Assessment of Urban Heat Island Effect in Guwahati—A Remote Sensing Based Study

Juri Borbora, Apurba Kumar Das, Rajesh Kumar Sah and Nabajit Hazarika

Abstract The manifestation of effects of urbanization on the thermal environment of a city is often related to Urban Heat Island (UHI) by various studies. The presence of abnormal warmth in urban areas as compared to rural surroundings is defined as UHI. Satellite images in thermal infrared can be used for assessing thermal environment as well as for defining Urban Heat Islands (UHIs) in urban areas. In this chapter, Guwahati city and its surrounding areas have been studied to observe the changes in the thermal environment that has occurred between the years 1989 and 2010 by means of satellite images provided by Landsat Thematic Mapper (TM) onboard Landsat 5. A range of influences have been investigated in the form of relationship between Normalized Difference Vegetation Index (NDVI) and Radiant Surface Temperature (Ts) to see the influence of sensible heat flux and urban density over the urban vegetation as an indicator of modified temperature regime over the years. The study tried to quantify the UHI phenomenon in the city by measuring Urban Heat Island Intensity (UHII) using remote sensing technique. The objective of the study was to quantify changes in the urban thermal environment of Guwahati, a rapidly growing city of Northeast India, which will help in studying various effects of urbanization in future.

1 Introduction

Urban Heat Island (UHI) is a phenomenon where surface and atmospheric modifications due to urbanization generally lead to a modified thermal climate that is warmer than the surrounding nonurbanized areas (Voogt and Oke 2003). UHI affects energy demand, human health, and environmental conditions related to pollution dispersion (Harlan et al. 2006; Crutzen 2004). Atmospheric heat island may be defined for the Urban Canopy Layer (UCL), the layer of the urban atmosphere extending upward from the surface to approximately mean building height.

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The canopy-layer urban heat island is typically detected by in situ sensors at standard meteorological height or traverse of vehicle-mounted sensors. The Urban Boundary Layer (UBL) is the layer that extends above the UCL and is influenced by the underlying urban surface. The boundary-layer level urban heat island is detected by the specialized sensor platforms like tall towers, radiosonde, low flying planes, or tethered balloon flights. Thermal remote sensors observe the Surface Urban Heat Island (SUHI), or more specifically they “see” the spatial pattern of upwelling thermal radiance received by the remote sensors (Voogt and Oke 2003). Thus, thermal remote sensing of urban surface temperature is a special case of observing land surface temperature which varies in response to the surface energy balance. Consequently, the resultant surface temperature incorporates the effects of surface radiative and thermodynamic properties. It is known that heat islands of the UBL and the UCL are larger at night, while, SUHIs are larger during the day (Roth et al. 1989).

Three major applications of thermal remote-sensing have been put forward by Voogt and Oke (2003). The first approach includes examining the spatial structure of urban thermal patterns and urban surface characteristics, while, the second approach considers the relation between atmospheric heat islands (UHIs of UBL and UCL) and SUHI. The third approach is centered around studying urban surface energy balances by coupling urban climate models with remotely sensed data. In this chapter, the first approach of the thermal remote-sensing technique has been used to examine the relationship between the spatial structure of the urban thermal pattern of Guwahati and urban surface characteristics.

Normalized Difference Vegetation Index (NDVI) has long been used as an indicator of the urban climate. Higher values of NDVI typically indicate a larger fraction of vegetation in a pixel. The amount of vegetation determines LST by latent heat flux from the surface to the atmosphere via evapotranspiration. Lower LSTs are found in areas with high NDVI. The negative correlation between NDVI and LST is valuable for urban climate studies (Yuan and Bauer 2007). It has been used for assessing the influence of urban environment over observed minimum temperature (Gallo et al. 1993). Thermal responses of urban land cover types between day and night and the relation between land cover radiance and vegetation amount using NDVI have been studied using the data from Advanced Thermal and Land Application Sensor (ATLAS) (Lo et al. 1997). In this chapter, an attempt has been made to investigate the changes occurring in the NDVI values of the study area (Fig. 1) as compared to changes in the LST over a period of 21 years, i.e., 1989–2010.

1.1 Study Area

Guwahati, (26° 10′ 45″N, 92° 45′ 0″E) being a gateway to the northeastern region of the country has undergone a rapid urbanization change in the past decade. The urban area is around 262 km^2 and population of about 12 lakhs (2011 census), the population is projected to grow up to 21.74 lakhs by 2025 (GDMA 2009).

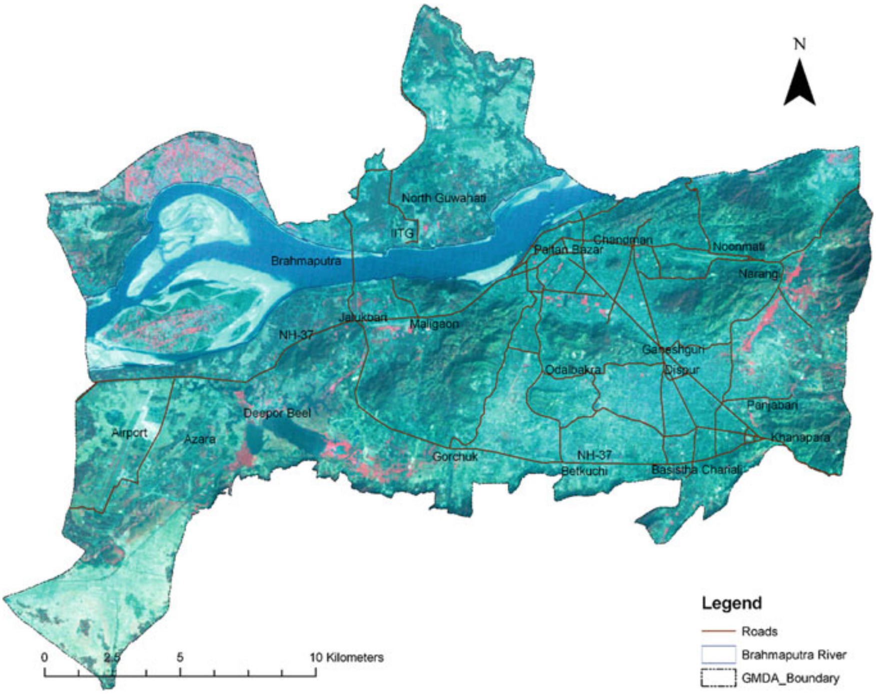
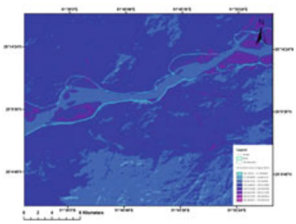


Fig. 1 Spatial extent of greater Guwahati

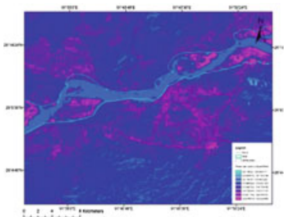
A considerable increase in the density of the population has occurred over the last decade that has resulted in expansion of urban areas into suburban extents. Replacement of natural vegetated areas with dry impervious surfaces, use of high heat capacity and low surface reflective building materials, reduced turbulent heat transfer due to street canyon geometry, and increased anthropogenic heat emission into the urban atmosphere are generally found to modify the thermal regime of a city. Presence of most of these factors in a city like Guwahati is believed to manifest itself in the form of observable "UHI" in coming years.

2 Materials and Method

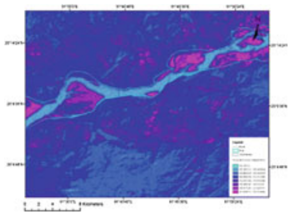
A pilot study was done with the thermal maps prepared from Landsat images of 1991 (TM, 26/11/1991), 2002 (ETM+, 17/02/2002), and 2006 (ETM+, 26/10/2006) to get an impression of changes occurring to the thermal environment of Guwahati city (Fig. 2). NDVI values are subject to seasonal variations. Additionally, it is more convenient to study the thermal modification of atmosphere through LST if seasonal variations are kept to minimum. Both of these observations have motivated us to search for Landsat images of the study area of the same season. Finally,



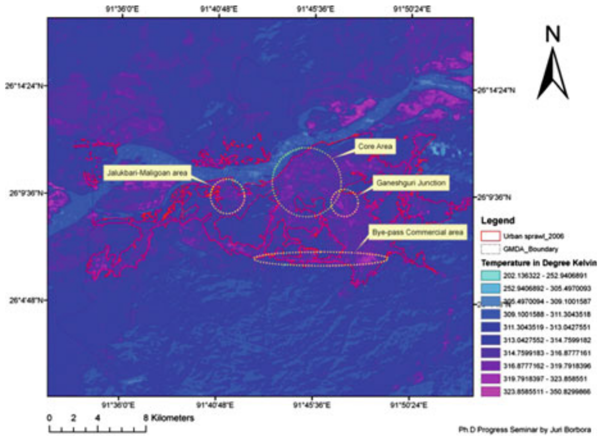
Thermal map of Guwahati for the year 1991(26/11/1991)



Thermal map of Guwahati for the year 2006 (26/10/2006)



Thermal map of Guwahati for the year 2002 (17/02/2002)



Overlay of urban sprawl boundary of Guwahati and the thermal of 2006

Fig. 2 LST retrieved images for the years of 1991, 2002, and 2006

Landsat TM images for the month of January for the years of 1989, 2000, and 2010 have been used for the study. The study area is covered under a 170 × 183 km scene (path 137, row 42). For all the years, band 6 was used for thermal analysis, while, bands 4 and 3 have been used for the calculation of NDVI.

1. **Calculation of Normalized Difference Vegetation Index (NDVI)**:

NDVI was calculated by the following formula:

$$\mathrm{NDVI} = \left(\frac{B4 - B3}{B4 + B3} + 1.0\right) \times 100.0,$$

where

$B4$ Reflectance measured in near-infrared wavelength.
$B3$ Reflectance measured in red wavelength.

2. **Retrieval of Surface Temperature (Ts)**

The thermal band (band 6) of TM was converted to Ts through the following steps (Chander and Markham 2003):

(a) ***Conversion of Digital Number (DN) to Spectral Radiance (L_λ)***
Conversion of the image DN values to spectral radiance is carried out using the gain and offset values given in the image header file (Eq. 1). Thus,

$$L_\lambda = ((L_{\mathrm{MAX}} - L_{\mathrm{MIN}})/(\mathrm{QCAL_{MAX}} - \mathrm{QCAL_{MIN}})) \\ * (\mathrm{QCAL} - \mathrm{QCAL_{MIN}}) + L_{\mathrm{MIN}}, \quad (1)$$

where $\mathrm{QCAL_{MIN}}$ = 1, $\mathrm{QCAL_{MAX}}$ = 255, and QCAL = Digital Number L_{MIN} and L_{MAX} = spectral radiance for band 6 at DN = 0 and 255.

(b) ***Conversion of Spectral Radiance to Brightness Temperature***
The TM thermal band data can be converted from spectral radiance to Brightness Temperature (BT) which assumes surface emissivity = 1 (Eq. 2)

$$\mathrm{BT} = K2/\ln(K1/L + 1), \quad (2)$$

where

BT Effective at-sensor brightness temperature in kelvin
$K1$ Calibration constant 1 [W/(m^2 sr μm)] (607.76)
$K2$ Calibration constant 2 in K (1260.56)
L Spectral radiance at-sensor [W/(m^2 sr μm)]

(c) ***Emissivity Correction***
Corrections for emissivity differences were carried out by land cover type by ratioing the BT image with the classified image in which the pixel values for the land cover class were replaced with the corresponding emissivity value. Thus, the emissivity corrected surface temperature (Ts) is derived by Eq. (3).

$$\mathrm{Ts} = \mathrm{BT}/[1 + (\lambda\mathrm{BT}/\rho)\ln\varepsilon], \quad (3)$$

where

λ Wavelength of emitted radiance (11.5 μm)
ρ hc/K (1.438×10^{-2} mK)
BT Brightness temperature
ε Spectral surface emissivity

(d) ***Generation of the Land Surface Temperature Image***:
By conversion of the Digital Number value to the spectral radiance values and further conversion to the BT values, a BT image in kelvin has been generated. After doing emissivity corrections, land surface temperature could be generated that directly depicted the temperature variations present over the urban areas as compared to the nonurbanized and the forest area.

3 Results and Discussion

1. **Normalized Difference Vegetation Index**:

NDVI values are generally expressed in the range of −1 to +1. A value of +1 generally depicts the highest value of NDVI indicating good health of vegetation, while −1 depicts the lowest value indicating the absence of any vegetation growth within the area. There is a considerable change observed in the NDVI values from 1989 to 2010 in and around Guwahati. In the NDVI image of 1989, we see that the lowest value of NDVI is in the range of −0.5 to −0.3. It was observed over the river Brahmaputra which could be due to the nonexistence of live vegetation in the freely flowing water. Riverine sand showed a low NDVI value in the range of −0.17 to 0. The highest values in the range of 0.33 to 0.5 were observed over parts of Khanapara, southeastern fringe of Deepor Beel, few areas within Azara and Plashbari showing the presence of thick green vegetation. The core city areas of Panbazar, Fancy Bazaar, Ganeshguri, and Chandmari areas showed relatively low NDVI values in between −0.67 and 0 depicting less greenery and more nonphotosynthesizing matter similar to sand which is most probably bare open land, roads, and concrete. Other areas showed moderate NDVI range of 0–0.67. In 2000, though the NDVI range for the city remained same, newer areas like Jalukbari, Maligaon, Noonmati, Naarengi, parts of Plasbari, Azara, Basistha Chariali, Betkuchi, Gorchuk, and North Guwahati were within the low NDVI range of −0.67 to 0, probably due to the removal of green areas for development activities. During 2010, low NDVI values in the range of −0.67 to 0 were not only present in the urban settlement areas but also had penetrated well into the suburban extents which were observed to be relatively greener in earlier two occasions. Thus, urban extension to accommodate rapid growth during the last decade could be well observed by decreased NDVI values over the settlement areas in 2010 as compared to 1989.

2. **Change in the Land Surface Temperature**

Like other tropical cities (Devadas and Rose 2009; Emmanuel 2003), careful comparison of thermal maps of 1991, 2002, and 2006 in the pilot study revealed that Guwahati too does not have a single UHI but has a collection of small UHIs separated by cooler areas. During the detailed study following the above, it was observed that almost uniform temperature regime prevailed within the study area during the year 1989 (Fig. 3). Except for a few places with riverine sand, no other place showed very high temperature as compared to rest of the surrounding. However, in the year 2000, it was observed that few pockets of land within the extent of the study area have shown warming up. These include areas like Azara, Polasbari, Betkuchi, Fatasil, Basisitha, Paltan bazaar, and North Guwahati. Urban Heat Island Intensity (UHII) of around 12 °C has been found in the year 2000. In the year 2010, it was observed that boundaries of the areas with high temperature have become more diffused and have brought more areas into its realm. However, UHII of around 5 °C could only be observed during this year. Warming up of the rural areas as relative to the previous years could be one of the reasons behind such a scenario.

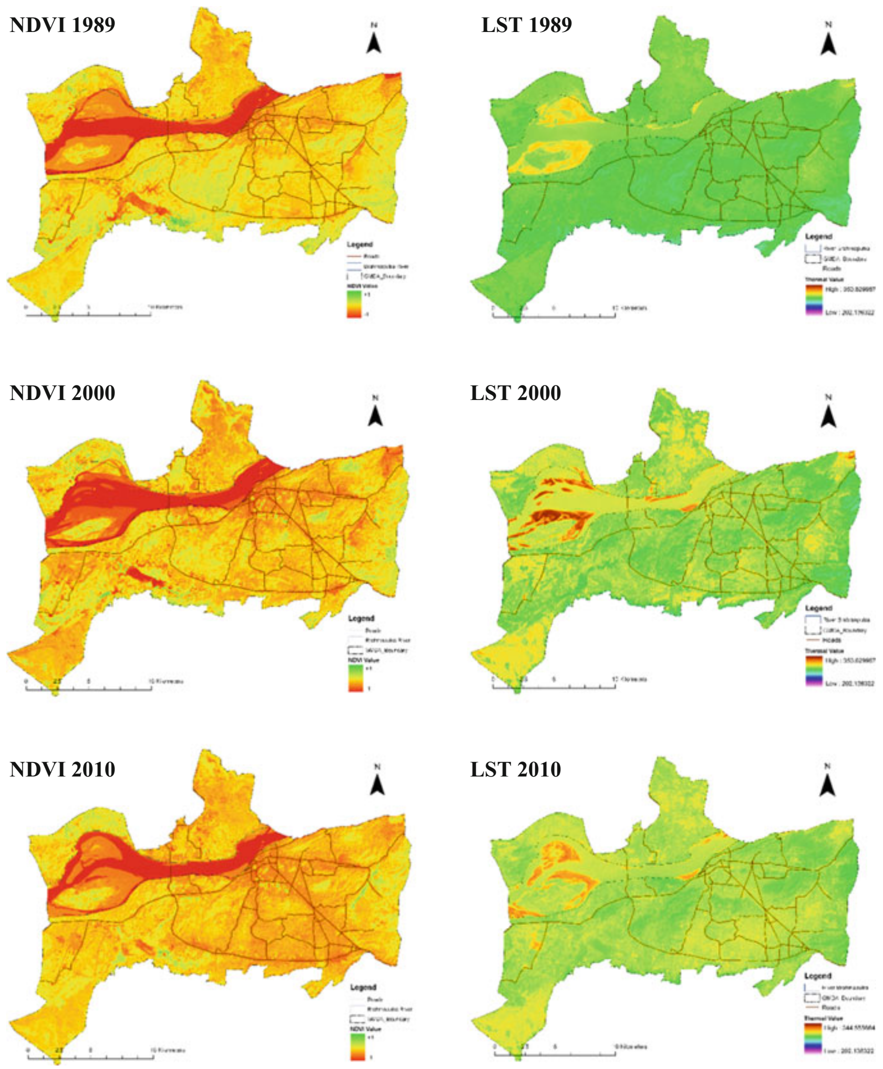


Fig. 3 NDVI and LST retrieved images for the years of 1989, 2000, and 2010

4 Conclusion

Relatively high temperature is found over Guwahati City as shown in the LST image of 2010 as compared to the one in 1989 (Fig. 3) where the average high temperature within the city was found mostly in certain urbanized pockets. The increased intensity of the surface layer temperature implies the presence of thermal anomaly in the form of UHI within its urban area. This can be attributed not only to the transition of urban landforms from vegetative cover to buildup areas but also as a cumulative effect of additional heat generation due to increased anthropogenic activities as a result of urbanization over the years. The urbanization has also caused an additional stress on the nearby vegetation cover as depicted by NDVI images which is often regarded as the representative of the vegetation vigor and expanse. The scenario within the urban area has much worsened during 2010 when the urbanization level had increased considerably. To improve the scenario, more plantation activities could be undertaken at relatively vulnerable core urban areas of Paltan bazaar–Fancy bazaar. Some stringent conservation measures are needed in Azara and near bypass area of Basistha Chariali to Gorchuk which are likely to witness more urbanization in future.

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