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BUILT FORM DETERMINANTS OF URBAN LAND SURFACE TEMPERATURE: A CASE OF MUMBAI

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Abstract

Mega cities like Mumbai are experiencing continuous decline in thermal comfort due to the change in its ecological functions caused by accelerated growth and changes in its built environment. This research conducts an analysis of spatial variation in Built Form types (BFT) of a ward of Mumbai. BFTs are categorised by both their surface properties and built structure. Furthermore, the study establishes linkages between Built Form (BFT) and variations in the Land Surface Temperatures (LST), and identifies significant indicators of urban temperatures. The analysis of built form parameters is done using urban surface cover Indices as well as volumetric indices like 'Building Heights' (BH) and 'Sky View Factor' (SVF). A regression analysis between Built form parameters and LST was carried out for the 'S' ward of Mumbai to understand the correlation of Built up area Index (NDBI) and Vegetation Index (NDVI) with LST. Also a correlation of BH and SVF indices is assessed statistically with LST. Results show a high positive correlation between LST and Built up area (NDBI), while a strong negative correlation was found between LST and vegetation index (NDVI). A correlation of LST with the building heights was found to be insignificant. The regression analysis carried out between SVF (at noon) and LST shows that BFTs with high SVF have a coherence with high LST, whereas high density low rise slum areas having low SVF show high LST. A current study indicates that the surface cover and the built geometry are significant parameters in assessing spatial variations in LST across different BFTs in the city.

Keywords

Urban Built Form; Land Surface Temperature; Sky view Factor

1 INTRODUCTION

Urban heating in particular is one of the critical issues in urban areas with warm and humid climate like mega cities such as Mumbai. The urban heating poses risks for outdoor activity, disrupts the ecosystem functioning as well as it increases energy use. Built form is one of the major contributors in influencing the temperatures in an urban area. Mumbai is the culmination of varied built form types as a result of spatial and temporal changes in the urbanisation pattern. Thus, his study attempts to identify the significant determinants of Urban Built Form and their linkages with urban the heating phenomenon. Urban 'Built form' is defined by its space configuration of built structures that have varied forms across space and time and are categorised as 'Built Form Types' (BFT). Different BFTs have different impacts in regulating the temperatures in an area. In this study, we are analysing the change in urban Land Surface Temperature (LST) as key ecosystem service that impacts the quality of life in urban areas with respect to BFTs. As described by [1] , the LST varies from place to place as it depends on the surface and geometry of a built area. The buildings, roads, vegetation etc. form the surface of the urban area that contributes to the heat energy exchanges in the city [2]. The urban heating phenomenon is caused due to influences of a net radiation flux in the near-ground surface of urban areas[3]. The

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higher level of sensible heat fluxes is caused by changes in land cover caused by the removal of the original vegetated areas that have high reflectivity and low thermal capacity [4] [5].

Urban Built Form as a spatial unit can be well understood at a neighbourhood scale[6]. It is the scale that defines both function and form of the built area. At neighbourhood scale, the land surface properties were analysed using vegetation and built-up indices. Built form structure was understood using 'Built Height' and Sky View Index (SVF). SVF provides the net radiation flux of a neighbourhood and its conversion to land surface temperatures. It also implies the exchange of energy within the atmosphere that varies with built form geometry and placement [9].Therefore, these indices that determine the Urban Built Form are useful in analysing the thermal comfort of outdoor built environments.

The objective of the study is listed as follows:

- To categorise Urban Built Form Types (BFTs) based on the surface and form properties
- To recognise spatial distribution of LST over a ward of Mumbai
- To identify parameters and variables to study relationships between Urban Built Form and LST
- To establish linkages between Urban Built Form parameters and LST

2 STUDY AREA

In order to understand variations in ecosystem services with respect to changes in Urban Built Form characteristics, the built neighbourhoods of 'S' ward of Mumbai were analysed. The 'S' ward is the central ward and it creates an ideal system boundary of ecosystems for the study with a lake and a thick vegetation cover at its north. It has different built forms that represent the transforming urban form characteristics of Mumbai. The ward thus serves as an appropriate testing ground for establishing relationships between Urban Built Form and LST.

Figure (1) below depicts the area under study, the 'S' ward of Mumbai. The ward is divided into 250m X 250m grids which form the basic unit for analysis. The 'S' ward covers an area of 64 sq.km and has a population of 7, 43,783.

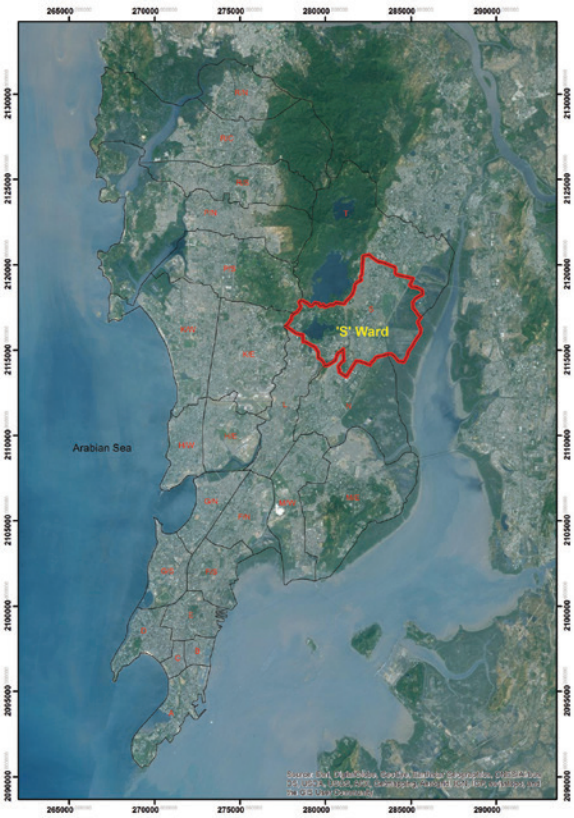

Fig. 1: Mumbai city and the study area, the 'S' Ward, as seen on Google Earth Map 2016.

3 METHODS AND MATERIAL

3.1 Methods and data sources

Variation in land surface temperatures are a continuous spatial phenomenon and cannot be analysed as a point phenomenon. GIS based analytical tools are used here to assess spatial dynamics of LST distribution over different Urban Built Forms. We have carried out an analysis at two levels: (i) Surface level (ii) Built geometry analysis at 3D level. The processing of indices and the generation of DEM is carried out using high resolution satellite images and Geospatial analytics. Open source, Landsat 8 OLI/TIRS+ from the United States Geological Survey (USGS) is used for computing land surface indices. High resolution satellite images, viz. stereo pair of Carstosat-1 was procured from National Remote Sensing Centre (NRSC) for the DSM creation. The processing and computation of various indices were done using Arc GIS 10.2.1, Arc Globe 10.2.1 and ERDAS LPS 9.2. Spatial analytical tools of ESRI Arc GIS 10.2.1 was used to create LST profiles of the 'S' ward and to identify areas of heterogeneity of surface temperatures.

3.2 Study Parameters

The study’s hypothesis is that the variation in LST is a function of both 'Surface cover' and 'Built form' types as depicted in equation (1) given below. The Surface cover indices include

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Normalised Differential Built Index (NDBI) and Normalised Differential Vegetative Index (NDVI) and the built form type is assessed using 'Average Built Height' and a Sky View Factor (SVF). The 'S' ward is divided into a 250m X 250m grid as a unit of analysis. All the above indices are independently analysed with respect to LST to understand their linkages.

LST = **f** (***surface cover, built structure***) (1)

3.2.1 Land Surface Temperatures (LST)

Land Surface Temperatures (LST) can be calculated from satellite images using a digital image processing software. LST of Mumbai was computed using Optical Land Imager (OLI) with a resolution of 30m and Thermal Infrared Sensor (TIR) data with a resolution of 100m of the year 2015. Two adjacent thermal bands are the newest thermal infrared sensor which is beneficial for the LST inversion using Split Window Algorithm [10]. Split window algorithm estimates brightness temperature of the surface using spectral radiance and emissivity that is derived from Landsat 8. The spectral radiance was estimated using TIR bands 10 and 11. Emissivity was derived with the help of NDVI threshold technique for which OLI bands 2, 3, 4 and 5 were used. As the SW algorithm uses both the TIR bands and OLI bands, the LST generated using them were more reliable and accurate [11].

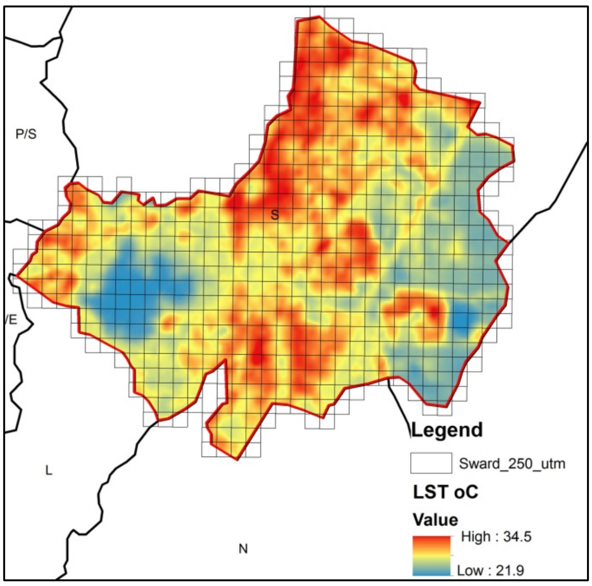

Fig. 2: LandSsurface Temperature as estimated from Landsat 8 OLI/TIRS Feb, 2015 image.

3.2.2 Normalised Deferential Built up Index (NDBI

To extract and analyse the total built up area in an urban area, NDBI is a useful and accurate way of automatic mapping.

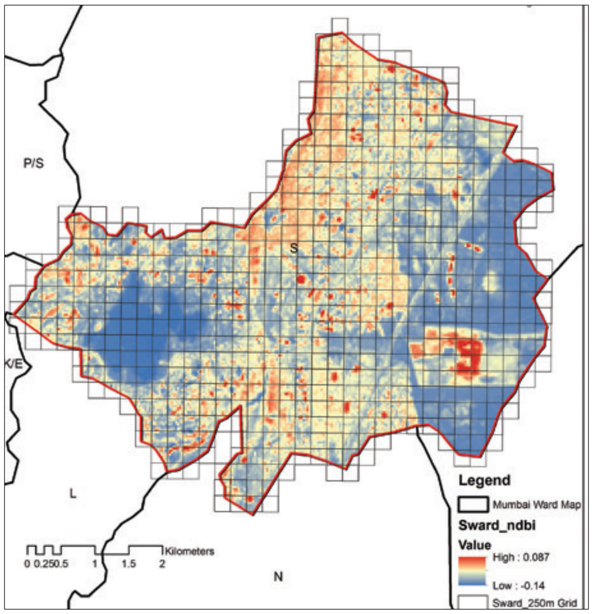

Fig. 3: Normalised Built Index of 'S' Ward clipped from Mumbai NDBI.

NDBI = (SWIR-NIR)/ (SWIR+NIR) *(2)*

Where, SWIR and NIR represent Short Wavelength Infrared Radiometer and Near Infrared band of the spectrum i.e. band 6 (1.57 – 1.65 μm) and band 5 (0.85-0.88 μm) of Landsat 8 OLI/TIRS. A high value of NDBI shows high built up area.

3.2.3 Normalised Deferential Vegetative Index

Normalised Deferential Vegetative Index (NDVI) gives the amount of vegetation on the land surface ranging from -1 to +1. A high value of NDVI denotes higher vegetation [12].

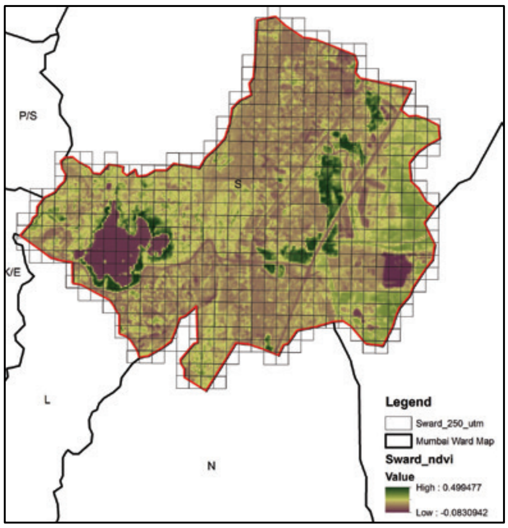

Fig. 4: NDVI map of S ward as obtained by Landsat 8, Feb 2015.

NDVI is calculated using BAND 4 and Band 5 of the Landsat 8 OLI/TIRS image as follows:

NDVI = (NIR-RED)/ (NIR+RED) ***(3)***

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Where, RED and NIR represent band 4 (0.64-0.67 µm) and band 5 (0.85-0.88 µm) of Landsat 8 OLI/TIRS+.

3.2.4 Building Height

Building height is an important variable to test the impact of roughness on land surface temperatures. Land surface properties along with the increase in building surfaces due to heights, lead to an attenuation of urban heating. The height information of each building is extracted from DSM created from CARTOSAT 2011 image. DSM was created in ERDAS Imagine LPS and then by using a building footprint, building heights were extracted in Arc GIS 10.2.1 using spatial analysis tools.

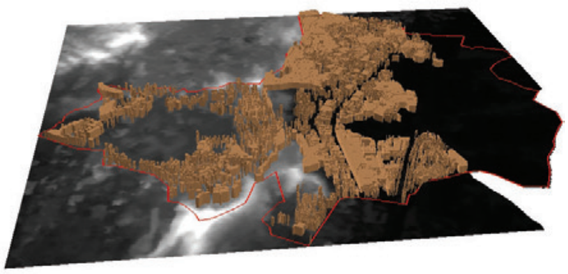

Fig. 5: Building heights extracted from DSM.

3.2.5 Sky View Factor

In recent urban form studies, Sky view Factor (SVF) is considered as an important parameter to ascertain built geometry and its effect on local climate as it provides useful input on the amount of radiation received and the change in emissivity caused by multiple scattering [13]. 11 grids of the ward (of 250m x 250m) were selected for computing the SVF. Selected grids cover different clusters of built form types (see figure 6).

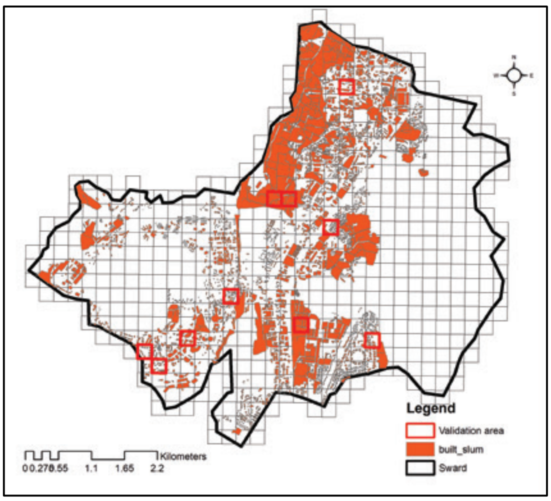

Fig. 6: Selected grids for computing SVF.

4 MODELS AND RESULTS

The first part of the study undertakes the regression analysis of land surface cover using both NDVI and NDBI indices (see Figure.7). Secondly, to understand the relationship between Built Form and LST, we have analysed the relation of LST with average Built Heights and SVF index for the study area. A correlation between LST and NDBI was found to be significant (C.I. 95%). The regression line plot shows positive correlation with R^2 = 0.64. The regression line plot between LST and NDVI was also correlated but with a negative slope with a correlation coefficient of R^2 = 0.5 (C.I. 95%). The number of samples is 602.

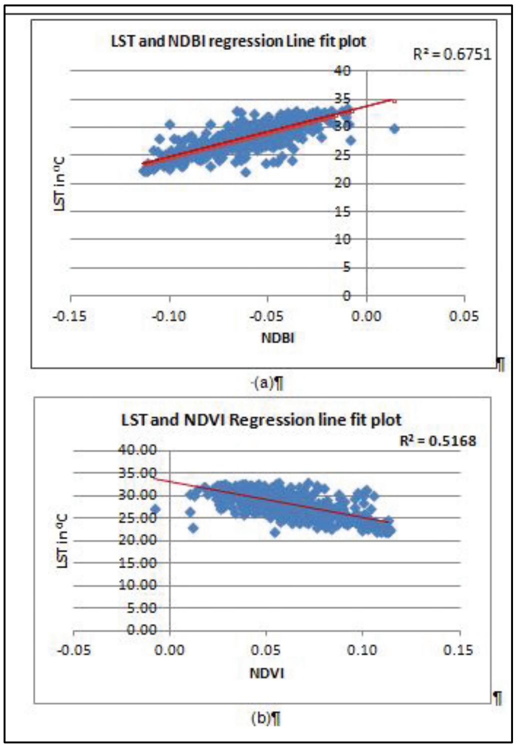

Fig. 7: Above figures show a grid wise regression line plot between (a) LST and NDBI (b) LST and NDVI for each grid of 'S' ward.

Furthermore, in order to understand the correlation of LST with building heights and form, a regression model was run between LST and average built-up heights for each grid. It was found that the average built height does not show a significant correlation with the LST. A built height analysis along with other built parameters may indicate a certain coherence. The SVF value indicates a three dimensional built geometry of the urban form, and was therefore assessed for its relation with LST. SVF was computed for the selected grids of the built form and analysed with respect to LST of the grid (refer Table 1).

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S.No	BFT	SVF (mean of below mean)	LST (^{o}C)
1	High Rise, Low density, High NDVI	0.31	27.3
2		0.38	28.9
3		0.24	24.2
4	Low Rise, Low density, Low NDVI	0.48	28.5
5		0.38	29.1
6		0.42	26.6
7	Low rise, High density, Low NDVI	0.30	32.1
8		0.26	34.4
9		0.32	29.3
10	High rise, High density, low NDVI	0.35	32.2
11		0.42	28 .8

Table 1: SVF and LST values for the selected grids of 'S' ward.

The relation between SVF and LST for 11 grids of the 'S' ward is given above in the Table 1. Results from the above show the relationship between SVF and LST as a linear positive coherence. An exception is observed in highly dense low rise built areas where SVF is low but have high LST.

5 DISCUSSIONS

Results from the regression model between Built up Index with LST imply that the high built-up area percentage in the 250 x 250 m^2 grids corresponds to high surface temperatures i.e. above 28^{o}C. This can be attributed to an increased built surface area that causes multiple scatterings and trappings of incident short and long waves that increase surface temperatures of the area. Regression analyses between NDVI Index and LST for each grid show that grids having a high NDVI index correlate with low LST, which confirms that the vegetation reduces the heating of the urban surfaces by transpiration thus reducing the temperature of the neighbourhood by a considerable amount. Green cover is a significant determinant of LST and therefore should be part of urban policy guidelines.

Average built heights do not show a significant relation with LST. This can be explained by the reason that only built height may not be a significant factor to assess LST, although when analysed along with other built parameters like SVF and density, it shows a coherence with LST. In grids where the average Built Height value is high and SVF is low, day time thermal Image analysis shows a low value of LST. This could be explained by the low SVF; there is mutual shading of surfaces and also has presence of high percentage of vegetation or NDVI value. This implies that we can reduce the heating of surfaces with an adequate SVF and vegetation between built structures. Exceptions to the above phenomenon were observed in low rise, highly dense built forms, where SVF is very low, but LST was found to be very high. (refer to Table 1). This is commonly found in slum areas of the ward, where due to low SVF, there are multiple radiations that result in high LST of the area. These grids also show a high Built up and a low NDVI index.

The above analysis infers that for understanding the thermal comfort of an urban area, we must consider both surface cover properties along with built structure types. The relationship between built form and LST can be helpful in formulating future urban form policy guidelines for Mumbai and similar cities.

6 CONCLUSIONS

Although it is complex to establish a relationship between urban form and LST due to multifaceted variability in an urban ecosystem, this study has attempted to critically analyse the impact of urban surfaces and built form geometry on LST.

It was found that a spatial variance of LST can be analysed using geo-spatial analytics. By using the output of thermal image derived LST, we could clearly show heterogeneity of LST across the study area and find correlations with the varying built form types. Another finding from the study is that the building density and geometry is a more significant factor than the building heights while assessing the impact on LST.

In future, the work would incorporate the tree canopy cover for the SVF analysis along with wind pattern simulations combined with other built form parameters like aspect ratio and facade density to understand the Built form and LST relationship in a more intrinsic way. This is a critical area which should be addressed, especially for cities like Mumbai where cooling demand is continuously increasing with higher urbanization rates.

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