



Impact of Green Spaces on the Urban Microclimate through Landsat 8 and TIRS Data, in Varanasi, India

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Abstract. Rapid urbanization is degrading urban environment quality day by day globally. Urban environment temperature is slowly rising globally, and some measures are required to mitigate it. Urban microclimate can be regulated by planting urban greenery. This study makes an attempt to assess the effect of urban greenery on land surface temperature (LST) for the improvement of micro-climatic conditions in Varanasi city, India. The influence of an urban heat island is studied using the Landsat-8 OLI/TIRS data in 2017 as a case study of Varanasi city, India. The spatial distribution of LST in the urban area is retrieved to describe their local effects on urban heat island (UHI). The correlation among LST, the normalized difference build-up index (NDBI), and the normalized difference vegetation index (NDVI) are examined to explore the influences of the urban granary and the build-up land on urban microclimate. Results exposed that the central portion of Varanasi displayed the highest surface temperature compared to the surrounding open area, the areas having dense built-up displayed higher temperatures, and the areas covered by vegetation and water bodies exhibited lower temperatures. This study shows that urban green space will help to mitigate the urban microclimate and it is important for the sustainable development of urban environments as well as to provide healthy quality of life to the urban dwellers.

Keywords. *LST, NDVI, NDBI, Varanasi, GIS, remote sensing, urban microclimate*

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Introduction

The urban climate is defined as a set of climatic conditions that prevails in a large metropolitan area and that differs from the climate of its rural surroundings region (Landsberg, 1981). A microclimate is a local atmospheric zone of a small-scale area, where the climate varies from the neighboring area. It comprises of local variations in humidity, wind, solar radiation, humidity, and temperature as a result of several factors. City microclimate factors are strongly affected by the urban heat island (UHI) phenomena, therefore remotely sensed data are more suitable than atmospheric data for analyzing the impact of urban greenery on microclimate zone of the urban area. UHI refers to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural area

(Kim, 1992). More specifically, the UHI phenomenon is influenced by the reduced vegetation in city areas, properties of city materials, anthropogenic heat, weather, urban geometry, and location. Some of the main dangerous impacts of UHI comprise of higher energy consumption, high emissions of air pollutants and greenhouse gases, compromised human health and comfort, and impaired water quality. Urbanization processes change the land-use land-cover pattern of the urban environment, which replace the natural land-cover types with common urban construction materials such as concrete, asphalt, stone, brick, and metal and has significantly changed the urban environment, by creating extreme stress.

Anthropogenic activities are extremely modifying the urban granary where it directly contributes to change urban microclimate through a variety of procedures. These include the plantation or cutting of surface vegetation and changes in the land surface, which affect urban microclimates by creating changes in the urban surface energy budgets.

The urban natural land cover was changed into built-up surfaces that absorb incoming solar radiation during the day and then re-radiate it at night. This is particularly true in the case of the holy city of Varanasi, where massive agricultural land, greenery, parks, open fields, each year are converted to urban land uses. Thus, the seriousness of UHI phenomena cannot be ignored and the mitigation approach should be applied to regulate the UHI effects in the large and small-scale urban environment. Thus, it is necessary to assess the influence of urban greenery on the urban microclimate.

Fast urbanization leads to reduced vegetated areas, increased land surface temperature, and changed urban microclimate (Nor et al., 2013). However, temperatures in the vegetated area and its surrounding keep the temperature lower than the core urban developed area. Furthermore, maturity of the greenery will be considered as a main parameter to ensure the heat is lower in urban areas through its shadow and transpiration. Furthermore, urban greenery also acts as a natural agent against air pollution in the urban environment (Buyadi et al., 2015).

Spatiotemporal analysis of urban climate using geospatial technology is acceptable as a technical methodology in analyzing the urban environment, especially in combating the UHI effect for past, present, and future uses. This study aims to evaluate the relationship among LST and LU/LC in Varanasi, India. Therefore, the objectives of this paper are (1) to estimate LST for Varanasi city using Landsat-8 OLI/TIRS data in 2017 (2) to generate a land-use/land-cover map using supervised classification and (3) to analyze the relationship between land surface temperature and land-use/land-cover using linear regression

between land surface temperature and NDVI, NDBI.

Study Area

Varanasi is situated in the eastern part of the state of Uttar Pradesh, along with the left bank of the River Ganges. The total area under the wards is around 209.7 Km². The population of Varanasi municipal corporation is 1,198,491 (2011 Census). The study area stretches between latitude 25°14'50"N to 25°23'15"N and longitude 82°55'0"E to 83°03'11"E. Normally, Varanasi experiences a southwest monsoon with its characteristic three seasons: rainy, winter, and summer. During the rainy season, which stretches from the middle of June to the end of September, about 80–90% of the total annual rainfall is received with intermittent dry periods. The average annual rainfall is 1,009 mm. The mean daily maximum temperature ranges from 32°C to 34°C, and the mean daily minimum temperature remains at around 26°C (Varshney, 1971; Figure 1).

Data Used

The satellite images of Landsat 8 OLI and TIRS 1T data product of March 25, 2014 (Path/Row - 142/043) of the study area were obtained from United States Geological Survey (<http://earthexplorer.usgs.gov/>), at free of cost, which had been resampled into 30 m for all bands to match the Operational Land Imager (OLI) spectral bands before delivery. Wang et al. (2015) specified that data from the Landsat 8/TIRS Band 11 have large uncertainty and recommended using TIRS band 10 data as a single spectral band for LST assessment; for this purpose, the present study makes use of Landsat 8, Band 10 data for LST retrieval (Bendib et al., 2016). On the other hand, the information acquired from remote sensing satellites data is analyzed in image processing software, to calculate the land surface temperature. For this analysis, two pieces of software, ArcGis10.1 and ERDAS IMAGINE 2015, is mainly used. Assessment of land surface temperature can be achieved through a thermal infrared remote sensing data. It can record the apparent temperature of the earth's surface by measuring the radiant energy exiting its surface.

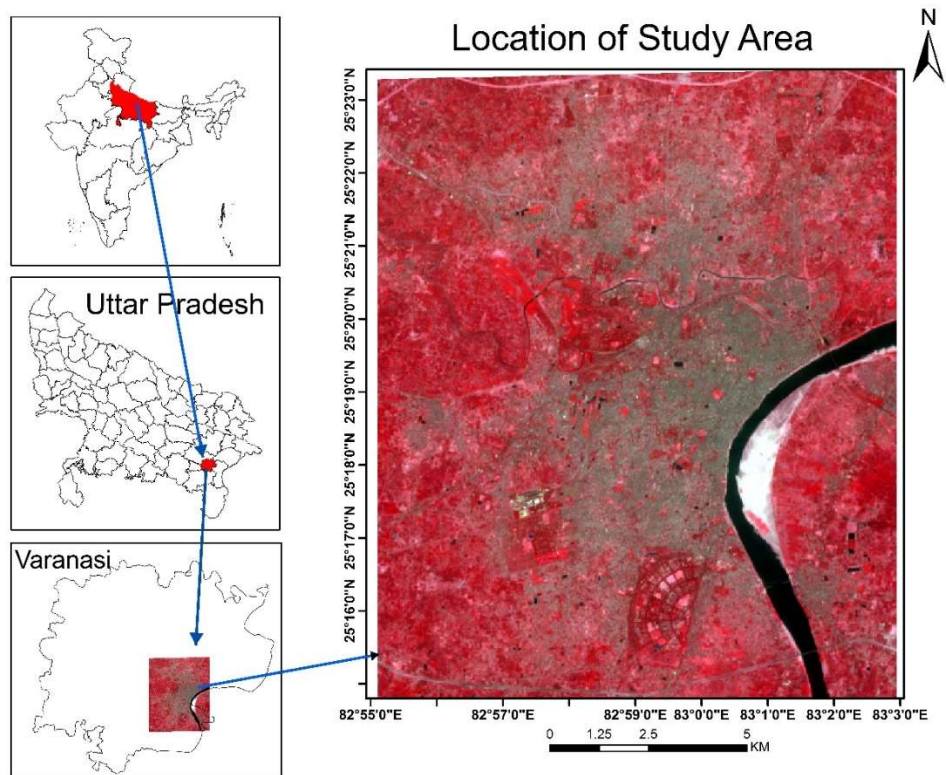


Figure 1: Location map of study area

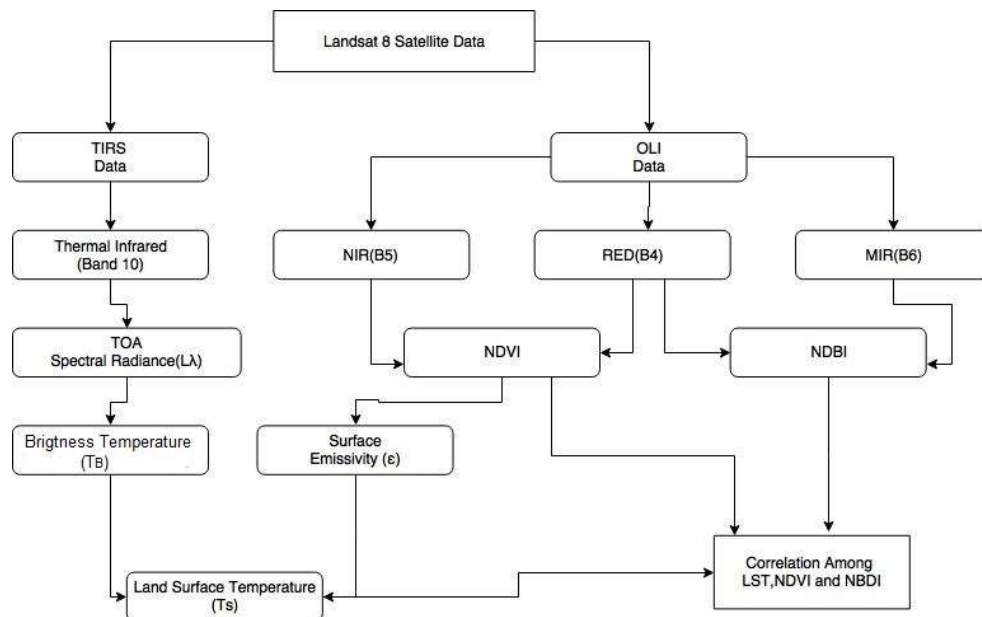


Figure 2: Flowchart of retrieving LST, NDVI, and NBDI from Landsat 8 image

Methodology

LST Extraction from Thermal Band

This research work mainly includes the following steps (Figure 2): conversion of pixel values of the Landsat thermal band to At-sensor spectral radiance, then transformed to At-sensor brightness temperature and LST by following the procedure described by Weng et al. (2004), was adopted for retrieval of land surface temperature (LST).

TOA (Top of Atmospheric) Spectral Radiance

TOA spectral radiance was calculated by multiplying the multiplicative radiometric rescaling factor of TIR bands with its corresponding TIR band and adding in the additive rescaling factor.

$$L_{\lambda} = M_L * Q_{cal} + A_L \quad [1]$$

where L_{λ} is the spectral radiance in watts/(m⁻² srad⁻¹ μm⁻¹); M_L is the band-specific multiplicative rescaling factor obtained from the metadata (3.3420E-04); A_L is the band-specific additive rescaling factor obtained from the metadata (0.10000); Q_{cal} is the DN value for the quantized and calibrated standard product pixel of band 10.

Brightness Temperature

Latif (2014) mentioned in his research that brightness temperature is the electromagnetic radiation traveling upward from the top of the earth's atmosphere. After getting the radiance value, it should be converted to brightness temperature (BT) with the help of the following equation.

$$T_{10} = \frac{K_2}{L_n \left(\frac{K_1}{L_{\lambda}} \right) + 1} \quad [2]$$

where T_{10} is the brightness temperature; K_1 and K_2 are thermal conversion constants which can be found in the metadata file of the Landsat image; L_{λ} is top of atmospheric radiance.

Land Surface Temperature (LST)

The brightness temperature was converted to kinetic temperature, or land surface temperature as described by Equation 3 (Artis and Carnahan, 1982).

$$T_S = \frac{T_B}{1 + \left(\lambda \times \frac{T_B}{\rho} \right) \ln \varepsilon} \quad [3]$$

where T_S land surface temperature (LST) in Kelvin, λ (11.5 μm) is the emitted radiance wavelength (Markham and Barker, 1984), the coefficient $\rho = 0.01438$ m K is generated from the equation $\rho = (h * c) / \sigma$ in which $h = 6.626 \times 10^{-34}$ J s is the Planck's constant, $C = 2.998 \times 10^8$ m/s is the velocity of light, and $\sigma = 1.38 \times 10^{-23}$ J/K is the Boltzmann constant, and ε is the surface emissivity ranges between 0.97 and 0.99.

Emissivity has been calculated by using following equation:

$$\varepsilon = 0.004 \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right)^2 + 0.986 \quad [4]$$

The brightness temperature is converted to LST according to the Planck equation (Artis and Carnahan, 1982; Weng et al., 2004).

Conversion of LST from Kelvin to Degrees Celsius

For simplicity of understanding of this temperature, the above derived LSTs' unit was converted to degrees Celsius using the relation of °C equals 273.15 K (Pal and Ziaul, 2016).

Derivation of NDVI

Landsat 8 is calculated from reflectance measurements in the red and near infrared (NIR) portion of the spectrum (Liu and Zhang, 2011). The NDVI is expressed as in Equation 5: where NIR = Band 5 (For Landsat 8) and R = Band 4 (For Landsat 8).

$$NDVI = \frac{NIR - R}{NIR + R} \quad [5]$$

Derivation of NDBI

Landsat ETM and Landsat 8 is calculated from reflectance measurements in the red and mid-infrared (MIR) portion of the spectrum (Liu and Zhang, 2011). The NDBI is expressed as in Equation 6: where MIR = Band 6 (for Landsat 8) and R = Band 4 (for Landsat 8).

$$NDBI = \frac{MIR - R}{MIR + R} \quad [6]$$

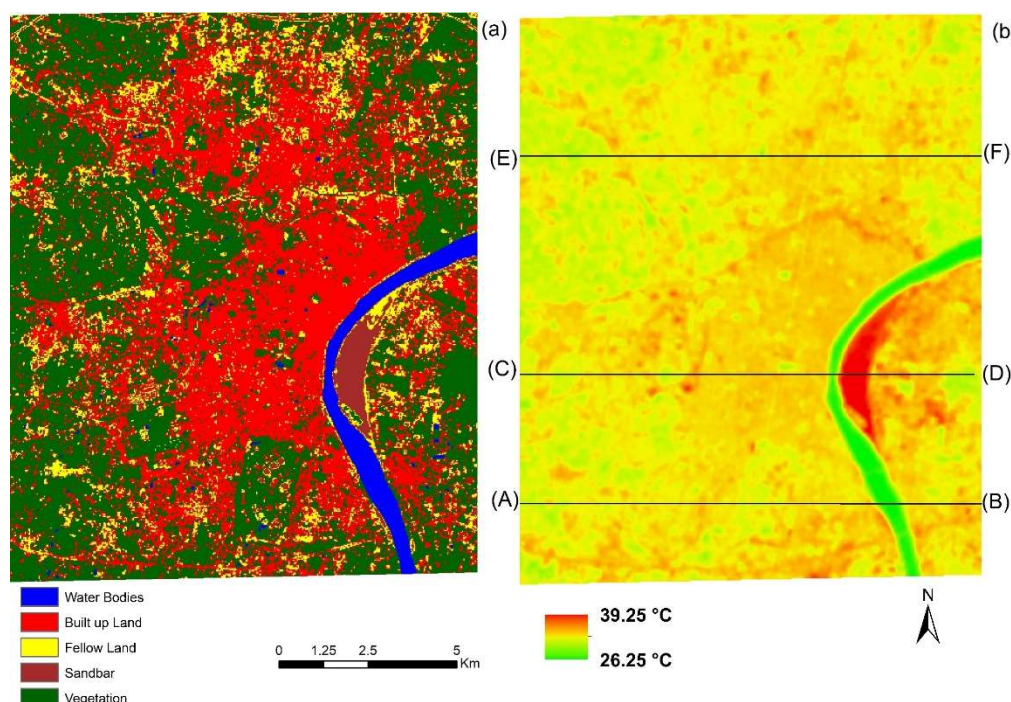


Figure 3: (a) Land-use/land-cover map of Varanasi City, 2017; (b) LST map of Varanasi, March 2017, three cross sections has been made across the study area

Land-Use/Land-Cover Map Preparation

A supervised classification scheme has been used for the process of image classification in which training sets were selected for image classification using a Maximum Likelihood classifier. One hundred and twenty spectral signatures from the study images have collected and merged for detecting each individual class use class properly. Image classification was used to define the land-use/land-cover types into five classes, namely, Settlement, Water body, Vegetation, Fallow lands, and Sandbar have been categorized. The image classification is done by using supervised classification techniques and accuracy assessment has been made through a confusion matrix. A total of 240 sample sites from Google Earth and ground verification were selected for accuracy assessment. Overall accuracy of the LULC map was 89.56% and Kappa coefficient was 0.857.

Results and Discussion

Relationship between LST and Land-Use/Land-Cover

The relationship between the land surface temperature values and land-use and land-cover classes is analyzed in this section. Through the visual interpretation, it is found that land surface temperature and LU/LC are related to each other (Figure 3). It is observed that urbanization and thermal environment of the city is mainly associated with urban build-up and barren land and decreased with vegetation cover (Figure 3a and 3b). When land use and land cover of the area changes, then the LST of the area also changes. It means that land surface temperature distribution pattern is depending on the LU/LC categories. Remote-sensing-based land surface temperature records the radiative energy emitted from the ground surface, including building roofs, paved surfaces, vegetation, bare ground, and water (Voogt and Oke, 2003). The result revealed that most urban built-up lands were located in the middle part, and high LST value are also associated with the central part of

the city, which is a core urban setup of Varanasi city and has a high population density (Figure 3a). To represent the land-use/land-cover wise land surface temperature, three cross sections were made across the Varanasi city AB, BC, and CD (Figure 3b and Figure 4). For a selected year, urban built-up land exhibits one of highest surface radiant temperature 34.5°C, followed by fallow land 33.0°C. One sandbar presented near to the River Ganges, showed the highest temperature (38.6°C), which gets heated directly by the sunlight. The lowest radiant temperature of 26.8°C is observed in waterbodies (rivers, ponds). Green space shows a significantly low radiant temperature because the amount of heat stored within urban vegetation (parks, trees, etc.) is reduced through transpiration. The average temperature of the vegetation area was observed at 31°C. Overall, our results show that

in Varanasi, the mean LST of a built-up area was 3.5°C higher than the mean LST of green space (forest, grassland, and cropland; Table 1 and Figure 3). This study observed that dense trees, matured green parks, and other urban vegetation can potentially reduce urban temperature to its neighboring area.

Table 1

LU/LC types and their LST values

LU/LC Class	Average LST value (°C)
Built up Land	34.5
Fallow Land	33.0
Sandbar	38.6
Vegetation	31.0
Waterbody	26.8

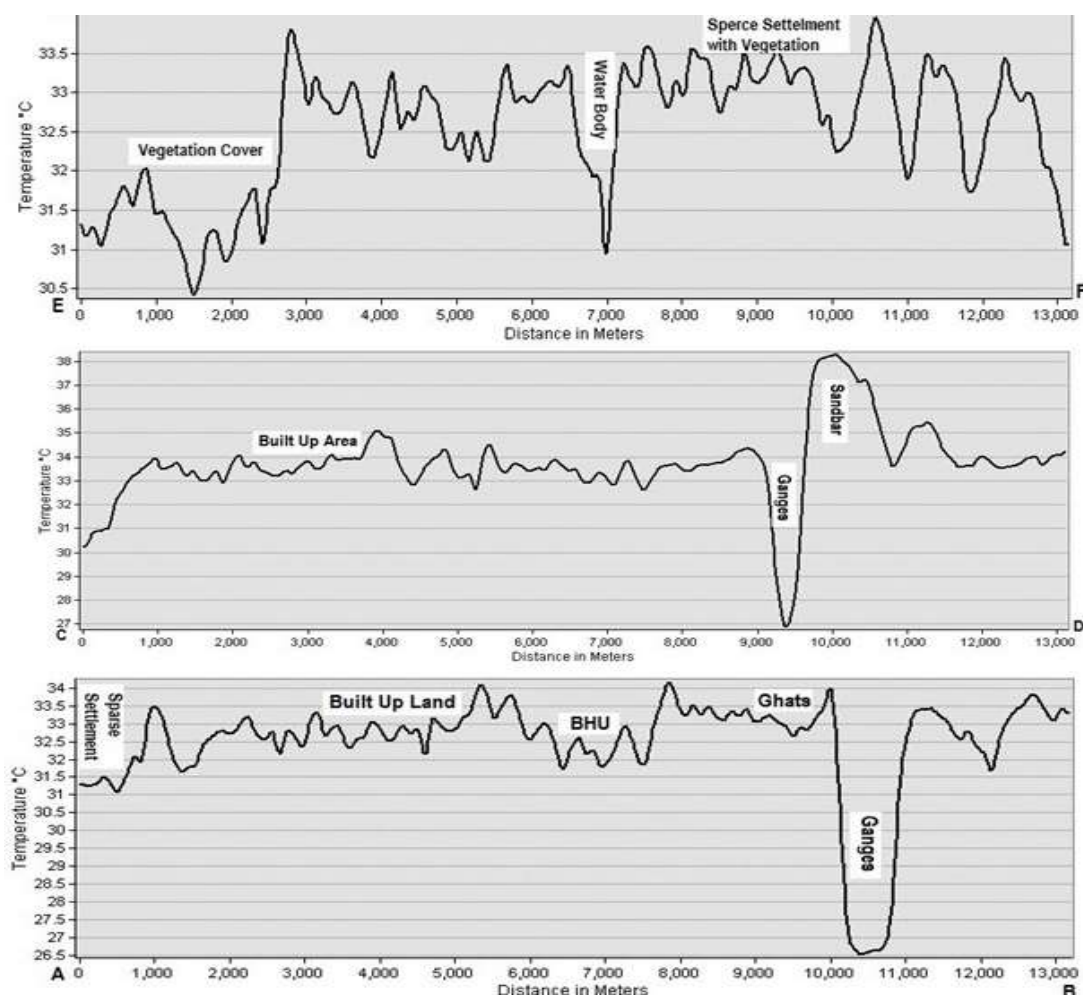


Figure 4: LST Profile (A-B, C-D, E-F) drawn over LST Map of March, 2017

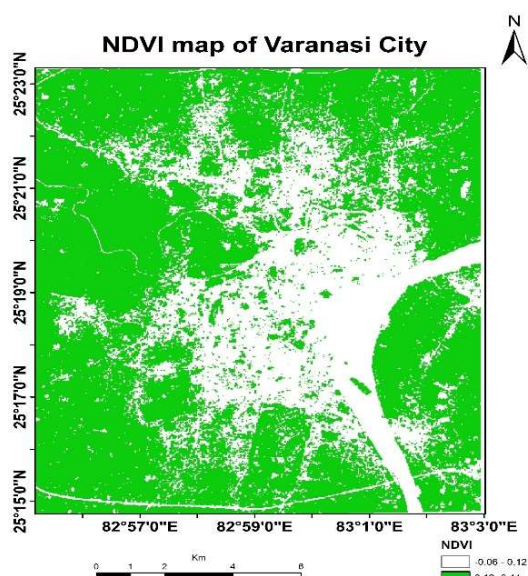


Figure 5: NDVI map of Varanasi city, March 2017

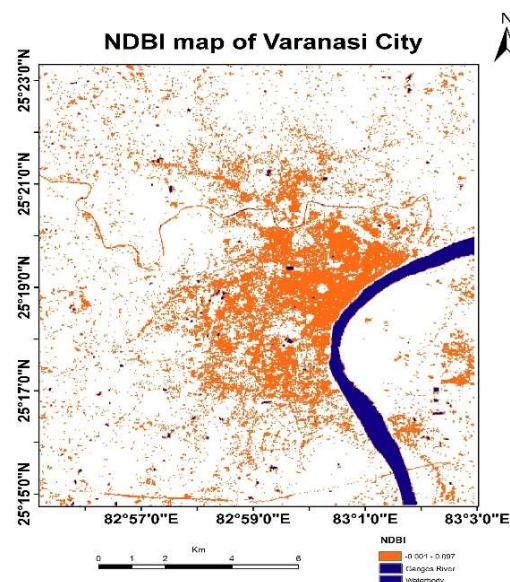


Figure 6: NBDI map of Varanasi city, March 2017

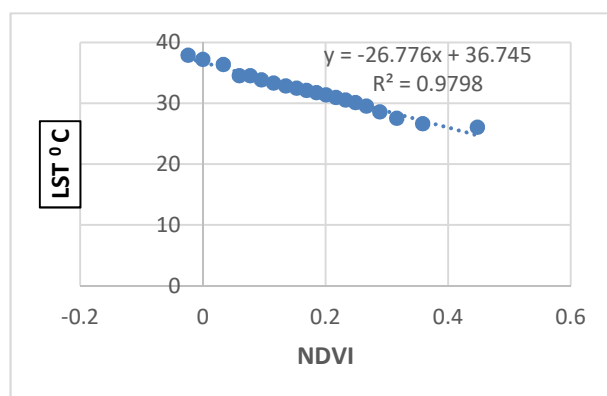


Figure 7: Relationship between LST and NDVI

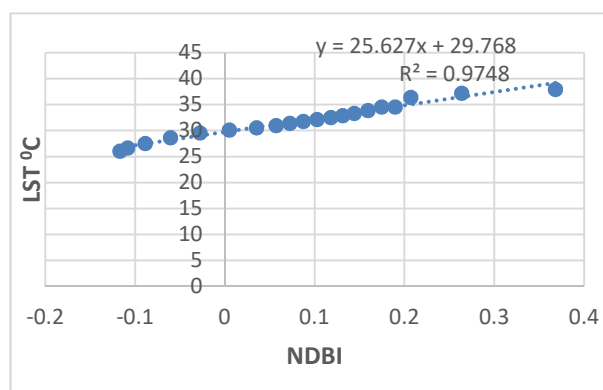


Figure 8: Relationship between LST and NBDI

Relationship between LST, NDVI, and NBDI

The results showed that the value of NDVI was located between -0.06 and 0.44. The high value of NDVI was distributed in the outskirts of the city. The low value of NDVI was mainly observed in urban and dense residential areas with less vegetation coverage (Figures 5-6). The results indicated that the vegetation covered areas weaken the effect of UHI (Liu and Zhang, 2011). Xiong et al. (2012) also found that high temperature anomalies are closely associated with built-up land, densely populated areas, and greatly industrialized zones.

The relationship between LST, NDVI, and NBDI was examined by using linear regression correlation analysis. For this, 40 ground control points were randomly tested to determine the correlation in the city. Based on these ground control points, a scatter plot was made between LST, NDVI, and NBDI (Figures 7 and 8). The relationship derived from the scatter plot shows high accuracy results since all correlation coefficients (r^2) were greater than 0.8 for regression analysis. From Figures 7 and 8, it can be clearly observed that there is a negative linear correlation between NDVI and LST (except water) and a positive linear correlation between NBDI and LST because built-up areas significantly absorb

more solar radiation than the surrounding rural areas. Kikon et al. (2016) also found that same result in their study, temporal changes in rising trends of urban heat islands (UHI). They concluded that the correlation between NDVI and temperature was negative but NDBI and temperature showed a positive correlation.

Conclusion

In this study, it is concluded that the spatial distribution of urban heat islands is mainly located in the central part of Varanasi city. The core of the city area experienced an average LST of 36.7°C, more than the surrounding rural area of 32.5°C. The areas with impervious surfaces, high population density, and low vegetation cover and human activities experienced high land surface temperature intensity. On the other hand, the low value of NDVI was mainly located in urban and high density residential areas. Correlation studies showed that the land surface temperature is negatively correlated with NDVI. LST and NDBI share a positive relationship. This finding assists in monitoring and mitigating the urban micro climate. LST, NDBI, and NDVI indices can be used to predict spatial characteristics of

the UHI and could be applied further to the establishment of environmentally friendly urban planning. Additionally, the presence of green spaces made important contributions to the regulation of the city climate, and green spaces increased humidity in the air and decreased the temperature, thus improving the air quality of surrounding urban microclimates. The important role played by green space as a temperature mitigating element is found. So, an urban climatic factor is a necessity to be considered as standards to perform sustainable development, as well as to mitigate urban heat island effects in the urban environment to provide better quality of life for urban residents. In addition, landscaping vegetation in an urban region will support to beautify the city environments and transform urban microclimates to make it health favorable for urban dwellers.

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