Variations of Surface Temperatures of Ahmedabad City and its Relationship with Vegetation Abundance

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***Abstract*— All cities of the world have undergone rapid urbanization and consequently urban areas show higher surface and air temperatures than the surrounding non- urbanized areas and exhibit urban heat island (UHI) effect. The present study has been carried out to understand the UHI effect of area surrounding Ahmedabad city, India. Remote sensing data from Moderate-Resolution Imaging Spectroradiometer (MODIS) and Operational Land Imager/Thermal Infrared (OLI/TIR) sensors have been used for the present study. The study has been undertaken for monsoon season, prevailing over the study area, by utilizing data of 2013 October 13. Analysis of land surface temperature (LST) data show that significant surface urban heat island (SUHI) exists over the study area. The relationship of LST with normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI) has also been investigated in the present work. Inverse relationship has been observed between LST and vegetation indices (VIs) and it is season dependent. The coefficient of correlation (R^2) values between mean LST and SAVI for day and night time are 0.75 and 0.83, respectively. The corresponding R^2 values for mean LST and NDVI for day and night time are 0.74 and 0.80, respectively. These results show that SAVI is a better parameter for UHI studies than NDVI and night LST-VIs relationship shows stronger relationship than the day LST-VIs relationship.**

Keywords—Land Surface Temperature; Urban Heat Island; NDVI; SAVI; MODIS

I. INTRODUCTION

Urbanization is one the most important human activities, generating huge impacts on the environment at the local, regional and global scales [1]. Urbanization negatively affects the environment strongly through producing the pollution, modification of the chemical and physical parts of the atmosphere, plus the soil surface covering on the ground. Urban heat island (UHI) refers to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than the surrounding rural areas due to urbanization [2]. Studies have shown that the UHI effect results in higher energy and water consumption. UHI during summer season has a major effect of increase in the energy demand and reduction in outdoor air quality levels. The peak urban electrical demand rises by about 2–4% for each 1°C rise in the daily maximum temperature above a threshold of 15–20°C [3]. Yuan & Bauer (2007) have investigated the relationship of LST with percent impervious surface area (%ISA) and have concluded that %ISA is an accurate indicator of SUHI effects with strong linear relationship between LST and %ISA for all study seasons [4]. Zhang et al. (2009), utilizing data from thematic mapper (TM) and enhanced thematic mapper plus (ETM+) imageries, have indicated strong positive correlation of LST with %ISA and normalized difference built-up index (NDBI), whereas the correlations between NDVI and LST have been found to be weak. The study suggests that %ISA combined with LST and NDBI can quantitatively describe the spatial distribution and temporal variation of urban thermal patterns and associated land-use/ land-cover (LU-LC) conditions [5]. Lo et al. (1997) have studied changes in the thermal responses of urban LC types and have found strong negative correlation between NDVI and irradiance of residential, agricultural, and vacant/transitional LC types, indicating that the irradiance of a LC type is greatly influenced by the amount of vegetation present [6]. Gallo & Owen (1999) have evaluated seasonal trends in NDVI and temperature and have found that about 40% of the variations in urban-rural temperature difference, i.e. UHI intensity, can be accounted for by difference in NDVI and LST [7]. SAVI has found to be an important step towards the development of simple global models that can describe dynamic soil-vegetation systems from remotely sensed data. SAVI is used to minimize soil brightness influences from spectral vegetation indices involving red and near-infrared (NIR) wavelengths. [8].

II. STUDY AREA

Ahmedabad is the fifth largest city and the former capital of Indian state Gujarat with a population of more than 5.8 million. Ahmedabad situated on 23.03°N, 72.58°E according to geographic–coordination system. It is situated on the western part of India near Sabarmati river passes near the Ahmedabad. It spreads in area of 464 km^2. Climatic condition of the Ahmedabad city is semi-arid and hot because it receives less rainfall during monsoon season. It is having three seasons of year, summer, monsoon & winter. Apart from the monsoon season, climate of Ahmedabad city is very extreme dry and hot from March to mid-June. Average maximum and minimum temperature of summer recorded are 42ºC and 28ºC, respectively. Maximum and minimum average temperature of winter are 30ºC and 15ºC, respectively.

Ahmedabad is situated on dry and sandy soil. So it is responsible for extra heating of the city because it absorbs the heat during day time and releases during night time so that environment of the city becomes so hot rather than its surrounding areas, this difference in temperature is called temperature gradient. So it is responsible for making the city environment too hostile and very difficult to survive under this kind of environmental impact which created by temperature gradient called urban heat island effect of that city.

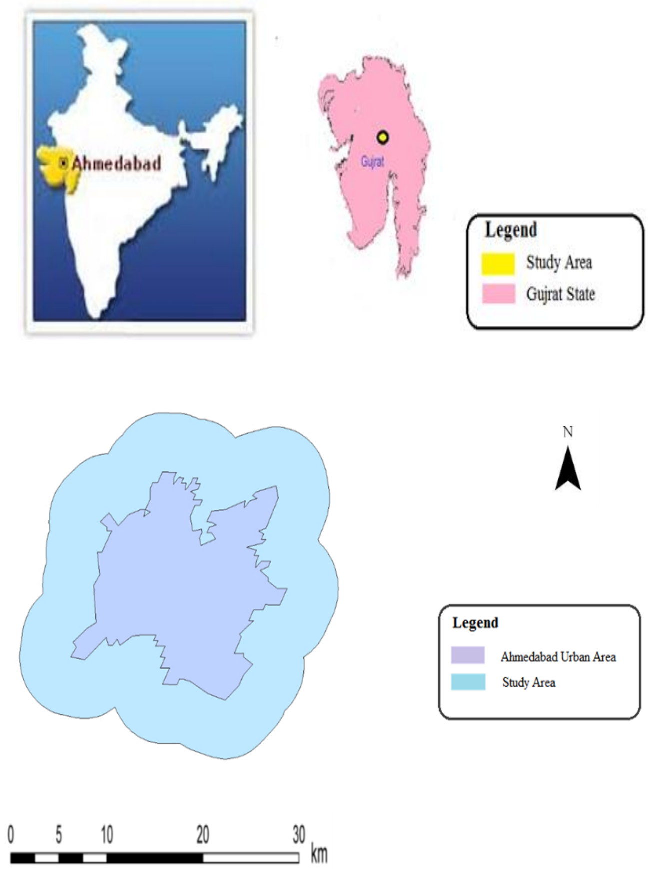

Fig.1. Ahmedabad study area

As UHI phenomenon indicates warmer thermal climate of urban land, compared to non-urbanized area, the study area must include sufficient non-urbanized/sub-urban area outside the urban area for UHI studies. The boundary of urban area of Ahmedabad city has been derived by extracting urban area polygon from the MODIS yearly land cover type image (MCD12Q1) of 2011. The urban area polygon from this map has been automatically converted by using raster to polygon conversion tool. The length and width of urban area polygon (hereafter referred as urban boundary) is approximately 12 km in North-South direction and 17 km in East-West direction. A buffer of 5 km has been added to the urban boundary to mark the boundary of study area and the study has been carried out for area falling within this boundary. The study area sufficiently includes non-urbanized/sub-urban areas and satellite towns of the city (figure 1). The study area covers approximately 690 km^2. The raster pixel size of LST product is 926.6 m and LST image of the study area contains 804 pixels.

III. DATA AND METHODOLOGY

One day, 1 km MOD11A1 land surface temperature and emissivity product of MODIS Terra of overlapping dates have been used for the present study. The land surface temperature and emissivity product is available with quality flag which has been checked to include only the good quality pixels in the analysis. Landsat Thermal Infrared (TIR) and Operational Land Imager (OLI) sensor images have also been selected for the present study for their good imaging quality.

TABLE I

REMOTE SENSING DATA USED FOR THE PRESENT WORK

Remote Sensing Product	Short Name	Sensor	Platform	Temporal Resolution	Spatial Resolution
Land Cover Type	MCD12Q1	MODIS	Combined Aqua & Terra	Yearly	463.3
Land Surface Temperature and Emissivity	MOD11A1	MODIS	Terra	1 Day	926.6 m
Landsat	-	OLI/TIR	-	16 Day	30m

The Landsat images have been geometrically rectified to the UTM projection system (datum WGS 84, Zone 43). The ground control points have been carefully selected in order to make sure that RMS errors lies below 0.5 pixels. A second-order polynomial and the nearest neighbor resampling method have been employed for implementing the georectification. The digital numbers of the OLI/TIR images have been converted to the ex-atmospheric reflectance using the methods provided by the Landsat 8 Science Data Users Hand book [9].

The downloaded MODIS data is in HDF-EOS format and in Sinusoidal Projection System. The Earth gridded tile area of each MODIS image covers approximately 1100 km x 1100 km. Pre-processing of downloaded MODIS images has been done using MODIS Re-projection Tools (MRT). MRT is used for sub setting of the data to smaller area. The data has also simultaneously been re-projected from Sinusoidal projection to UTM Zone 43N projection system with WGS84 datum and has been reformatted from HDF-EOS to GeoTIFF format.

A. *Retrieval of LST*

OLI and TIRS band data can be converted to Top of Atmosphere (TOA) spectral radiance using the radiance rescaling factors provided in the metadata file [9]:

$$L_\lambda = M_L * Q_{cal} + A_L \qquad (1)$$

where:

L_λ = TOA spectral radiance (Watts/ (m^2 * srad * μm))

M_L= Band-specific multiplicative rescaling factor from the metadata (Radiance_Mult_Band_10/11)

A_L=Band-specific additive rescaling factor from the metadata (Radiance_Add_Band_10/11)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

Rescaling factors of band 11 and band 12 are given in table II

TABLE II
RESCALING FACTOR

Rescaling Factor	Band 10	Band 11
M_L	0.000342	0.000342
A_L	0.1	0.1

The effective at-satellite temperatures of the viewed Earth-atmosphere system is derived from the at-sensor radiance under an assumption of unity emissivity (USGS). This is also referred to as blackbody temperature and represents a surface that absorbs most of the the electromagnetic radiation that reaches it:

$$T_B = \frac{K2}{\ln\left[\left(\frac{K1}{L_\lambda}\right)+1\right]} \quad (2)$$

Where:

T_B = At-satellite brightness temperature (K)

L_λ = TOA spectral radiance (Watts/ (m^2 * srad * μm))

K1 = Band-specific thermal conversion constant from the metadata (K1_Constant_Band_10/11)

K2 = Band-specific thermal conversion constant from the metadata (K2_Constant_band_10/11)

K1 and K2 values of band 10 and band 11 are given in table III.

TABLE III

K1 AND K2 VALUES

Thermal Constant	Band 10	Band11
K1	774.8853	480.8883
K2	1321.0789	1201.1442

Since T is a reference blackbody temperature, the final step involves correcting for spectral emissivity according to the nature of the surface [10, 11]:

$$LST = \frac{T_B}{1+\left(\lambda * \frac{T_B}{\rho}\right)\ln\varepsilon} \quad (3)$$

Where:

T_B = Blackbody temperature from Equation 2.

λ = Wavelength of emitted radiance (11.5 μm)

ρ = h x c/σ =1.438 x 10^{-2} mK (σ=Boltzmann constant=1.38 x 10^{-23} J/K, h=Planck's constant=6.626 x 10^{-34} Js, c=velocity of light=2.998 x 10^{8} m/s)

ε = Land surface emissivity

B. Calculation of NDVI

The normalized difference vegetation index can be calculated using the following formula:

$$NDVI = \frac{\rho_5-\rho_4}{\rho_5+\rho_4} \quad (4)$$

Where ρ_5 is the reflectance measured in the near infrared wave bands and ρ_4 is the reflectance corresponding to the red wave bands [12]. In order to get the reflectance of each band, Eq. (5) is used.

$$\rho_p = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_S} \quad (5)$$

Where:

L_λ = spectral radiance

ρ_p = exoatmospheric reflectance

d= the Earth-Sun distance

$ESUN_\lambda$ = mean solar exoatmospheric irradiance

θ_S=solar zenith angle

C. Calculation of SAVI

The soil adjusted vegetation index can be calculated using the following formula:

$$SAVI = \frac{\rho_5-\rho_4}{(\rho_5+\rho_4+L)} * (1+L) \quad (6)$$

Where ρ_5 is the reflectance measured in the near infrared wave bands and ρ_4 is the reflectance corresponding to the red wave bands [8]. The value of L varies by cover of green vegetation. High vegetation areas L= 0; the areas have no green vegetation then L=1. Generally L=0.5 in most cases and it works well.

IV. RESULTS AND DISCUSSION

A. Pattern of LST and Statistics

Day LST has been derived from Landsat TIRS and MODIS images acquired on October 2013 are shown in fig.2 and fig.3 with mean temperature of 304.47K and 305.51K, respectively. The corresponding MODIS night time mean LST is 298.17K. The UHI intensity has been estimated as the difference between urban area temperature and as that of rural area temperature. MODIS day and night UHI intensity has been observed as 4.08K and 6.04, respectively. Because of low resolution, MODIS LSTs show less accuracy compared to Landsat LST. Table IV shows Statistical results of MODIS and TIR sensor LST (K) of October 2013.

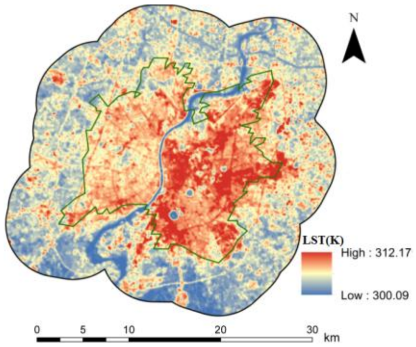

Fig. 2. LST image derived from Landsat TIRS acquired on 2013 October 13

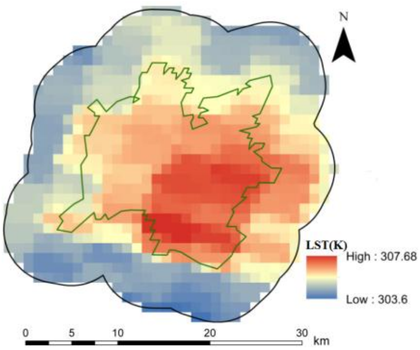

Fig. 3. LST image derived from MODIS day acquired on 2013 October 13

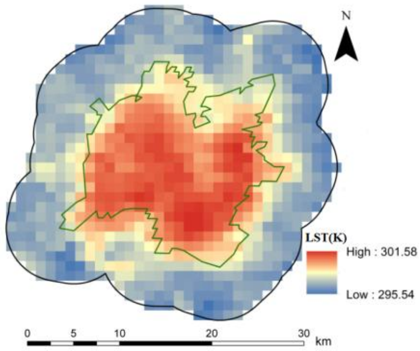

Fig. 4. LST image derived from MODIS night acquired on 2013 October 13

TABLE IV
STATISTICAL RESULTS OF LAND SURFACE TEMPERATURE (K)

Sensor	Maximum	Minimum	Mean	Standard Deviation
Landsat	312.18	300.09	304.47	1.83
MODIS Day	307.68	303.60	305.51	0.90
MODIS Night	301.58	295.54	298.17	1.674

The LST pattern were well distributed in the high density commercial areas, residential areas and industrial areas of Ahmedabad city. In the present study, it has been observed that most of the hot pixels are located in the north east and eastern part of the Ahmedabad city where airport and industrial areas are situated. Central part of the city shows very less number of hot pixels especially during day time due to the presence of Sabarmati river, green spaces and parks which can lower the LST.

B. *Correlation of LST with NDVI and SAVI*

In the present study, it has been observed that higher values of NDVI and SAVI have been observed in north east and south east agricultural fields and lower values of NDVI and SAVI have been observed in built-up areas inside the city with less vegetation coverage. Fig. 5 and Fig. 7 show NDVI and SAVI images derived from Landsat data acquired on 2013 October 13. Fig. 6 and Fig. 8 show aggregated NDVI and SAVI images (926.6m resolution) of the corresponding NDVI and SAVI images of 30m resolution. Sabarmati river and lakes in Ahmedabad city show negative values of NDVI and SAVI as shown in fig. 5 and Fig. 7. The statistical results of NDVI and SAVI are shown in table V.

TABLE V
STATISTICAL RESULTS OF NDVI AND SAVI

Vegetation Indices	Maximum	Minimum	Mean	Standard Deviation
NDVI	0.567	-0.183	0.252	0.121
Aggregated NDVI	0.520	-0.081	0.252	0.125
SAVI	0.849	-0.277	0.378	0.182
Aggregated SAVI	0.802	-0.122	0.377	0.184

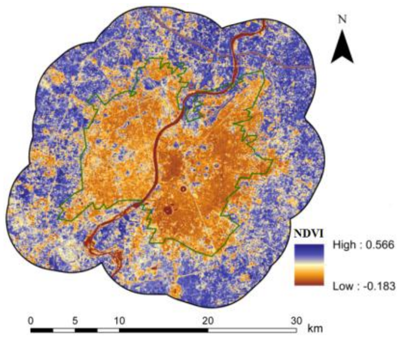

Fig. 5. NDVI image derived from Landsat data acquired on 2013 October 13

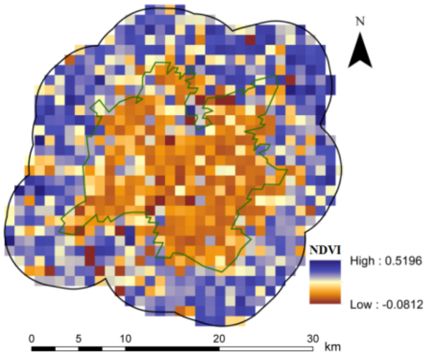

Fig. 6. Aggregated NDVI image derived from Landsat data acquired on 2013 October 13

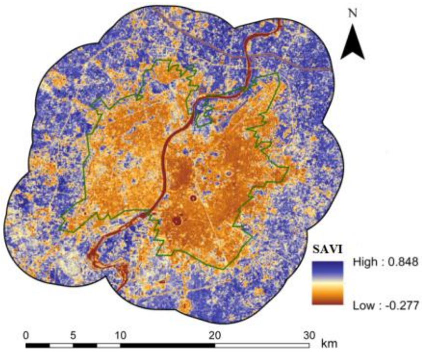

Fig. 7. SAVI image derived from Landsat data acquired on 2013 October 13

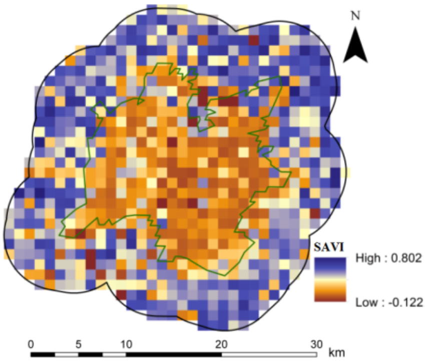

Fig. 8. Aggregated SAVI image derived from Landsat data acquired on 2013 October 13

The ranges between the maximum and minimum values of NDVI and SAVI were 0.75 and 1.13, respectively as per the statistical results in table V. Regression analysis has been applied to find out the relationship between LST with NDVI and SAVI.

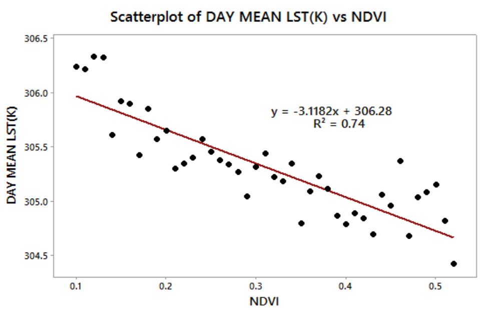

Fig. 9. Day mean LST vs NDVI scatterplots of the study area for 2013 October 13

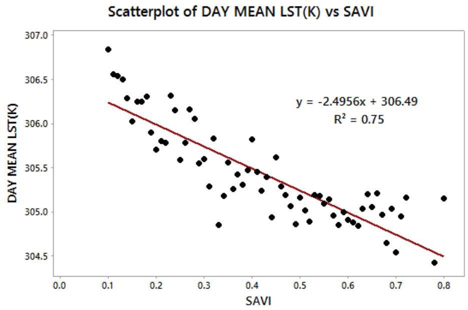

Fig. 10. Day mean LST vs SAVI scatterplots of the study area for 2013 October 13

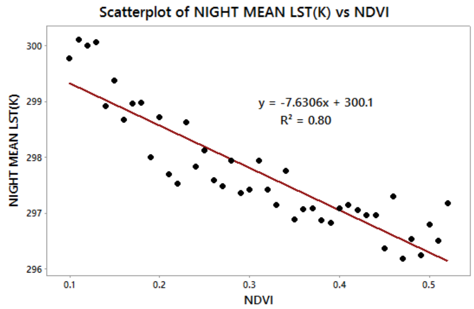

Fig. 11. Night mean LST vs NDVI scatterplots of the study area for 2013 October 13

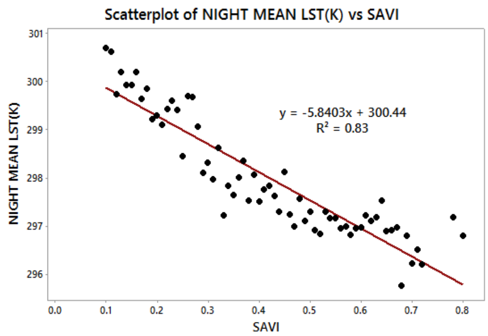

Fig. 12. Night mean LST vs SAVI scatterplots of the study area for 2013 October 13

Fig. 9 and Fig. 10 show day mean LST vs NDVI and day mean LST vs SAVI scatterplots, respectively of the study area for 2013 October 13. It has been observed that there is a negative correlation between LST and vegetation indices which means that green spaces can reduce the effect of UHI. The coefficient of correlation (R^2) between mean LST and SAVI for day and night time are 0.75 and 0.83, respectively. The corresponding R^2 value for mean LST and NDVI for day and night time are 0.74 and 0.80, respectively. These results show that SAVI is a better parameter for UHI studies than NDVI and night LST-VIs relationship shows stronger relationship than the day LST-VIs relationship.

V. CONCLUSION

In the present study, LST, NDVI and SAVI have been derived using Landsat OLI/TIR and MODIS sensor data and the relationships between LST with NDVI and SAVI have been investigated for the Ahmedabad study area. It has been observed that most of the hot pixels are located in the north east and eastern part of the Ahmedabad city where airport and industrial areas are situated. Central part of the city shows very less number of hot pixels especially during day time due to the presence of Sabarmati river. The areas with built-up areas and human activities show higher LST compared to green vegetation cover areas. That is urban areas show smaller NDVI and SAVI values compared to rural areas and there is a strong negative relationship between LST and vegetation indices in the study area. From the results, it has been concluded that SAVI can be used as a good parameter for UHI studies than NDVI which shows strong negative relationship with LST especially during night time. Urban sprawling also contributes the major changes in the surface temperatures of Ahmedabad study area.

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