Study of Diurnal Variation in LST with Different Land Covers and Indices Using Landsat Satellite Data

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ABSTRACT: Urban Heat Island (UHI) refers to the occurrence of higher temperatures in urban areas in relation to surrounding rural areas. The aim of this study is to investigate the diurnal variation in Land Surface Temperature (LST) with respect to different land covers and indices like Normalized Difference Vegetation Index and Normalized Difference Built-up Index in urban region. Landsat 8 Operational Land Imager (OLI) was used for the estimation of LST and calculation of NDVI and NDBI. UHI formation was found to be clearly significant during night time but not during day time due to the difference in behavior of land covers on LST during day and night time. First as well as second order polynomial relation of LST with NDVI and NDBI was obtained during day time as well as night time. Our results indicate that day time LST is better explained by NDBI using linear regression and NDVI using second order regression, respectively. Night time LST is better explained by NDVI using linear regression but NDBI do not show good correlation for both linear and second order regression.
Keywords: LST, NDVI, NDBI, Landsat 8 OLI

I. INTRODUCTION

The Urban Heat Island (UHI) refers to the urban areas whose surface and atmospheric temperatures are significantly higher than the neighbouring rural areas due to urbanization, particularly at night. Urbanization has replaced large amount of natural land surfaces with artificial built surfaces made up of non-evaporating impervious materials which absorbs radiation during the day and re-radiates during the night time [1]. The so-called heat islands are formed due to the increase in artificial materials that have high heat capacities, increase in anthropogenic heat discharge by industries, vehicles, and buildings, and also the decrease in vegetation and natural surfaces that reduces temperatures through evapotranspiration. Moreover, the compact urban geometry also contributes to temperature rise due to less convection.

Higher temperature in urban areas increases the demand for air conditioners, raises the pollution levels, increases dryness and also modifies the natural cycle of precipitation [2]. As a result, study of Land Surface Temperature (LST) of urban areas and also different land covers has become important for the requirement of sustainable planning and environmental protection [3],[4]. The factors responsible for resultant temperature rise must be identified in order to attenuate the UHI effect. Here, behaviour of LST with different land covers has been identified for both the day and night time to study about the formation of Urban Heat Island.

II. DATA & METHODS

A. Study Area:

Ahmedabad is the largest city in the state of Gujarat in India with area coverage of 464 km2. It is the sixth largest city and seventh largest metropolitan area in India. It lies at the coordinates 23.030 N, 72.580 E and at an elevation of 53 m. Sabarmati river passes through the centre of the Ahmedabad city. Ahmedabad has a hot and semi-arid climate and is extremely dry apart from the monsoon season.

B. Satellite Data:

Landsat 8 Operational land Imager (OLI) images have been downloaded from the USGS site i.e. https://earthexplorer.usgs.gov/. These Landsat images have 30 m spatial, 16-day temporal and 12-bit radiometric resolution. The spatial resolution of Landsat 8 OLI image thermal bands is 100 m and is resampled to 30 m. It contains 11 bands from which band 10 and band 11 are thermal bands. Here, band 10 was used for the estimation of LST. All the images acquired were taken during clear sky condition.

C. Methodology:

Landsat 8 OLI images of date 31 October 2015 (day time) and 3 November 2015 (night time) have been used in the present study. Change in land cover is almost negligible in three days, so these maps can be used for the study of diurnal variation in LST with land cover, NDVI and NDBI.

*LST calculation***:** The Top of atmosphere radiance (TOA) is computed using the thermal band from Landsat using equation 1

$$L_{\lambda} = M_{L} * DN + A_{L} \quad (1)$$

where, M_L and A_L are multiplicative and additive rescaling factor for thermal bands obtained from metadata file. DN is the digital number of band 10 for Landsat 8 image.

The TOA radiance was corrected by removing atmospheric effects in the thermal region. The atmospheric parameters like transmission (τ), upwelling radiance (L_{μ}) and downwelling radiances (L_d) values were obtained from an atmospheric correction tool developed by [5] as available at for Landsat 4-5, 7 and 8 satellite images. Equation (2) was used for converting TOA radiance into surface leaving radiance

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

where, L_T is the surface leaving radiance and ε is the emissivity values which were taken from [6] as shown in Table 1.

TABLE I. EMISSIVITY VALUES OF LAND COVERS

Land Cover	**Emissivity (ε)**
Water/ Vegetation	0.990
Bare Soil	0.962
Low Albedo Built Up	0.957
High Albedo Built Up/Roads	0.964

The surface leaving radiance was converted into LST using equation 3.

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

where, K_1 and K_2 are thermal constants.

NDVI calculation: NDVI was calculated using equation 4.

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \quad (4)$$

where, R_{NIR} is the surface reflectance of NIR (Near Infra-Red) band and R_{RED} is the surface reflectance of Red band.

NDBI calculation: NDBI was calculated using equation 5.

$$NDBI = \frac{R_{SWIR\ 1} - R_{NIR}}{R_{SWIR\ 1} + R_{NIR}} \quad (5)$$

where, R_{SWIR1} is the surface reflectance of SWIR1 (Short wave Infra-Red) band and R_{NIR} is the surface reflectance of NIR (Near Infra-Red) band.

III. RESULTS AND DISCUSSIONS

The day and night time LST map was obtained and diurnal variation of LST with different land covers was studied as shown in figure 2. The relation of LST with NDVI and NDBI was also studied and linear and second order regression was obtained to determine the correlation as shown in figure 3.

The day and night time LST map reveals that UHI effect is more significant during night time but not during day time. Eastern Ahmedabad region consists of mainly residential, industrial areas and also compact and very old buildings made up of low albedo materials whereas western region consists mainly of parks, educational institutions and residential areas made up of high albedo materials. It results lower LST during day time in the western region than the eastern region in Ahmedabad. During night time, all the built up region show higher LST whereas natural land covers shows lower LST resulting in clear patterns of UHI.

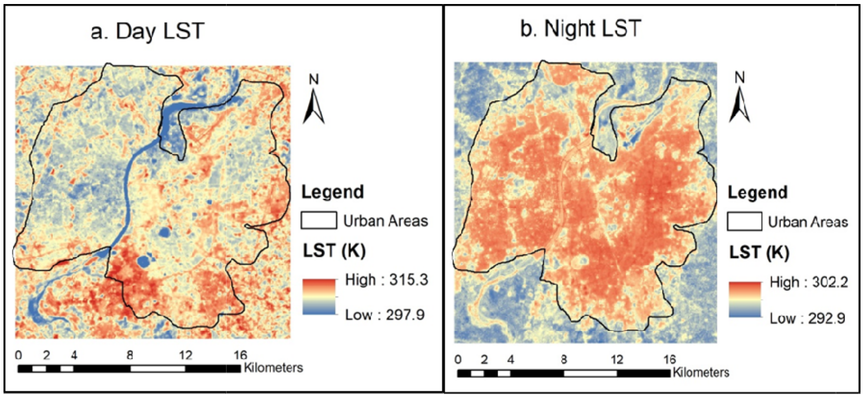

Fig1: Day and Night Time LST Maps

The Landsat image was classified using maximum likelihood classification technique and by using zonal statistics, Mean LST for each land cover type was obtained as shown in figure 2.

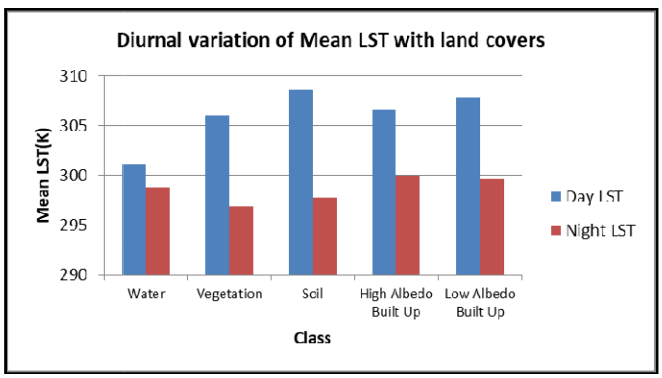

Fig2: Diurnal Variation of Mean LST with Land Covers

Different land covers show different behavior towards LST during day and night time. From the graph shown in Figure 2, day and night time LST of land covers kept in increasing order is shown below:

Day time LST:

Water -> Vegetation -> High Albedo Built Up -> Low Albedo Built Up -> Soil

Night time LST:

Vegetation -> Soil -> Water -> Low Albedo Built up -> High Albedo Built Up

The bare soil areas was found to be warmer than other land covers during the day-time [7] [8], whereas built-up areas are hottest surfaces during the night-time [9] [10]. The day-time temperature of water was found to be 5 – 8 K lower than other land covers. The day-time temperature of vegetation was found to be almost 5 K higher than water and almost 3 K lower than soil. Soil was found to be the hottest land cover during day time. But during night time, vegetation and soil shows lower temperatures while built up shows higher temperatures.

On comparing the day and night time LST, it was found that LST of soil, vegetation, built-up region with low albedo, built-up with high albedo and water decreased by ~12 K,~9.5 K,~9 K, ~8 K and ~3 K respectively, during night time. Hence, it was observed that different land covers exhibit different behaviour towards LST due to their respective heat capacity or heat transfer capacity. Heat capacity is the amount of energy or heat required to increase the temperature of the system by 1 K. During day time, all the land covers acquire heat from the sun and raise the temperature but during night time, due to absence of heat energy, temperature of all land cover starts decreasing. The speed of decrease or increase in temperature depends on the heat capacity of the material of the land cover. Very high heat capacity of water reveals the behaviour of LST of water and very low heat capacity of soil reveals LST behaviour of soil. Vegetation shows lower temperature during both day and night time due to evapotranspiration. Heat capacity of high albedo built up is greater as compared to that of low albedo built up which explains the lower LST of high albedo built up region during day time. High albedo built-up shows lower LST values as compared to low albedo built-up which is similar to the results given by [11]. Heat capacities of some common substances found in urban region are shown in table.

TABLE II.HEAT CAPACITY OF SOME COMMON SUBSTANCES

Substance	**Heat Capacity ($kJ\ kg^{-1}\ K^{-1}$)**
Dry sand/soil	0.80
Asphalt	0.92
Concrete	0.75
Wood	1.00
Brick	1.00
Bituminous	1.38
Dry cement	1.55
Water	4.18

From the table, heat capacity of dry bare soil is found to be very low and that of water is very high. Built ups are made up of materials like asphalt, concrete, brick, cement shows higher heat capacity than soil. Hence, dry soil shows higher LST values during day time but lower LST values during night as compared to built-up region. Hence, higher temperatures of dry bare soil and lower temperatures of high albedo built up result in lower differences in the temperature of rural and urban areas during the day time. But during night time, pervious surfaces i.e. soil and vegetation shows lower temperatures and impervious surfaces shows higher temperatures which results in formation of UHI during night time. Similarly, during day-time water absorbs heat at much lower rate, thereby showing a relatively lower temperature than adjoining areas, but during night time its heat dissipation is much lower resulting into higher temperature than that of its surroundings.

The relation of day and night time LST with NDVI and NDBI was obtained by determining the mean LST at every 0.01 increment in NDVI and NDBI and plotted as shown in figure 3. In order to facilitate our comparison, water pixels were excluded from the study. The linear and nonlinear (second order) regression was obtained for all the plots. The regression analysis indicates inverse relation of LST with NDVI, whereas its positive relation was obtained with NDBI [12], [13].

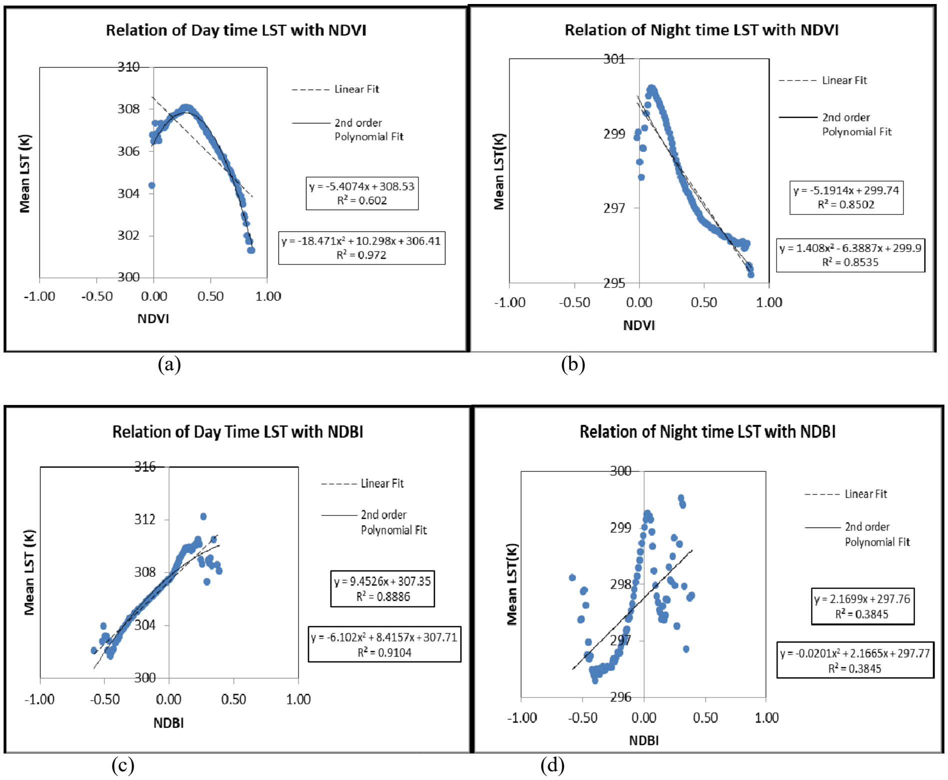

Fig3: Relation of Day and Night LST with NDVI (a, b) and NDBI(c, d)

Figure 3a shows the relation of day time LST with NDVI where LST is found to increase with NDVI up to certain NDVI value (i.e. 0.25) and then found to decrease sharply with increase in NDVI value. The NDVI values for built-up region are less than 0.2 whereas its value for bare soil is ~0.2. Hence, the day LST was found to increase with NDVI at NDVI values less than 0.25. Day LST value decreases with NDVI for NDVI values greater than 0.25 due to increase in vegetation. Figure 3b shows that night LST decreases sharply with increase in NDVI. This is because built up region shows higher LST during night time compared to the natural land covers as shown in figure 2. Since, NDVI of water is negative; NDVI values near to zero can be at areas with greater moisture content showing lower temperatures. Figure 3c shows the relation of day time LST with NDBI and figure 3d shows relation of night LST with NDBI. Day LST shows positive correlation with NDBI. Night time LST shows nonlinear relation with NDBI. Night LST shows positive linear relation with NDBI at NDBI range from -0.5 to 0. Since, NDBI of water and vegetation is less than 0, lower LST values are due to the vegetation areas and higher LST value at NDBI less than -0.5 can be due to areas of greater moisture content. Higher LST values at NDBI value near to zero is due to the built up areas. NDBI value of soil is found to be greater than 0, lower LST value at positive NDBI value can be due to the bare soil areas.

TABLE III.CORRELATION COEFFICIENT OF DAY AND NIGHT LST-NDVI AND NDBI RELATION

Correlation Coefficient (R^2)				
Regression	**LST-NDVI relation**		**LST-NDBI relation**	
	Day	*Night*	*Day*	*Night*
Linear	0.602	0.850	0.888	0.384
Second Order	0.972	0.853	0.910	0.384

The result of linear and second order regression analysis is presented in figure 3 and the coefficient of determination (R^2) is shown in table 3. The linear regression for day and night LST with NDVI shows that night LST is more linearly correlated to NDVI as compared to day LST and the linear regression for day and night LST with NDBI shows that day LST is more linearly correlated to NDBI as compared to night LST.

The second order regression for day LST with NDVI shows very high correlation whereas that of night LST shows similar correlation to that of linear regression. Hence, the day LST is found more correlated to NDVI as compared to night LST using second order regression. The second order regression for day and night LST with NDBI has correlation similar to that of linear regression. Hence, NDBI explains the behaviour of day time LST better than that of night time using both linear as well as second order regression. But, NDVI explains the behaviour of night time LST better than day time using linear regression and explains the behaviour of day time LST better than night time using second order regression.

IV. CONCLUSION

UHI effect was found significant during night time but not during day time. Day time LST is better explained by NDBI and NDVI using linear regression and second order regression, respectively. Night time LST is better explained by NDVI using linear regression while NDBI do not show good correlation for both linear and second order regression.

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