

A COMPARATIVE STUDY OF LAND SURFACE TEMPERATURE WITH DIFFERENT INDICES ON HETEROGENEOUS LAND COVER USING LANDSAT 8 DATA

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ABSTRACT:

The temperature rise in urban areas has become a major environmental concern. Hence, the study of Land surface temperature (LST) in urban areas is important to understand the behaviour of different land covers on temperature. Relation of LST with different indices is required to study LST in urban areas using satellite data. The present study focuses on the relation of LST with the selected indices based on different land cover using Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) data in Varanasi, India. A regression analysis was done between LST and Normalized Difference Vegetation index (NDVI), Normalized Difference Soil Index (NDSI), Normalized Difference Built-up Index (NDBI) and Normalized Difference Water Index (NDWI). The non-linear relations of LST with NDVI and NDWI were observed, whereas NDBI and NDSI were found to show positive linear relation with LST. The correlation of LST with NDSI was found better than NDBI. Further analysis was done by choosing 25 pure pixels from each land cover of water, vegetation, bare soil and urban areas to determine the behaviour of indices on LST for each land cover. The investigation shows that NDSI and NDBI can be effectively used for study of LST in urban areas. However, NDBI can explain urban LST in the better way for the regions without water body.

1. INTRODUCTION

Urban Heat Island (UHI) refers to the urban areas which has temperatures higher than the surrounding suburban or rural areas due to increase in urbanization. Urbanization has led to the replacement of natural land covers with the artificial built up surfaces made up of impervious materials and decrease of vegetation which helps in reducing temperatures due to evapotranspiration (Voogt and Oke, 2003). Various previous studies have shown that bare soil and built up areas have higher temperatures whereas waterbodies and vegetated land have lower temperatures (Song et al. 2014). The study of LST of urban areas and also different land covers has become important for the requirement of sustainable planning and environmental protection. The factors responsible for resultant temperature rise must be identified in order to attenuate the UHI effect (Kaufmann et al. 2007, Mountrakis and Luo. 2011).

Thermal bands in remote sensing satellite are the most important source for determining LST. Various satellites contain thermal bands like Landsat, Aster, AVHRR, MODIS etc. Fine spatial resolution is required for the study of LST variation in urban areas due to greater heterogeneity in urban areas. Landsat and Aster data has been widely

used for study of UHI effect in urban areas due to its fine spatial resolution (Tsou et al. 2017, Yu et al. 2014).

Various scholars have studied on the correlation between LST and some land use (LU) /land cover (LC) indices for different study area and found that the correlation of LST with LU–LC indices was different (Deilami and Kamruzzaman, 2017; Ma et al. 2016, Mathew et al. 2016, Nie et al. 2016, Tran. et al. 2017). So, this study focuses on the relation of LST with the selected indices i.e. NDVI, NDBI, NDSI and NDWI based on different land cover using Landsat 8 data in Varanasi, India. In order to understand the relation, 25 pure pixels for each land cover of water, vegetation, bare soil and urban areas were chosen to determine behaviour of LST and indices with the land covers.

2. STUDY AREA

The study area, Varanasi city, is a very old city located at the banks of River Ganges in the Eastern part of the state of Uttar Pradesh, North India. The city lies at the coordinates 25.28 °N and 82.96 °E at an elevation of 80.71 meters and covers an area of 82.10 km². Varanasi experiences a humid subtropical climate. Location map of study area is shown in Figure 1.

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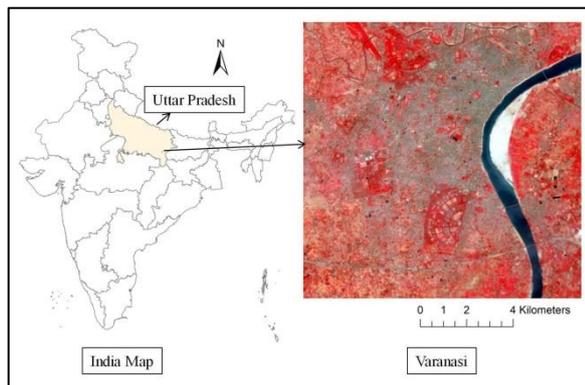


Figure 1. Location map of study area

This image of Varanasi is the false color composite image obtained from Landsat data. The city was chosen for this study due to the availability of land covers like waterbody, urban areas, bare soil region as well as vegetated land covering sufficient area which makes this useful to study the behaviour of each land cover.

3. DATA USED AND IMAGE PRE-PROCESSING

Landsat satellite images were generated and distributed by the U.S. Geological Survey (USGS) since 1972. Landsat level 1 data products are geometric, radiometric and terrain corrected. Landsat 8 images contain 11 bands of which band 10 and 11 are thermal bands. The Landsat 8 images have 30 m spatial, 12 bit radiometric and 16 days temporal resolution. The spatial resolution of thermal bands is 100 m, and is resampled to 30 m for distribution.

Landsat 8 images were downloaded from the USGS website i.e. <https://earthexplorer.usgs.gov/> of the date 10/04/2017 (Path 142/ Row 42) for day time. The Varanasi region was clipped from the image for the study. The original Digital numbers of OLI images were converted to reflectance using methods provided by Landsat 8 Data user Handbook (2016).

4. METHODOLOGY

4.1 Calculation of Indices

The indices used in the study were obtained from the visible, Near Infra-Red and Short Wave Infra-Red reflectance bands from the Landsat satellite data. The index maps were obtained using the equations as shown in Table 1.

Indices	Equations
Normalized Difference Vegetation Index (NDVI)	$\frac{NIR - RED}{NIR + RED}$
Normalized Difference Built-up Index (NDBI)	$\frac{SWIR_1 - NIR}{SWIR_1 + NIR}$
Normalized Difference Soil Index (NDSI)	$\frac{SWIR_2 - GREEN}{SWIR_2 + GREEN}$
Normalized Difference Water Index (NDWI)	$\frac{GREEN - NIR}{GREEN + NIR}$

Table 1. Equations for estimating different Indices

4.2 Calculation of LST

Thermal band (band 10) of Landsat 8 images was used for determining LST image. Various steps are involved in the estimation of LST from Landsat image (Essa et al. 2012). The digital number of thermal band was first rescaled into Top of atmosphere radiance (TOA) using Equation (1).

$$L_{\lambda} = M_L \times (DN) + A_L \quad (1)$$

where M_L = multiplicative rescaling factor
 A_L = additive rescaling factor
 DN = digital number of thermal band.

The TOA radiance includes a mixed signal that contains emission from land as well as atmosphere. Hence, atmospheric correction was performed to eliminate the contribution from the atmosphere. Therefore, TOA radiance was converted into surface leaving radiance (L_T) using Equation (2).

$$L_T = \frac{(L_{\lambda}) - L_{\mu} - \tau \times (1 - \varepsilon) \times L_d}{\tau \times \varepsilon} \quad (2)$$

where L_{μ} = upwelling radiance
 L_d = downwelling radiance
 τ = transmission
 ε = emissivity

The atmospheric parameters like transmission (τ), upwelling radiance (L_{μ}) and downwelling radiance (L_d) values were obtained from an atmospheric correction tool available at <http://atmcorr.gsfc.nasa.gov/> only for Landsat 4-5, 7 and 8 satellite images developed by Barsi et al. (2005) and the emissivity values were estimated using NDVI (Van de Griend and Owe, 1993) as shown in the Table (2).

NDVI	Land surface emissivity
NDVI < -0.185	0.995
-0.185 < NDVI < 0.157	0.970
0.157 < NDVI < 0.727	$1.0094 + 0.047 \ln(\text{NDVI})$
NDVI > 0.727	0.990

Table 2. Land Surface Emissivity estimation from NDVI

Then, the surface leaving radiance was converted into LST using Planck's law as given in Equation (3)

$$T_s = \frac{K_2}{\ln\left(1 + \frac{K_1}{L_T}\right)} \quad (3)$$

where K_1, K_2 = thermal constants
 T_s = Land Surface Temperature.

5. RESULTS AND DISCUSSIONS

In order to study the behaviour of LST in the city, the LST image was generated as shown in Figure 2. It was observed that the River Ganges show very low LST, the dry sandy area at the bank of River Ganga shows very high LST. The urban areas of the city show LST higher than the vegetated areas and waterbody but lower than the bare soil or dry sandy areas.

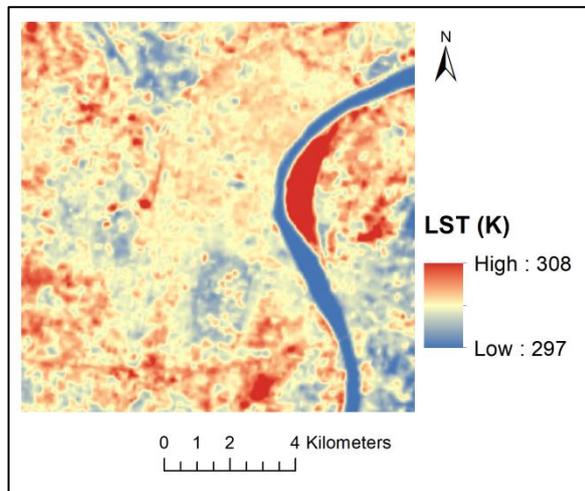


Figure 2. LST image of Varanasi

In order to study the relation of LST with the respective indices, scatter plots were obtained for LST with NDVI, NDBI, NDSI and NDWI and are shown in Figures 3 – 6 respectively.

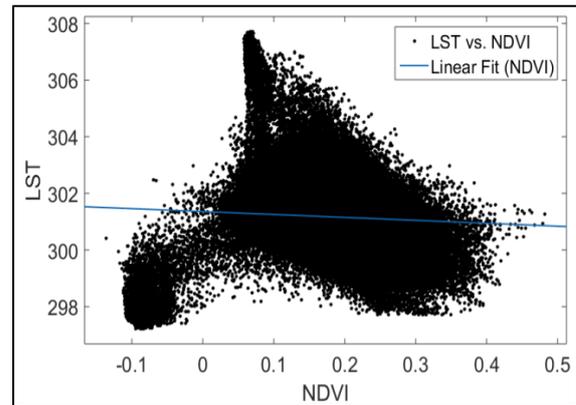


Figure 3. Scatter plot of LST with NDVI

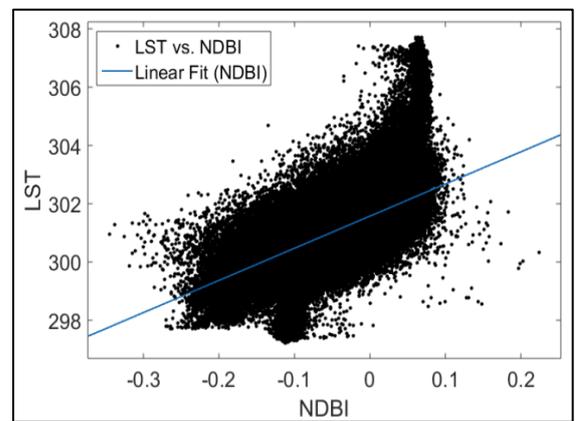


Figure 4. Scatter plot of LST with NDBI

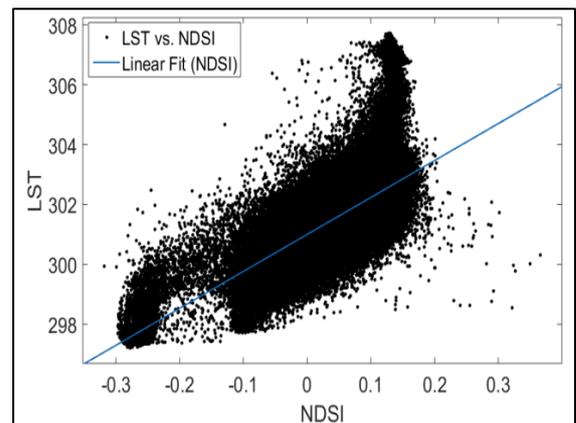


Figure 5. Scatter plot of LST with NDSI

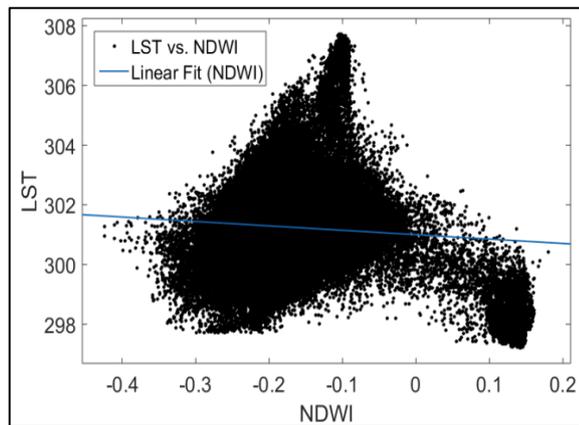


Figure 6. Scatter plot of LST with NDWI

Indices	Slope	Intercept	R-square	RMSE
NDVI	-1.029	301.4	0.2912	1.103
NDBI	11.04	301.6	0.5815	0.8474
NDSI	12.35	301.0	0.7251	0.6868
NDWI	-1.476	301.0	0.3137	0.9503

Table3. Regression parameters for LST relation with indices

It was observed from the scatterplot that NDVI and NDWI shows non-linear relation but NDBI and NDSI shows positive linear relation with LST. The regression parameters obtained from the relation of LST with indices are shown in Table 3. The correlation of NDVI and NDWI was found very low and that of NDBI and NDSI was higher. Different land covers have different behaviour towards LST as well as indices. Waterbodies and vegetation shows lower LST whereas built up and bare soil region shows higher LST during day time (Amiri et al. 2009). The relation of LST with different LU-LC indices depends on the type of land cover present in the region. So for further analysis, 25 pure pixels were chosen for each land cover of vegetation, water, urban and vegetated areas. Then, the relation of LST with the indices was determined for these pure pixels to understand the behaviour of different land cover. The relation of LST with NDVI, NDBI, NDSI and NDWI based on each land cover obtained are shown in Figures 7 – 10 respectively.

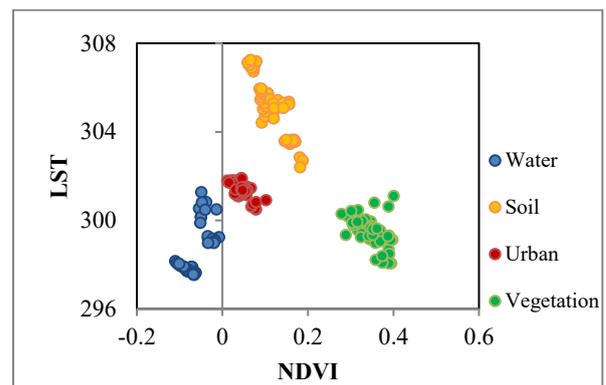


Figure7. LST-NDVI relation with land cover

Waterbodies has lower LST but shows negative values of NDVI and other land covers shows positive values. The vegetative land covers shows higher positive values than bare soil and urban regions but lower LST values. This explains the non-linear behaviour of LST with NDVI. Since, urban areas also include soil, vegetation and water, NDVI cannot explain LST in urban regions due to greater heterogeneity in land cover. But agricultural region contains only bare soil and vegetation, so NDVI can explain LST better in agricultural regions.

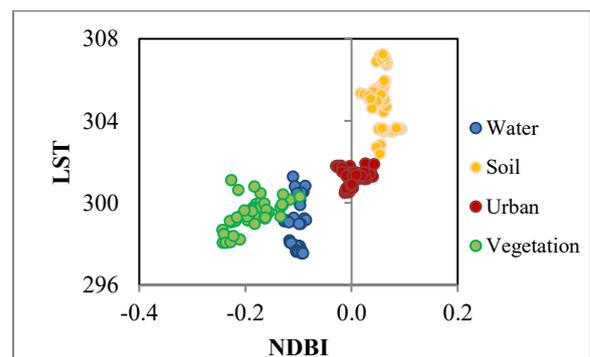


Figure8. LST-NDBI relation with land cover

Negative values of NDBI shows waterbodies as well as vegetation which shows lower LST values and higher LST land covers i.e. urban and bare soil regions shows NDBI values nearby or greater than zero. This explains the linear relation of LST with NDBI. Hence, NDBI can be used to study LST in region containing heterogeneous land covers.

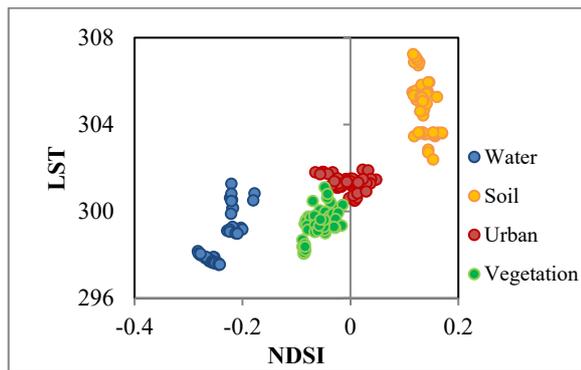


Figure9. LST-NDSI relation with land cover

Waterbodies shows very low negative values for NDSI whereas bare soil shows very high positive NDSI values. Urban areas have NDSI values near to zero with positive as well as negative values of NDSI. Vegetation shows negative values of NDSI near to zero. This explains linear relation of LST with NDSI.

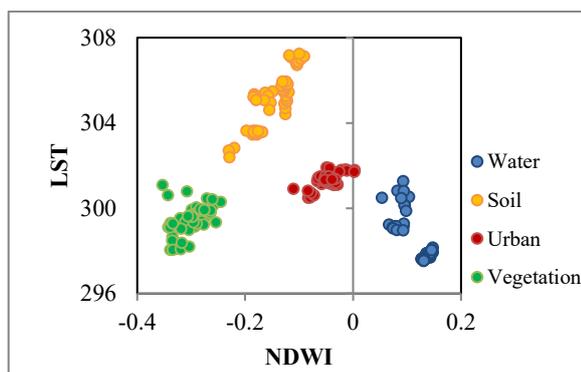


Figure10. LST-NDWI relation with land cover

Waterbodies shows positive values of NDWI with lower LST whereas other land covers shows negative values. Vegetated pixels shows very low negative values but also lower LST. This explains the non-linear behaviour of LST with NDWI. Hence, NDWI cannot be used in study of LST in urban areas. NDWI can explain LST in those urban areas with no vegetation cover because bare soil, urban and water has linear relation of LST with NDWI.

The nonlinear relation of LST with NDVI and NDWI was observed because the NDVI and NDWI values of higher LST pixels i.e. urban and bare soil lies between two lower LST pixels i.e. vegetation and waterbodies. Hence, NDVI and NDWI are found not suitable for study of LST in heterogeneous land cover. The positive linear relation of LST with NDBI and NDSI was observed because the land covers with positive NDBI and NDSI values shows higher LST whereas those with negative NDBI and NDSI values shows lower LST. The correlation was found greater for NDSI than NDBI. In case of NDBI, water pixels shows higher NDBI than vegetated pixels but LST is lower for water pixels than vegetated pixels which results in lower R-

square. In case of NDSI, water, vegetation, soil as well as urban pixels shows positive relation with LST making it more suitable for study of LST in urban areas. NDBI can also explain urban LST better in regions without water body.

6. CONCLUSIONS

The study focuses on the relation of LST with the selected indices i.e. NDVI, NDBI, NDSI and NDWI using Landsat 8 OLI and TIRS data. A regression analysis was done between LST and the selected indices. The non-linear relations of LST with NDVI and NDWI were observed, whereas NDBI and NDSI were found to show positive linear relation with LST. The correlation of LST with NDSI was found better than NDBI. Further analysis was done by choosing 25 pure pixels from each land cover of water, vegetation, bare soil and urban areas and plotted to determine the behaviour of indices on LST for each land cover. The investigation shows that NDSI and NDBI can be effectively used for study of LST in urban areas. However, NDBI can explain urban LST in the better way for the regions without water body.

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