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Land Surface Temperature Estimation using Landsat ETM+ Data

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Abstract
Land Surface Temperature (LST) can be estimated from remotely sensed satellite data. LST is a key parameter in the physics of land surface processes because it is involved in the energy balance as well as in the evapo-transpiration and desertification processes. The knowledge of surface temperature is important to a range of issues and themes in earth sciences central to urban climatology, global environmental change, and human-environment interactions. In this study an attempt has been made to estimate surface temperature over a part of Thar Desert area using Landsat-7 ETM+ satellite data. The variability of these retrieved LSTs has been investigated with respect to different land use/ land cover (LULC) types determined from the Landsat visible and NIR channels. The emissivity per pixel has been retrieved directly from satellite data and has been estimated as narrow band emissivity at the satellite sensor channel in order to have least error in the surface temperature estimation. The results suggest that the methodology is feasible to estimate NDVI and surface temperature with reasonable accuracy over desertic terrain.

Keywords: *land surface temperature, NDVI, satellite data, Landsat ETM+*

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INTRODUCTION

Land Surface Temperature (LST) can be estimated from remotely sensed satellite data. LST is a key parameter in the physics of land surface processes because it is involved in the energy balance as well as in the evapotranspiration and desertification processes [1].The extensive requirement of land surface temperature (LST) for environmental studies and management activities of the Earth's resources has made the remote sensing of LST an important academic topic during the last two decades[2]. Land surface temperature can provide important information about the surface physical properties and climate which plays a role in many environmental processes [3]. LST is sensitive to vegetation, soil moisture and it can be used to detect LU/LC changes, e.g. tendencies towards urbanization, desertification, etc. One of the most important parameters in all surface-atmosphere interactions and energy fluxes between the ground and the atmosphere is land surface temperature [4]. In the literature review, normally researchers use split window methods for retrieving the LST values. But Landsat ETM+ has only one thermal band due to which it makes use of split window impossible. The objective of this study was to propose a mono window technique for retrieving the LST from Landsat ETM+ with combined surface emissivity and the solar angle, θ. The emissivity values used in this study were calculated based on the NDVI values.

METHODOLOGY

Satellite Landsat ETM+ image of 5^{th} May 2010 was used for LST retrieval over Thar Desert in Jaisalmer district of Rajasthan. Surface emissivity values were considered to be 1 as the area is mostly covered by sand. An easy procedure for retrieving the land surface emissivity (LSE) was based on the NDVI [5]. The method proposed obtains the emissivity values from the NDVI considering different cases:

(a) *NDVI < 0.2*

In this case, the pixel is considered as bare soil and the mean emissivity value was 0.97 (Sobrino et al., 2004).

(b) *NDVI>0.5*

Pixels with NDVI values higher than 0.5 are considered as fully vegetated, and then a constant value for the emissivity is assumed, typically of 0.99.

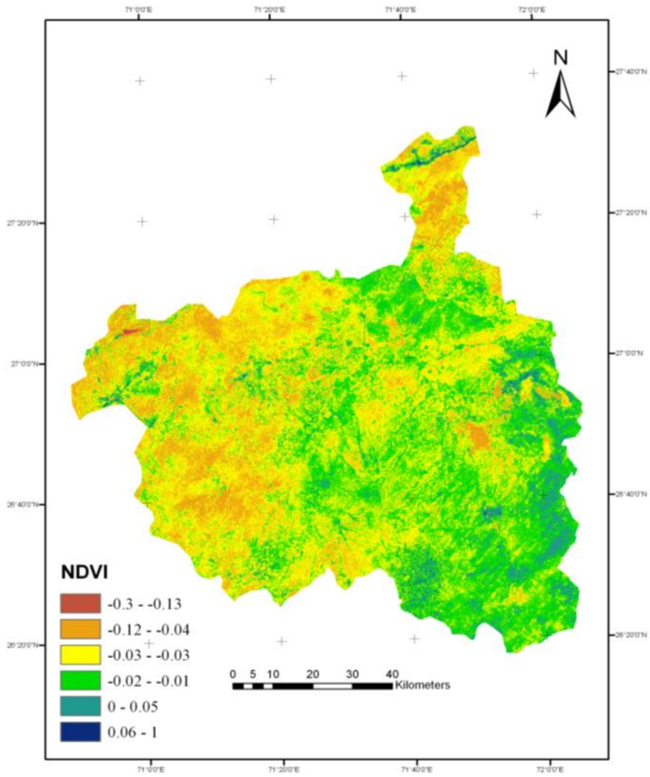

Fig. 1: *NDVI Map of the Study Area.*

(c) *0.2<NDVI<0.5*

In this case, a mixture of the bare soil and vegetation composes the pixel, and the emissivity is calculated according to the following equation:

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s (1 - P_v) + d\varepsilon$$

where ε_v is the emissivity of the vegetation and ε_s is the soil emissivity, P_v is the vegetation proportion obtained according to (Sobrino et al., 2004):

$$P_v = \left[\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right]^2$$

where $NDVI_{max}$=0.5 & $NDVI_{min}$=0.2

The term in equation for emissivity include the effect of the geometrical distribution of the natural surfaces and also the internal reflections. For plain surfaces, this term is negligible, but for heterogeneous and rough surfaces, as forest, this term can reach a value of 2%. A good approximation for this term can be given by:

$$d\varepsilon = (1 - \varepsilon_s)(1 - P_v) F \varepsilon_v$$

Where, *F* is a shape factor [6] whose mean value, assuming different geometrical distribution, is 0.55.

However in the present study we did not obtain NDVI value more than 0.2. Thus our study belonged to case (a).

Estimation of Surface Temperature by using Landsat-7 ETM++

The maximum radiance depends on the spectral band and gain setting (Table 1). Conversions from digital number (DN) to spectral radiance of each band are done as follows:

$$L_\lambda = Gain \times DN + Bias = \left(\frac{L_{\max} - L_{\min}}{255} \right) \times DN + Bias$$

where, L_λ= Spectral radiance at the sensor ($Wm^{-2}sr^{-1}\mu m^{-1}$) & Bias = L_{min}

Table 1: *Landsat-7 ETM+ spectral radiance range ($Wm^2/sr/\mu m$).*

Band number	Before July 1, 2000				After July 1, 2000			
	Low Gain		High Gain		Low Gain		High Gain	
	Lmin	Lmax	Lmin	Lmax	Lmin	Lmax	Lmin	Lmax
1	-6.2	297.5	-6.2	194.3	-6.2	293.7	-6.2	191.6
2	-6.0	303.4	-6.0	202.4	-6.4	300.9	-6.4	196.5
3	-4.5	235.5	-4.5	158.6	-5.0	234.4	-5.0	152.9
4	-4.5	235.0	-4.5	157.5	-5.1	241.1	-5.1	157.4
5	-1.0	47.70	-1.0	31.76	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65	0.0	17.04	3.2	12.65
7	-0.35	16.60	-0.35	10.932	-0.35	16.54	-0.35	10.80
8	-5.0	244.0	-5.0	158.40	-4.7	243.1	-4.7	158.3

Source: Landsat-7 ETM+ user handbook

Band 6L was used in the estimation of surface temperatures. The thermal radiance values were converted to surface temperatures using the pre-launch calibration constants [7]. The surface temperature for Landsat-7 ETM+ is estimated using,

$$Ts_6 = \frac{K_2}{Ln\left(\varepsilon_{o\_final} \times (K_1 / L_\lambda) + 1\right)}$$

Where Ts_6 is the effective satellite temperature (Kelvin), K_2 and K_1 are calibration constants (Table 2), and L_λ is spectral radiance in $Wm^{-2}sr^{-1}\mu m^{-1}$.

Table 2: *Thermal Band Calibration Constants.*

Band	K_1 ($Wm^{-2}sr^{-1}\mu m^{-1}$)	K_2 **(Kelvin)**
Band 6L	666.09	1282.71

Source: Landsat-7 ETM+ user handbook

The above algorithm was used for derivation of surface temperature. The algorithm was modeled using model maker in Erdas Imagine 9.2. (Figure 2)

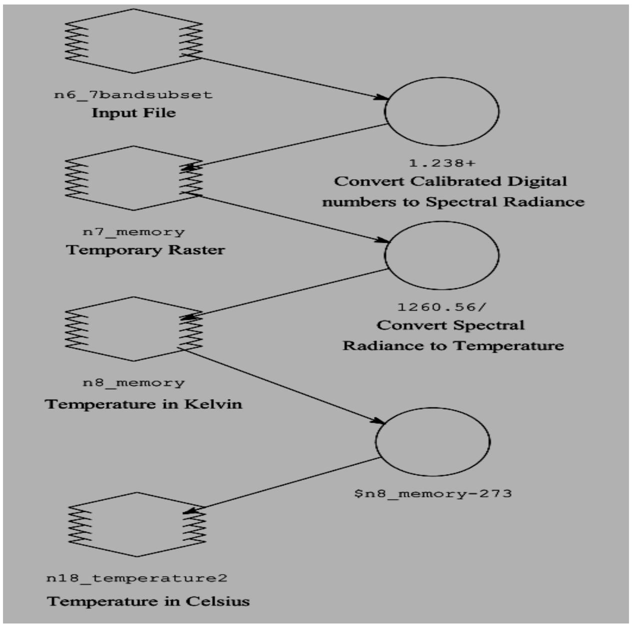

Fig. 2: *Model used to estimate surface temperature using Model Maker.*

RESULTS AND DISCUSSION

A total set of 35 observations of temperature was recorded in the study area during the 1st week of May 2010. We observed a good correlation (Figure 3) between the field values and the values derived from the landsat data with a little deviation as many factors affect the retrieval of LST from satellite thermal infrared data, such as transmittance, air moisture, down welling and upwelling radiance, which are usually difficult to obtain, especially from satellite observations. We did not remove this variable from the model because Sutherland and Bartholdi (1979) [8] had demonstrated that for an assumed emissivity at the quantity of 1.00, an error of as high as 6ºC could arise, whereas if an adjustment on emissivity was made, a maximum error could be only 0.8ºC. Thus if more ground truth temperature data is collected in different 'emissivity classes', the accuracy of the model can be further improved.

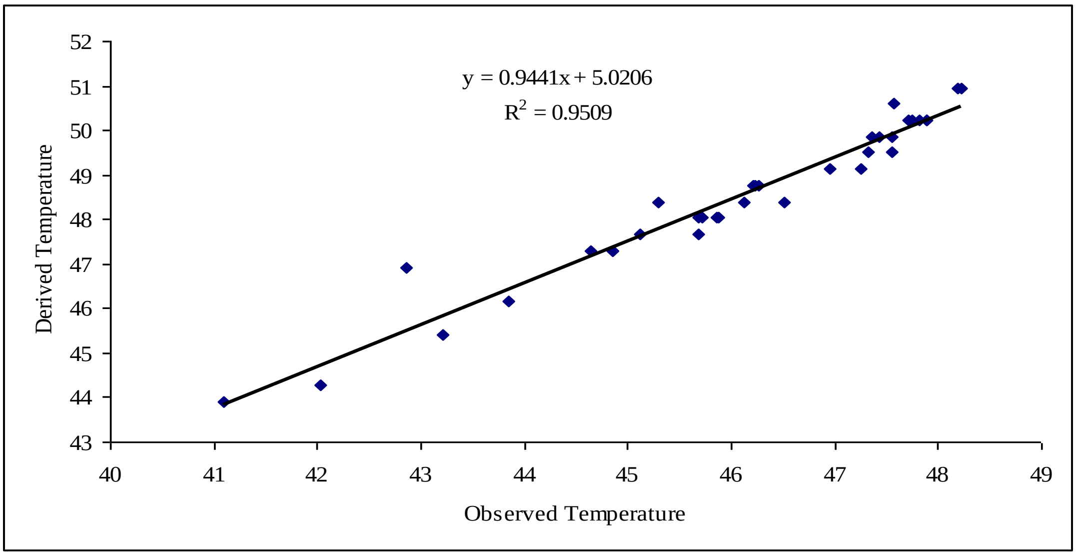

Fig. 3: *Correlation of Observed and Derived Temperature Values.*

Analysis of Surface Temperature of Landsat-7 ETM+

Figure 4 shows the spatial distribution of surface temperature of Landsat-7 ETM+. The LST ranged from 30.01 to 54.19 °C. It is observed that northern, north-western part exhibits high temperature mainly due to presence of sand sheet/dunes or bare soil or eroded hills. Lower temperatures are observed in western (near Jaisalmer Town) and some of southern part of the study area due to presence of moisture content in the soil and water bodies. Table 3 shows the estimated surface temperature values over different LULC classes. The impact of soil moisture or high water content can be clearly observed in some western and southern parts of study area.

Analysis of Land use/Land Cover

The FCC image of Landsat-7 ETM+ data (5th May, 2010) was used for LULC analysis. Hybrid classification was used to perform classification of the Landsat-7 ETM+ image. The maximum part of the study area had classes as open land which is actually sand sheet (58.7%) followed by agriculture land (17.80%), scrubland (16.35%) and dunes (5.5%). Rest of the classes such as wasteland, playa, water, built-up and trees cover a very small portion in the study area (Figure 5). The overall classification accuracy of 82.86% and kappa statistics of 0.79 has been observed.

After validating the model based on observed and derived temperature values we calculated the temperature values of different land use and land cover classes. The average values of derived temperature from Landsat-ETM+ data for different LULC classes are given in Table 3.

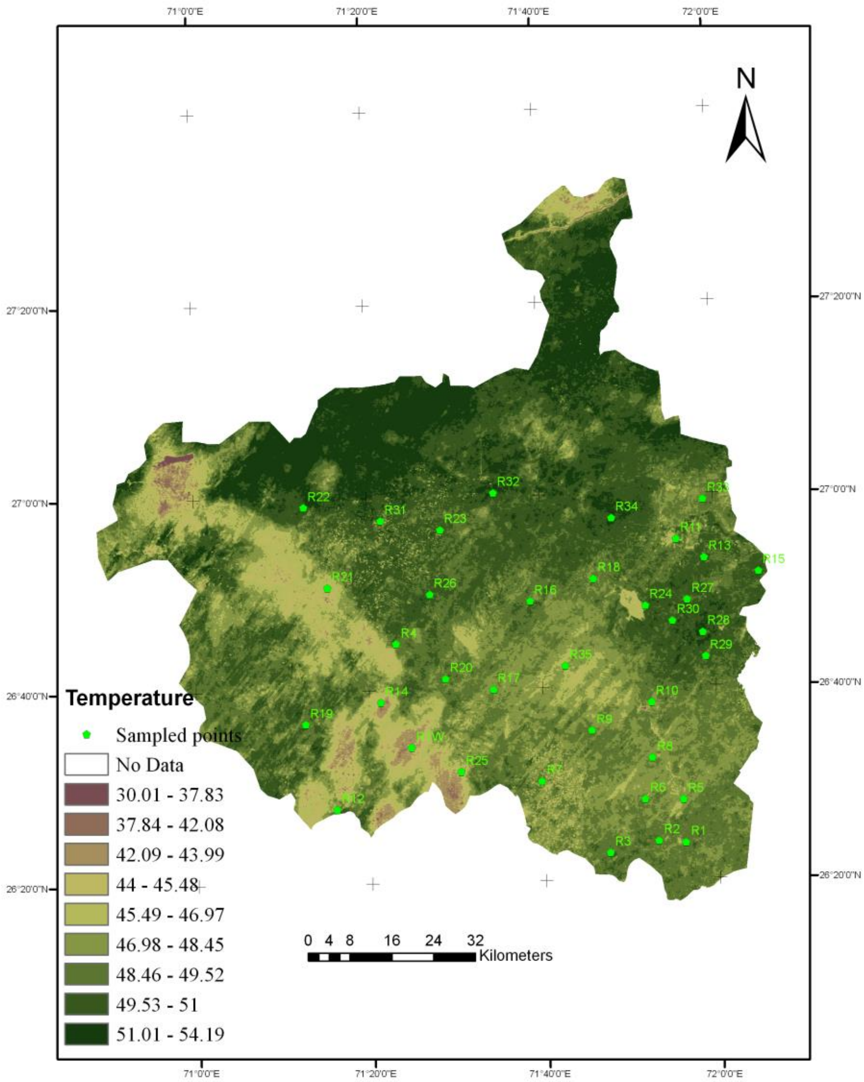

Fig. 4: *Temperature derived using Landsat-ETM+ Data.*

Table 3: *Temperature of LULC Classes derived from Landsat-ETM+ data.*

LULC Classes	Derived Temperature
Builtup	47.29
Dunes	50.23
Openland	50.96
Agricultural Land	49.87
Scrubland	49.87
Playa	49.87
Playa With Water	46.17
Water Body	32.87
Wasteland	49.13
Canal Water	41.62
Trees	49.50

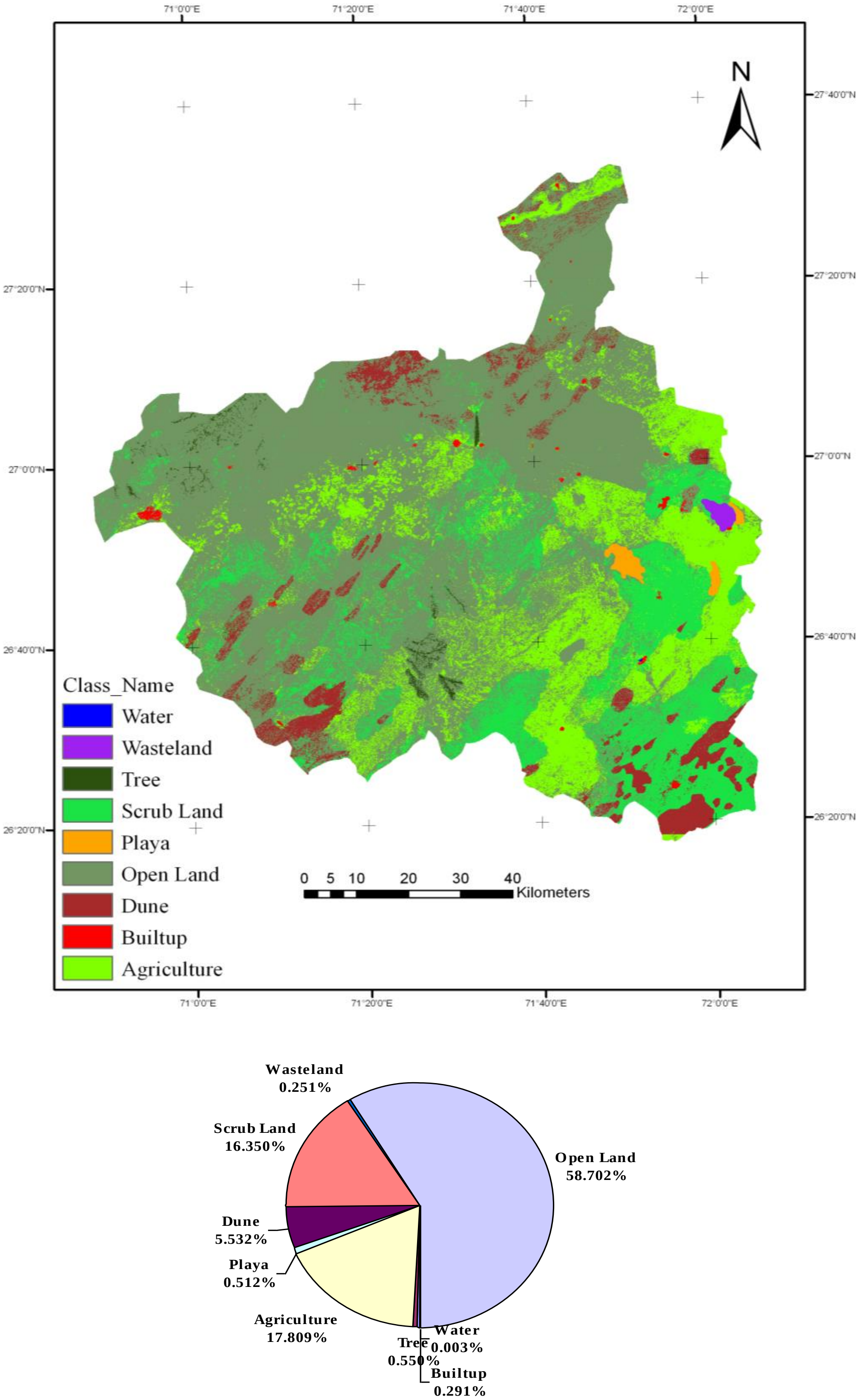

Fig. 5: *LULC Map of study area with percentage contribution of LULC classes.*

CONCLUSION

The potential of remote sensing to study the desert temperature variability is presented by estimating the spatial distribution. Emissivity and surface temperature enables better understanding of the overall suitability of land classes and in turn helps in understanding the energy budget issues. This suggests causes and effects, as an important addition to conventional methods of monitoring the desertic environment. The results show that the satellite derived temperature values showed good correlation with field data. The derived surface temperature values are found to be in good agreement with the field measured values.

In summary, this simple method can be applied to achieve a quick prediction of LST from Landsat ETM+ data with fewer parameters in reasonable accuracy.

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