Indian Journal of Spatial Science Vol - 5.0 No. 2 Winter Issue 2014 pp. 70 - 76

Indian Journal of Spatial Science

EISSN: 2249 - 4316 homepage: www.indiansss.org ISSN: 2249 - 3921

Distribution of Land Surface Temperature over Built-up Area by Web-GIS Techniques

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Article Info

Article History
Received on:
21 March 2014
Accepted in *Revised Form* on:
30 June 2014
Available *Online* on and from:
23 September 2014

Key Words
Urban Heat Island (UHI)
Land Surface Temperature (LST)
NDBI
NDBaI
NDPI
MBI

Abstract

Global warming has obtained more and more attention because the global mean surface temperature has increased since the late 19th century. As more than 50% of the human population lives in cities, urbanization has become an important contributor for global warming. Barasat municipality in West Bengal is one of the regions experiencing rapid urbanization that has resulted in remarkable Urban Heat Island (UHI) effect, which will be sure to influence the regional climate, environment, and socio-economic development. In this study, Landsat ETM$^+$ image of 2011 has been used to retrieve the brightness temperatures and urban built-up area. A new index MBI has been propounded for detection of urban built-up area. The approach of quantitative remote sensing vis-s-vis digital indexing, correlation and regression analysis, Web GIS techniques validated that built-up area expansion and urban sprawl has direct impact over the environmental properties. Urban Heat Island effect has been more prominent in the core impervious zone of the Barasat (CBD region) town.

Introduction

Urbanization is a form of metropolitan growth that is a response to often bewildering sets of economic, social, and political forces and to the physical geography of an area. It is the increase in the population of cities in proportion to the region's rural population. The 20th century is witnessing "the rapid urbanization of the world's population", as the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 and is projected to rise to 60% (4.9 billion) by 2030 (World Urbanization Prospects, 2005). The process of urbanization contributed by infrastructure initiatives, consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros.

Urbanization and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation) etc. Remote sensing images are useful for monitoring the spatial distribution and growth of urban built-up areas due to synoptic views of urban land cover in temporal time frame (Xu 2008; Bhatta 2009; Griffiths et al. 2010).

Over the past two decades, researchers have become increasingly interested in using remotely sensed imagery to address urban and peri-urban problems (Jacquin et al. 2008). Land cover plays a pivotal role in impacting and linking many parts of the human and physical environments (Foody, et al., 2002). At present, the extraction accuracy of built-up area is still unsatisfactory, which usually varies around 70%-80%. This is mainly due to the heterogenous nature of urban areas, where continuous and discrete elements occur side by side (Aplin, 2003). Another reason is the problem of mixed pixels, which is particularly serious in an urban environment (Lo and Choi, 2004). The situation is more critical for urban areas with interspersed *bare land units* because the spectral difference between urban areas and the surrounding land surface is usually not enough to discriminate urban area from other land covers. Urban heat island (UHI) has long been a concern. One of the earliest UHI studies was conducted in the urban southern Singapore. Extensive urbanized surfaces modify the energy and water balance processes and influence the dynamics of air movement (Oke, 1987). The characteristics of the UHI effect have been studied extensively.

Urban Heat Island

It is well known and documented that urbanization can have significant effects on local weather and climate. Of these effects one of the most familiar is the urban heat island, which is the direct representation of environmental degradation. An urban heat island is a metropolitan area which is significantly warmer than its surrounding rural areas; the higher urbanization leads to more distinct urban heat island with huge temperature differences between urban and rural areas. As early as 1833, the concept of urban heat island was described by Luke Howard, and since then this research topic has received even more attention.

Recently, with the development of society and acceleration of the process of urbanization, the urban heat island has become more and more significant and has had severe impact on urban development and human living environments. The buildings, concrete, asphalt and industrial activity of urban areas causes the urban heat island. Replacing natural land cover with pavements, buildings and other infrastructures takes away the natural cooling effects. Again, tall buildings and narrow streets can heat the air trapped between them and reduce airflow. In addition, heat from vehicles, factories and air conditioners adds warmth to the surroundings, further exacerbating the heat island effect. Urban heat island mainly appeared in the spatial distribution of land surface temperature (LST), which is governed by surface heat fluxes and obviously affected by urbanization. Consequently, acquiring LST is the primary and key step to the urban heat island analysis (Liu and Zhang et al., 2011).

Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials. These materials have high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, reduce surface temperature through evapotranspiration. Urban Heat Islands (UHIs) were first identified in the 1800s when the differences between London's temperatures and the surrounding countryside were noted (Streuther, 2002). Application of the quantitative remote sensing, mapping and modeling technology to the UHI are, in its own right, a multidisciplinary exploration. Urban heat islands are the result of urban rural differences in surface materials, drainage characteristics, heat sources, pollutants, and configuration of surfaces. This contrast between rural and urban areas creates an artificial or anthropogenic temperature increase and a change in the local climate of the city area (Robinson and Sellers, 1999).

Objectives

The following are the objectives of the current study —

1. Detection of built-up area in Barasat Town,
2. Estimation of Land Surface Temperature (LST),
3. Mapping Urban Heat Island (UHI) by Web GIS technique,
4. Investigating the relation between built-up area and LST,
5. Establishing the importance of Digital Remote Sensing in this in this kind of analysis.

The Study Area

Barasat, a district headquarters town (31.41 km^2) within the jurisdiction of Kolkata Metropolitan Development Authority (KMDA), West Bengal has been chosen as our area of interest (Fig. 1). This town is located between 88°27´E and 88°31´E and 22°40´58´´ N and 22°44´44´´N. It is divided into 32 Wards that together contain a population of 283, 443 with 50.7% male and 49.3% female. It has a population density of 9023 persons/ km^2. Since independence and after the Partition of Bengal, its volume of population has been steadily increasing. No. of Wards have increased from 6 to 32. It has experienced about 115.3% of population growth during 1991 2001 whereas it is only 19.8% for West Bengal. Barasat also experienced higher growth rate compared to that of average all India figure of 32.60%.

Methodology

In this study LANDSAT ETM + digital data (P/R 138/44) acquired on November 16^{th}, 2011 georeferenced to UTM coordinate system based on rectified high resolution Quick Bird image, Google Earth data and SOI 1:50,000 Topographical Maps have been used and processed in TNT MIPS professional environment.For Landuse / Land Cover classification, Chavez's OIF (Optimum Index Factor) model has been applied with 5 : 4 : 1 band combination and accordingly the training sites have been prepared (Fig. 2).

To examine the patterns and dynamics of Landuse/ Land Cover the supervised classification technique has been used. The images of Barasat Municipality area has been segregated into 5 (five) types of land use/cover categories like – i) agricultural fallow, ii) green space, iii) settlement with vegetation, iv) water bodies, and v) concrete urban. According to the error matrix it has got the high accuracy level (Table - 1). The sampling points were randomly taken across the study area, which were also relatively and uniformly distributed among these land use/cover types. The overall accuracy of classification is approximately 97.19% with Khat statistic of 96.04%.

To estimate the built-up area, first the Normalized Difference Built-up Index (NDBI) has been calculated to extract the built-up area. There remained few confusion between bare areas and settlement areas in the positive range of NDBI (Zha, 2003) values.

Thus, to remove the bare soil area Normalized Difference Bareness Index (NDBaI) (Zhao & Chen, 2005) was calculated and then a Modified Built-up Index (MBI) has been formulated (Fig. 3) as —

$$NDBI = (MIR - NIR) / (MIR+NIR)$$
$$NDBaI=(MIR - TIR) / (MIR+TIR)$$
$$MBI= (NDBI - NDBaI)$$

Next challenge was to remove the hidden water bodies from MBI. Thus Normalized Difference Pond Index (NDPI) (Lacaux, 2007) was also calculated using the following equation —

$$NDPI= (MIR - GREEN) / (MIR+GREEN)$$

Then a script was written using MBI and NDPI to extract a particular range with threshold values (Table - 2) with positive values for NDPI (because negative values of NDPI denote pond area) and MBI (because positive values denote built-up area). The result was satisfactory because it extracted the real concrete built-up area (Fig.3) which is very much like the urban class specified by supervised classification (using maximum likelihood classifier) map with an overall accuracy of 97.19%.

For extracting the Land Surface Temperature (LST) Chen et al. (2002) proposed a method of deriving brightness temperature in two steps:

First, the digital numbers (DNs) of Band 6 are converted to radiation luminance (RTM6, mW cm−2sr−1) by the following formula:

$$R_{TM6} = V/255 (R_{max} - R_{min}) + R_{min}$$

Where, V = DN of Band 6, R_{max} = 1.896 (mW*cm^{-2*}sr^{-1}) and R_{min} = 0.1534 (mW*cm^{-2*}sr^{-1})

Then radiation luminance has been converted to at-satellite brightness temperature in Kelvin, T (K), by the following equation:

$$T= K1/ [1N (K2/R_{TM6}/b) +1]$$

Where, K1=1260.56K and K2=60.766(mW*cm^{-2*}sr^{-1}μm−1), which are pre-launch calibration constants; b represents the effective spectral range. When the sensor's response is more than 50%, b=1.239(μm).

The Landsat 7 ETM+ products were used for retrieving the temperatures in 2011 in two separate steps as follows (Landsat 7 User's Handbook) —

First, the DNs of Band 6 were converted to radiance by the following formula:

$$Radiance = gain*DN + offset$$

This can also be expressed as:

$$Radiance = (L_{max} - L_{min}/QCAL_{max} \times QCAL_{min}) * (QCAL_{max} \times QCAL_{min})+L_{min}$$

Where, the gain and offset can be obtained from the header file of the images, $QCAL_{min}$=1, $QCAL_{max}$=255, QCAL=DN, and L_{max} and L_{min} (also given in the header file of the images) are the spectral radiances for Band 6 at digital numbers 1 and 255 (i.e., $QCAL_{min}$ and $QCAL_{max}$) respectively.

Then the effective at-satellite temperature of the viewed Earth-atmosphere system under the assumption of a uniform emissivity could be obtained from the above spectral radiance by the following equation:

$$T= K2 / 1n (K1 / L_\lambda+1)$$

Where, T is the effective at-satellite brightness temperature in Kelvin; K1=666.09(watts/ (meter squared*ster*μm)) and K2=1282.71(Kelvin) are calibration constants; and L_λ is the spectral radiance in watts / (meter quared*ster*μm).

Finally, the Urban Heat Islands over the Built-up Area of Google Earth Data have been delineated by Web-GIS Techniques. After preparing the Land Surface Temperature (LST) map of the study area the temperature differences in different land use/cover were observed and a few spots has been selected to show the relation between Urban-Heat Island and built-up area. To show the relation the temperature raster has been converted into point vector layer for interpolation and isothermal lines were drawn and vector layer was exported to KML file format and plotted over the Google earth map by Web-GIS techniques and then visually interpreted (Fig. 5 and 6).

Result and Discussion

Barasat town is an upcoming important area of West Bengal. This town experienced 115.3% of population growth during 1991 to 2001 whereas West Bengal (urban) had 19.88% growth which was much less than this town. Barasat also had higher growth rate in comparison to that of all India (urban) rate of 32.60%. The main reason behind this kind of high population growth is its increasing importance as a district head quarter. Various kinds of land use land cover characteristics can be seen in this municipality. Seeing the growing importance new road, rails and building area were constructed in last few decades. These constructions lead to the increase of built-up area over Barasat town. The main goal of this study was to find out the built-up area due to urban sprawl. The extracted concrete urban built-up area is 3.8934 sq. k.m. which constitutes 12.40 % of total municipal area.

The Impact of Built-up Area on LST

The digital remote sensing method provides not only a measure of the magnitude of surface temperatures of the entire town area, but also the spatial distribution of the surface heat on urban land use. In this study, we have selected a single time data of 16th November, 2011 and built-up area of the Barasat municipality town was detected by using various indices and algorithms. Fig. 3 (right image) shows the actual urban built-up area over Barasat municipality. It can be seen that a star like urban morphological extension is occurring from the middle part of this municipality town. Settlements are mainly extended along with roads and railway lines. The middle part where the main bus(stands) Chanpadali more is located acts as the central point of settlement extension. Settlements can be seen along with Barasat- Barrack pore road towards north-west and along with Kolkata and Basirhat roads towards south-west and north-east respectively. Within the urban central area, numerous sub-centers (Fig. 7) of LST with higher surface radiant temperature were mainly located in the old and recently congested built-up features. In figure 5, it can clearly be identified that the heat island totally concentrated over the CBD region (Chanpadali more, a bus terminus) of Barasat municipality town. Here temperature varies from 17.19°C to 17.60°C. In figure 6, another heat island can be seen along Barasat station and rail lines. Here too the temperature varies from 17.19°C to 17.60°C.

Relation between Built-up area and LST

igure 10 shows the relation between built-up index and LST of the extracted built-up area. Correlation coefficient of this correlation is 0.0772456 which means the more built-up area the higher LST reflectance. The relationship of the built-up index and LST is shown in the simulated graph. The graph in this figure indicates that the LST is increasing with the increasing value of Built-up Index (BI). Positive value of BI represents the Built-up area, bare soil and earth fill or sand.

Conclusion

From the above study and investigative work it can be concluded that Urban Heat Island phenomena is related with the urbanization process. The approach of quantitative remote sensing vis-s-vis digital indexing, correlation and regression analysis, Web GIS techniques validated that built-up area expansion and urban sprawl has direct impact over the environmental properties. Urban Heat Island effect has been more prominent in the core of the Barasat (CBD region) town. It's also observed that the urban development introduces UHI intensity through the process of degradation and degeneration of vegetation covers. The results showed that remote sensing image is ideal for analyzing Urban Heat Island effect.

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Table – 1: Accuracy Assessment and Error Matrix

Name	T_1	T_2	T_3	T_4	T_5	Total	User's Accuracy (%)
Urban Settlement	145	0	0	0	0	145	100.00
Settlement & Vegetation	1	41	9	0	0	51	80.39
Green Space	0	0	183	0	0	183	100.00
Water Bodies	3	0	0	35	0	38	92.11
Agricultural Fallows	0	0	0	0	46	46	100.00
Total	149	41	192	35	46	463	
Producer's Accuracy (%)	97.32	100.00	95.31	100.00	100.00		
Overall Accuracy =97.19%				Khat Statistics = 96.04%			

Source: Computed by the Authors

Table – 2: Extracted Ranges of Different Indices

Indices	Minimum	Maximum	Mean	Threshold Values (taken)
NDBI	-0.340659	0.4853800	0.0949842	-
NDBal	-0.832168	0.0109091	-0.4323660	-
MBI	0.158484	0.7744570	0.5273500	0.651262 to 0.774457
NDPI	-0.458333	0.5487810	0.2329090	-0.458333 to 0.145935
Extracted Result for Urban Built-up Area	0.589666	0.7301530	0.6135590	

Source: Computed by the Authors

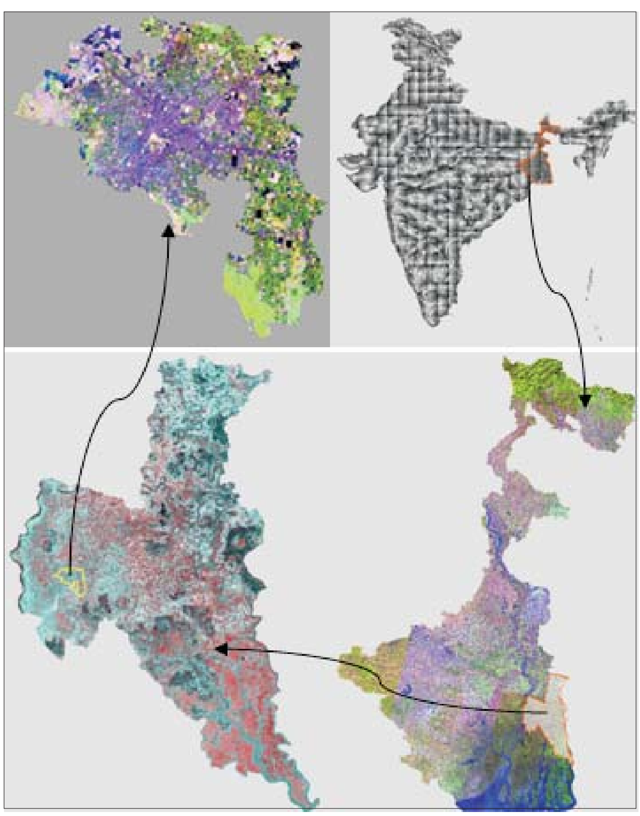

Fig. 1: Location Map of Barasat Municipality

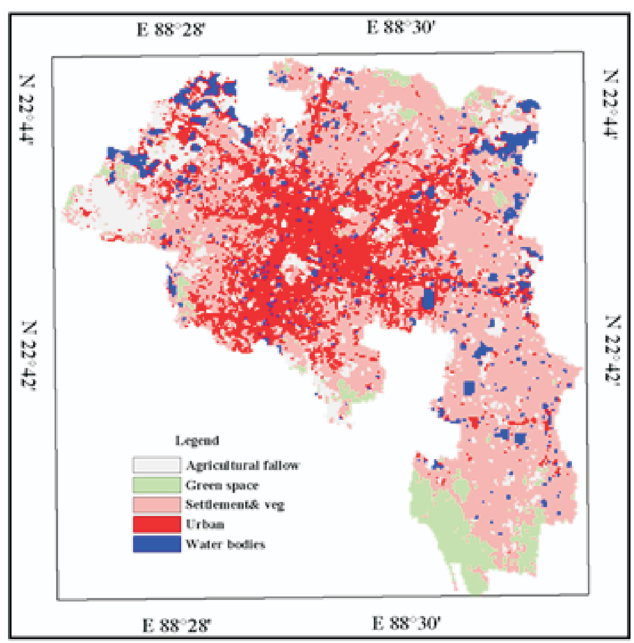

Fig. 2: Landuse / Land Cover Map of Barasat (2011)

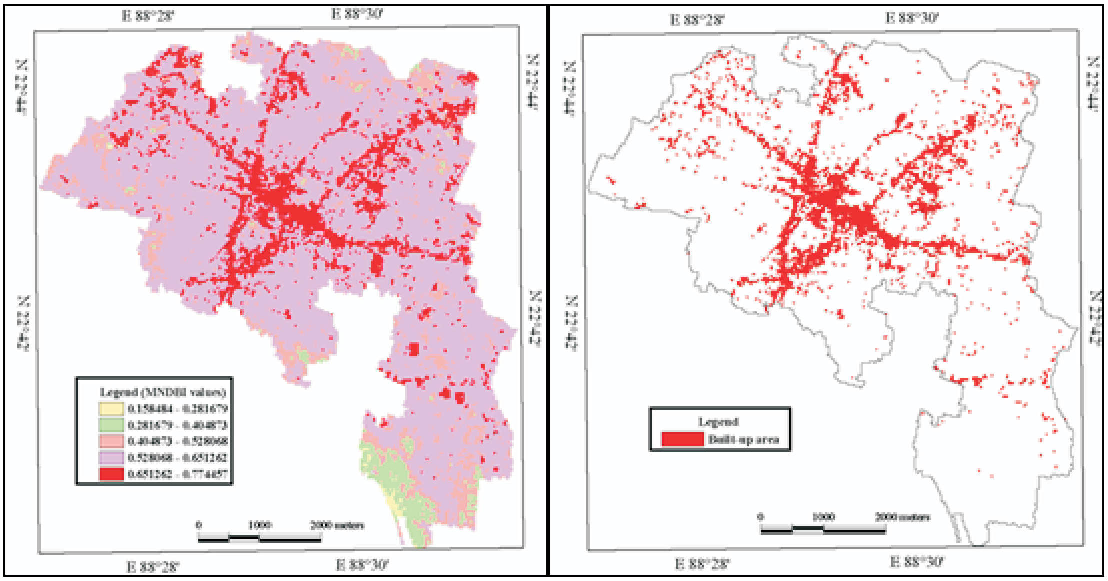

Fig. 3: Left: Modified Built-up Index (MBI) and right: Extracted Built-up Area of Barasat

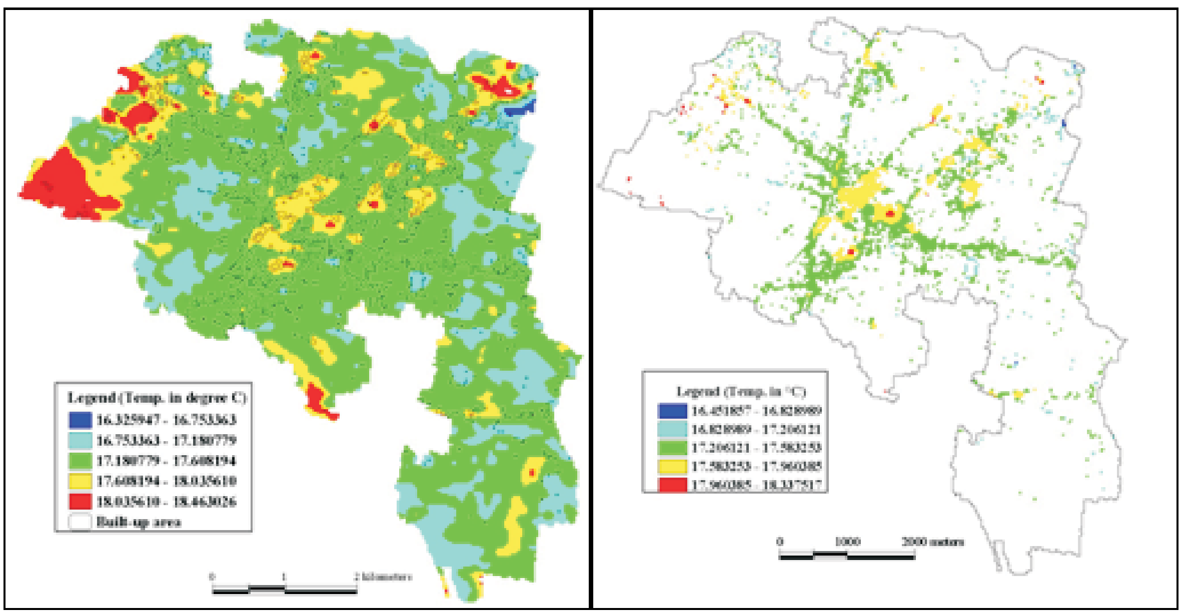

Fig. 4: Left: Overlay of Built-up Area over the LST Map of Barasat (2011) Right: LST of the Built-up Area of Barasat (2011)

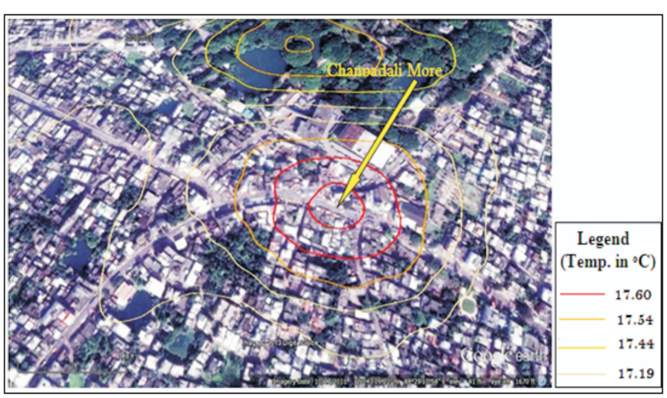

Fig. 5: Heat Island at Chanpadali More (centre of Barasat Municipality)

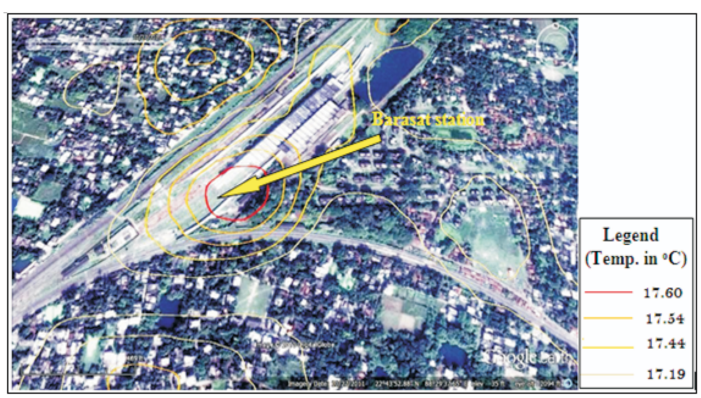

Fig. 6: Heat Island near Barasat Station

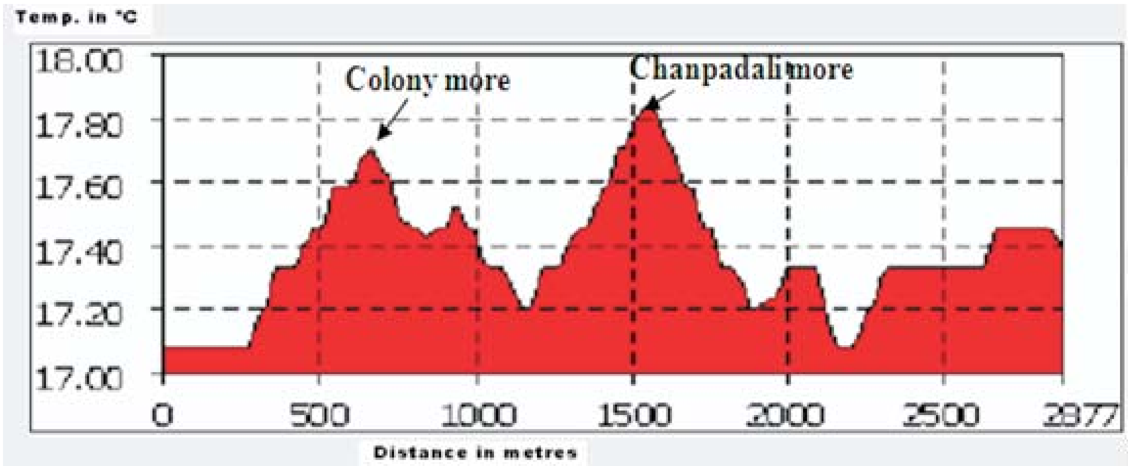

Fig. 7: Heat Islands at Chanpadali and Colony Crossings (central part of Barasat)

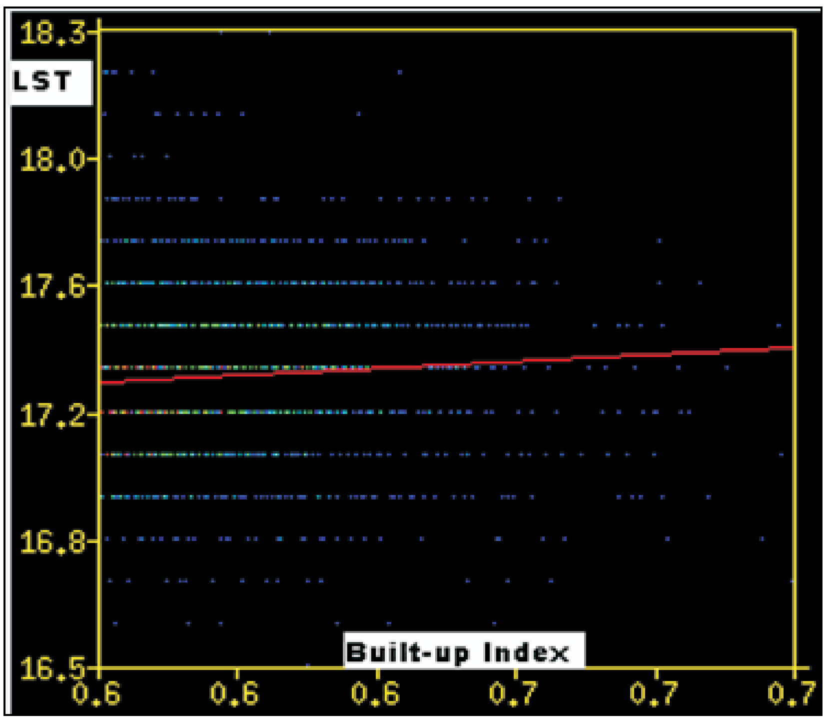

Fig. 8: Relation between Built-up Index and LST of the Extracted Built-up Area of Barasat

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