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Heat Island Analysis of Nagpur and Surrounding Area using Geomatics Techniques

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***Abstract*—In this paper, the urban heat island (UHI) effect is analyzed using the Landsat ETM+ data of Nagpur and surrounding area of 14 Dec 2006. Mono window algorithm is applied for retrieving the land surface temperature (LST). The correlation of normalised difference vegetation index (NDVI) and LST also analysed and it shows the green land can weaken the strength of LST and vice versa. The LST were correlated to different land use and land cover (LULC) class in the city. The result shows that the UHI effect occurs in central part of Nagpur.**

Keywords—Landsat ETM+, urban heat island, land surface temperature, normalised difference vegetation index, Nagpur.

INTRODUCTION

More than the 50% population living in the urban area, and in future this proportion is continue to grow (PRB, 2009). This population does lots of activity in the urban area, so due to these urbanization, industrialization there is a temperature difference between urban and surrounding area. The urban areas are found to be generally warmer than the surrounding rural parts (Oke ,1997) and this phenomenon known as, "urban heat island." An urban heat island (UHI) study using remotely sensed data (Quattrochi and Luvall ,1997) exhibits different characteristics compared to the measurements from sparse air-temperature observations. The Landsat ETM+ satellite data is one of the most widely used for LST retrieving because of its high resolution (60m) and free download availability from the website of global land cover facility (GLCF), which has one thermal infrared (TIR) band. This makes retrieving LST from a single band more difficult than from multiple thermal bands. In 2001, Qin *et al.* proposed a mono-window algorithm for retrieving LST using Landsat TM TIR band data (Qin et al 2001). The mono-window algorithm provided a simple and highly effective method for retrieving land surface temperatures for the analysis of urban heat island effect (Lu, 2009).

Study area and Data used: The data have been used for the study is Landsat ETM+ remote sensing data from Global Land Cover Facility (GLCF) website of dated 14 Dec 2006 of Nagpur and surrounding area. The secondary data is meteorological information taken from the weather underground website WU (2006), like rainfall, near surface air temperature, and calculated water vapour contents etc., Nagpur and surrounding area is selected for the study area, this is the city centrally located in India (between 21° 4'30" N to 21° 20'30" N and 79°0'0" E to 79°12'0" E). Fig 1 is the study area.

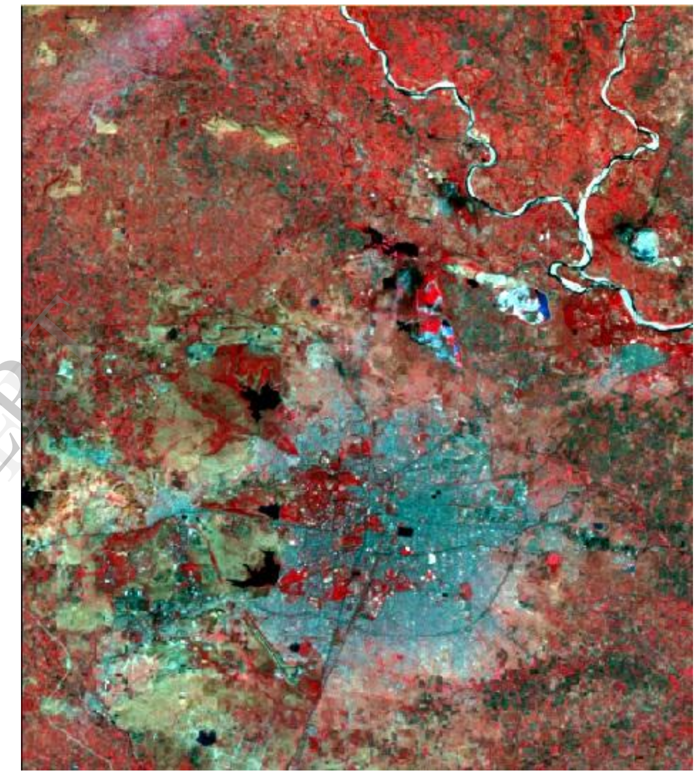


Fig. 1: Subset of Study area of Nagpur and surrounding area

Objective of Study:

- To apply the geomatics techniques useful in urban heat island analysis.
- To understand how the thermal remote sensing imagery can assist evaluation of land surface temperature of urban heat island.
- To demarcate distribution of heat island effect in urban area using the Remote sensing data.
- To establish the relationship between various land use land cover (LULC) classes with the temperature zones.

Data Preprocessing:

The preprocessing of ETM+ data have been performed using ERDAS imagine software. Each ETM+

independent band is composed into single band using the layer stacking tool of ERDAS imagine software. So in this way the all independent bands of ETM+ image is combined to multi band. Then after the geometric corrections was made to this multi band image. After that, with the help of image subset tool the study area of Nagpur and surrounding area is clipped. Following figure shows the above all steps: (Fig 2)

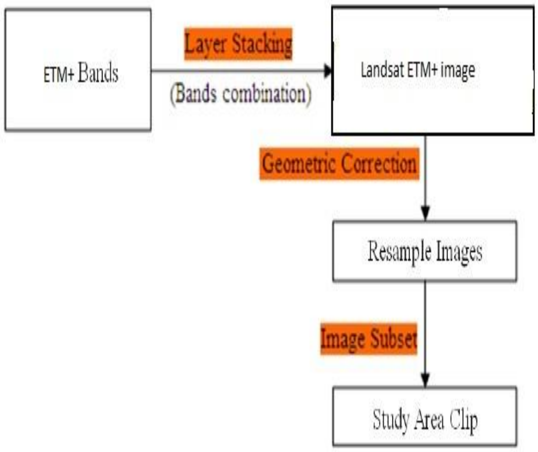


Fig. 2: The data preprocessing Procedures

METHODOLOGY

Qin *et al.* in 2001, proposed the mono window algorithm for retrieving LST from Landsat ETM+ 6 data. The mono window algorithm for LST only requires three parameters: transmittance, emissivity, and effective mean atmospheric temperature, to retrieve land surface temperature from Landsat ETM+ data. Spectral range used for band 6 is 10.4 to 12.5 µm records the radiation of earth surface.

So for finding the LST of Nagpur urban region, the Mono window algorithm is used in this study. The most important software used in the field of remote sensing is either ENVI or ERDAS Imagine, so for this study used software is ERDAS Imagine and their spatial modeller tool for finding the LST and a brightness temperature. So for this spatial modeller tool requires only few parameters like surface air temperature and water vapour content and these data is obtained from Indian meteorological department or local weather stations when the satellite passing on the same date. Now then these parameters will convert to transmittance and mean atmospheric temperature with the calculation or with the help of modeller tool. And the last one parameter is emissivity, this will obtained from the NDVI. The remaining values all be obtained from the Meta file of satellite image data.

Following Steps are required for retrieving LST.

1) Converting Digital number (DN) of ETM+ Data to Spectral Radiance:

Following Equation is used for converting the DN of ETM+ data to radiance

$$S_i=S_{min}+(S_{max}-S_{min})Q_{DN}/Q_{max}$$

where , S_i is the at sensor spectral radiance in ($MW.cm^{-2}.sr^{-1}.\mu m^{-1}$);

S_{max} is the maximum at sensor spectral radiance;

S_{min} is the minimum at sensor spectral radiance; Q_{max} represents the maximum digital number value of pixel and Q_{DN} represents the digital number value of pixel.

The data used for S_{min}, S_{max} and Q_{max} from Landsat ETM+ metadata file.

Now convert this Spectral radiance to brightness temperature it is nothing but the land surface temperature of the particular area in this Nagpur urban region.

2) Converting Spectral Radiance to Brightness temperature in Kelvin with the use of Plancks radiance equation as follows-

$$T_6=K_2/(LOG(K_1/S_i)+1)$$

Where, T_6 is the at satellite brightness temperature of ETM+ band 6 in ^oK, K_1 and K_2 are pre launch calibration constants of Landsat 7 ETM+.

$K_1=666.09\ MW.cm^{-2}.sr^{-1}.\mu m^{-1}$ and $K_2=1260.56\ ^oK$.

Now this is the brightness temperature of the particular area i.e., Nagpur urban region of date 14 Dec 2006 mens land surface temperature , now the study wants the actual temperature of the study area for this the Mono window algorithm is used .The data for the mono window algorithm is taken from the local weather station when the satellite passes from the Nagpur area on dated 14 Dec 2006 like rainfall, mean atmospheric temperature etc.

3) Converting Brightness temperature to LST:

i) Estimation of NDVI(Normalised Difference vegetation Index):

The normalised vegetation can be calculated using the band 3 and band 4 of Landsat ETM+ data i.e., Red and NIR (Near Infrared) band respectively. The NDVI is used for the vegetation information of particular area, the formula is as follows:

$$NDVI=(NIR-RED)/(NIR+RED)$$

Where, Where, RED stands for reflectance in Red wavelength region and NIR stands for reflectance in Near Infrared Region

ii) Estimation of Land surface Emmissivity:

The land surface emissivity can be calculated from the NDVI as follows:

When NDVI values from 0.157 to 0.727, Owen (1998) gave an equation-

$$E_i=1.0094+0.0047\ LOG(NDVI)$$

iii) Estimation of Water vapour Contents :

The water vapour content can be obtained from the data taken from Indian meterological department when the satellite passes over the Nagpur region on dated 14 Dec 2006 as follows:

$$W_i=0.0981*(10*0.6108*exp(17.27*(T_0-273.15)/237.3+(T_0-273.15))*RH)+0.1697$$

Where, W_i is the water vapour contents in (g/cm^2), T_0 is the near surface air temperature in ^oK, and RH is the relative humidity on dated 14 Dec 2006.

Once we have water vapour content then we can estimate the atmospheric transmittance from the water vapour content.

iv) Estimation of Atmospheric Transmittance;
Atmospheric transmittance can be calculated from the water vapour content with the help of following relationship as follows:

$$\Gamma_6 = 1.031412 - 0.11536 \times W_i$$

Where, Γ_6 is the atmospheric transmittance of Landsat ETM+ data and the W_i is the Water vapour content.

v) Estimation of Mean Atmospheric Temperature:
Mean atmospheric temperature can be calculated from the near surface air temperature which is taken from the IMD on dated 14 Dec 2006 and standard formulae for the Estimation of mean atmospheric temperature in table1:

Table 1. Calculation of mean atmospheric temperature.

Area	**Atmospheric temperature equation (T_a) (^{o}K)**
For Tropical region	$17.9769 + 0.91715 \times T_0$
Mid Latitude Summer	$16.0110 + 0.92621 \times T_0$
Mid Latitude Winter	$19.2704 + 0.91118 \times T_0$

According to the location of Nagpur, Following Equation is used for the estimation of mean atmospheric temperature:

$$T_a = 19.2704 + 0.91118 \times T_0$$

Where, T_0 is the near surface air temperature in (^{o}K).

vi) Estimating LST with the help of Mono Window algorithm:
Now three parameter land surface emissivity, atmospheric transmittance and mean atmospheric temperature will input to the mono window algorithm as follows:

$$T_{LST}=\{a(1-C_6-D_6)+[b(1-C_6-D_6)+C_6+D_6]T_6-D_6.Ta\}/C_6$$

Where, $a = -67.355351$, $b = 0.458606$, $C_6 = E_i * \Gamma_6$, $D6=(1-\Gamma_6)(1+(1-E_i)*\Gamma_6)$,

T_{LST} is the LST (^{o}K); T_6 is the brightness temperature (^{o}K), E_i is the land surface emissivity, which can be computed by NDVI, Γ_6 is the Atmospheric transmittance and T_a is the mean atmospheric temperature.

LULC classification:
In Supervised classification, Maximum likelihood Classification is applied for making LULC map. Fig 3, shows the LULC classification of Nagpur area.This classification has been performed on the DN values of image. There are seven LULC classes and they are cleary visible in the LULC map.

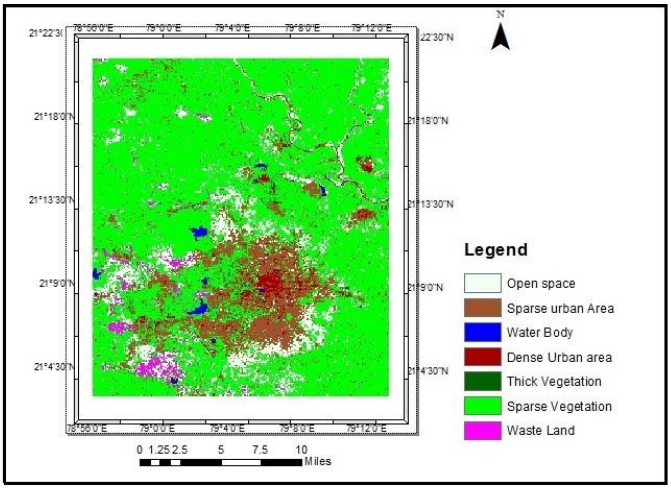


Fig.3 LULC Classification

RESULTS AND DISCUSSION

1. Accuracy Verification of LST Retrieval:
In this study, to verify the final retrived LST the near-surface air temperature is used. For the Landsat ETM+ data, the mean LST is 22.58 °C of Nagpur area and the mean near surface air temperature on 14 Dec 2006 is 22 °C. The error of LST retrieving error is about 0.58 ^{o}C. Thus, the mono window algorithm retrieving method from Landsat ETM+ data has a much better accuracy, which provides the high quality retrieved LST temperature data for the analysis of urban heat island.

2. The Distribution of urban heat island in Nagpur Area:
From Figure 4, it shows that the urban heat island effect exists in Nagpur area. These urban heat islands effects are mainly distributed in several region of Nagpur area, such as the main distribution of LST is near Lakadganj, Lodhipura, Hansapuri and Mahal has the LST temperature is 22 to 22.45 ^{o}C, also the area belongs to dense part of Nagpur Ramwadi, Milind nagar, vaishali nagar has the same range of temperature. But in the same Nagpur area the part i.e., sparse urban area namely Ulhas nagar, Shanti nagar, north part of Manewada, Omkar nagar, Akash nagar, Vitthal nagar etc has the LST temperature is in between 21.10 to 21.58 ^{o}C, now this shows the dense urban area in Nagpur has the more or increased temperature (upto 1 ^{o}C) than the sparse area. This is because the more urbanization, loss of vegetation and industrialization in that part of area than the sparse region.

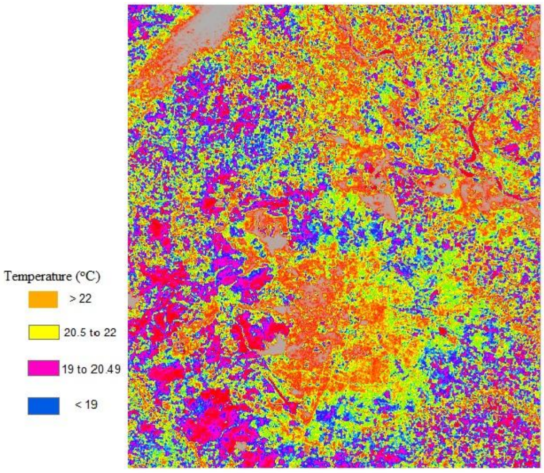


Fig. 4 The LST distribution in Nagpur on 14 Dec 2006

In vegetated part of Nagpur area such as Madha colony, Sitabuldi, western part of Sadar bazaar, north-west part of Uday and Wanjari nagar these area contains the somehow forest area, green gardens, parks so these area has the LST temperature between the 20.11 to 20.24 °C, now this analysis shows the same Nagpur area but the temperature value ranges upto 2°C from sparse, dense and vegetated part. Since the heat pockets are formed in the dense urban region due to structure of urban geometry, anthropogenic heat, reduced vegetation in that area.

The same type of effect happen on the water bodies inside and outside of Nagpur city, the LST temperature of outside water bodies like Phutala lake, Gorewada lake has the LST temperature around is 17.67 °C but the inside water bodies in Nagpur city has more temperature like Ambazari lake, Shukrawari talab, Sakkardara lake has 18.09 to 18.28 °C, so this shows upto 0.5 °C is variation , this because the temperature inside Nagpur city is warmer due to human activity like urbanisation, anthropogenic heat, reduced vegetation, industrialization etc.

Consider the outside part of Nagpur city for semiurban and rural area named the region kamatee and Patansavangi. The LST temperature of Kamatee area is 20.97 °C and the LST temperature of Patansavangi rural area is 18.76 °C, this shows the LST between urban and semiurban area is 1.41 °C, semiurban area and rural area is 2.21 °C and the LST between urban and rural area is upto 3.62 °C, this confirms due to the reduced vegetation, urbanisation, industrialization the heat island occurs in the urban area of Nagpur region.

3. NDVI vs LST:

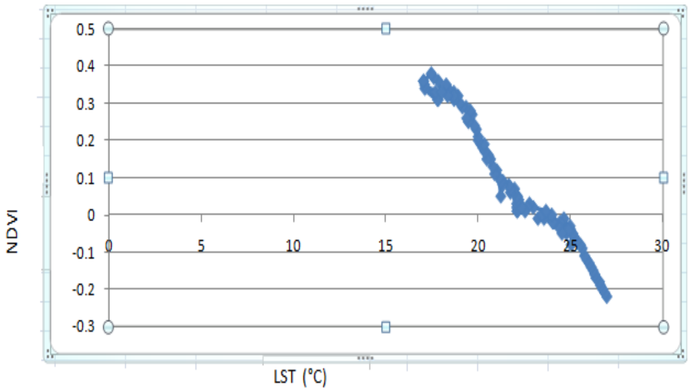
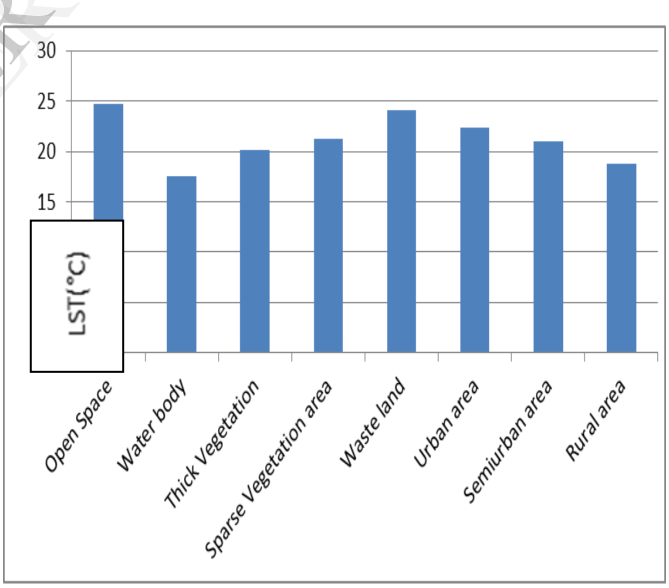


Fig.5 NDVI vs LST

From figure 5, it is clearly shows that for less vegetation their is a more or increased temperature, i.e., in above figure, the NDVI values range between -0.1 to -0.25 has temperature above 25 °C and for NDVI values above 0.2 their is a less temperature i.e., below 18 °C. This shows their is a inverse correlation between NDVI and LST.

4. LST temperature relationship between LULC classes:

The figure 6 shows the LST temperature relationship between LULC classes.



LULC classes

Fig. 6 LULC classes and their relationship for LST

From figure 6, it shows that urban area has clearly more temperature than the semiurban and the rural area, this is due to the heat island effect occurs in the Nagpur region, due to reduced vegetation, pavement surfaces, buildings, industrialization, anthropogenic heat etc. These classes are different from the LULC map, because here area is Nagpur and surrounding region and in LULC map area is Nagpur only.

CONCLUSION

The Thermal infrared remote sensing technology is the most dominated technology for detecting urban heat island effect in Urban regions.

For this study, the mono window algorithm is used for retrieving the land surface temperature of Nagpur and surrounding area using the Landsat ETM+ data.

From this land surface temperature, it is concluded that the distribution of urban heat island in Nagpur is mainly located in central part due to large compact urban activity like reduced vegetation, buildings, pavement roads and anthropogenic heat etc.,

In addition to this, the inverse correlation is found between LST and NDVI of Nagpur and surrounding area, this relation shows that, if there is a less vegetation then the LST is more and vice versa. Also urban activity, like buildings, roads, anthropogenic heat adds more heat island effect.

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