create a PCI effect due to its location in the leeward direction, and as far as site 4 is concerned, it's NDVI was found to be very high in the year 2017 than in the year 2008 and vice versa in the case of NDWI. Next, for the sites 7, 10 and 12 their NDVIs/ NDWIs were found to be directly proportional to the LSTs present in these sites. Site number 10 is a part of a river, which is extremely narrow and highly polluted whereas the site number 12 has an equal concentration of both green cover and waterbody. These might be the reasons for their resultant relation. The rest of the sites were found to exhibit an indirect proportionality of their NDVIs/ NDWIs with the corresponding LSTs present in these sites as was found in the existing studies by the researchers.
Moreover, the city of Pune has acknowledged the growing concern related to environmental degradation and is actively participating towards its restoration since the past couple of years. The Municipal Corporation of the city now has a separate Trees, Gardens and Environment Department which have taken up many initiatives such as plantation programs, creating more number of public open spaces, River water restoration and Riverfront Development, etc. in the recent past. There are more than ten parks created by the year 2017 since the past decade, and seven more are upcoming. The canals/nallas are being beautified and converted into beautiful Nalla Gardens which are also open to the public. In the Equation-1 substituting the values of PAR=0.005, LSI=1.2, NDVI=0.6[1], NDWI=-0.33[2] and area=1000 we get LST= 28.16⁰C. And by substituting the values of PAR=0.005, LSI=1.2, NDVI=-0.0879[3], NDWI=0.099[4] and area=1000 we get LST= 27.74⁰C. Moreover, by the hit-and-trial method, substituting different values in the equation it was found that the maximum area up to which a waterbody can exhibit a cooling effect is 1,00,000 m^2 beyond which the temperature keeps increasing. Also, it was found that the smallest regular shape which exhibits a PCI effect is a circle having radius 100m. As per the Equation 1 and findings, it is clear that the irregular but compact shapes could exhibit a much lower LST than the regular shapes as the PAR value of the regular shapes is much higher than the irregular ones.

6 CONCLUSIONS

Pune city was found to exhibit the maximum UHII, i.e., 10⁰ C, among the other important Indian cities like Mumbai, New Delhi, Kolkata and Chennai. The high UHII is due to the high LSTs in the peripheral part of the city which has been wiped clean of any existing vegetation for the expansion of the urban sector. Because even the city core is not as high on LST as the periphery due to the presence of ample green spaces in the form of public open spaces and amenity green spaces. Surprisingly, the areas which were devoid of any urban green spaces in their proximity and even the amenity green spaces but consisted of someone or two or maybe a row of trees were much cooler than compared to the peripheral region of the city.

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[1] Taking cue from site no. 8
[2] Taking cue from site no. 8
[3] Taking cue from site no. 12
[4] Taking cue from site no. 12

Acknowledgements

The second author is thankful to the Ministry of Human Resource Development, GoI for providing necessary computational facilities through the project 14MHRD005 funding. Authors are thankful to USGS for providing Landsat 8 data free of cost. We thank Head, Department of Planning, School of Planning and Architecture, Vijayawada, for his support throughout the research.

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