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ESTIMATION OF LAND SURFACE TEMPERATURE-VEGETATION ABUNDANCE RELATIONSHIP USING LANDSAT TM 5 DATA

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ABSTRACT

Land surface temperature (LST) is an important factor for range of issue such as global climate change, desertification, deforestation, land cover assessment, energy balance estimations ,environmental studies and change in agricultural pattern .Vegetation abundance is one of the most influential factors in controlling LST measures through partitioning of solar radiation into fluxes of sensible and latent heat and by limiting the proportions of vegetation and ground .In the study, an attempt has been made to estimate surface temperature using Landsat TM satellite data. Thermal emissivity was estimated using Vegetation Cover Method (VCM) which is a important factor for surface temperature estimation. Relationship between land surface temperature and different land cover were analyzed. Strong correlation was observed between surface temperature and vegetation abundance over different land cover in study area. Relation between land surface temperature and vegetation abundance has also been estimated and indicating that surface temperatures can be predicted if NDVI or vegetation farction values are known. The results suggest that land surface emissivity estimation from VCM and land surface temperature using Landsat Tm 5 data can be used in vegetation condition assessment.

KEYWORDS: Land surface temperature, vegetation abundance, emissivity Landsat TM 5

INTRODUCTION

Land surface Temperature (LST) controlled by the surface energy balance, atmospheric state, thermal properties of the surface and is an important factor controlling most physical, chemical and biological processes of the earth [1].LST is a good indicator of land degradation and climate change and may be used for drought detection and impact assessment based on the estimation of indices of vegetation stress, especially designed to monitor vegetation health, moisture and thermal condition [2].

Surface radiant temperature response is a function of varying surface soil water content and vegetation cover [3] .A higher level of latent heat exchange was found with more vegetated areas while sensible heat exchange more favored by sparsely vegetated such as urban areas [4].

Retrieval of LST from multispectral TIR data requires an accurate measurement of emissivity value of the surface (Caselles et. al 1995).Emissivity of a surface is controlled by water content, chemical composition, structure and roughness [5].

For vegetated surfaces, emissivity can vary significantly with plant species, areal density and growth stage [5].Emissivity is a function of wavelength, commonly referred to as spectral emissivity [6].

Estimation of emissivities for ground objects from passive sensor data has been measured using different techniques. Among these techniques are the, Normalized emissivity method [7],thermal spectral indices [1],spectral ratio method [8],alpha residual method [9] ,NDVI method [10] ,classification based estimation [5](Snyder et al 1998 and the temperature emissivity separation method [7].These techniques are applicable to separate temperature from emissivity ,so that the effect of emissivity on estimated LST can be determined.

Fractional vegetation cover depicts the amount and nature of vegetation cover and modulates the proportion of vegetation and ground (bare soil) visible to a sensor.as the amount of vegetation cover increase ,the radiative temperature recorded by a sensor approximate more closely the temperature of green leaves [11].In general, for image pixels that are not completely occupied by a single homogeneous vegetation or bare soils,LST measurement reflect a mixture of soil and vegetation canopy temperature ,resulting from a composite signature.

For any surface materials, certain internal properties, such as heat capacity .thermal conductivity and inertia, play important roles in governing the temperature of a body at equilibrium with its surroundings [12].These thermal properties vary with soil type and moisture content [13].Dry, bare and low density soils have been linked to high LST as a result of relatively low thermal inertia [14] , [15].The emissivity of soils is a function of soil moisture condition and soil density [15] .

The relationship between LST and vegetation indices such as NDVI has been extensively documented in literature. The basis for using NDVI in LST estimation is that amount of vegetation present is an important factor and NDVI can be used to infer general vegetation conditions. The combination of LST and NDVI by scatterplot result in triangular shape [16], [17],[18.The slope of LST-NDVI curve has been related to soil moisture condition [11],[16],[17],[18] ,[19] and evapotranspiration of the surface [20].

In the present study, we have used the Vegetation Cover Method (VCM) developed by [10] based on the relationship between emissivity in thermal infrared and normalized difference vegetation index. In the VCM, surface emissivities are predicted from visible and near infrared bands because VCM identifies vegetated areas and soil for which ε is known a-priori.The objective of this study was to (1) Estimate the emissivity value using VCM (2) retrieve the land surface temperature from Landsat 5 TM thermal band (10.4-12.5 µm) (3) estimation of land surface temperature - vegetation abundance relationship (NDVI and vegetation fraction).

STUDY AREA AND DATA ACQUISITION

Sirsa district in Haryana state, India, lies between $29^0$14’ and 30^0 North latitude and 74^0 29’ and 75^0 18’East longitudes, forming the extreme west corner of Haryana shown in Fig.1. It is bounded by Punjab in the north, Ganga Nagar district of Rajasthan in the west and Hisar district in the east. It lies in arid hot agro ecological zone of India.

Fig.1: Study area map

Landsat image on, 21st September 2009 was downloaded free of charge from U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) via http://glovis.usgs.gov. The satellite track in path and row is (148/39, 148/40).Atmospheric correction of satellite data was done using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) module of ENVI 4.7. Training sites were selected for different land covers throughout the study area and statistics (mean and standard deviation) were extracted for NDVI, surface temperature, vegetation farction and emissivity. Landsat TM 5 (VNIR) band was resampled to 120 m pixel size to match pixel sizes with Thermal band 6.

METHODOLOGY

DN value were converted to at sensor radiance for Landsat TM5 using

$$L\lambda = \frac{(\mathrm{Lmax}-\mathrm{Lmin})}{(\mathrm{Qcalmax}-\mathrm{Qcalmin})} * (\mathrm{DN}-\mathrm{Qcalmin}) + \mathrm{Lmin} \quad \dots (1)$$

$L\lambda$ = spectral radiance at sensor’s aperture for each band ($\mathrm{Wm^{-2}Sr^{-1}\lambda^{-1}}$)
Lmax = maximum spectral radiance for each band
Lmin = minimum spectral radiance for each band
Qcalmax = Maximum Digital number Value
Qcalmin = Minimum Digital number Value

Normalized Difference Vegetation index

Normalized Difference Vegetation index (NDVI) for each pixel through satellite data is calculated using the following relation [21],

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \quad \text{..... (2)}$$

Where ρ_{nir} = reflectance in near infrared band (TM band 4)
ρ_{red} = reflectance in Red band (TM band 3)

Estimation of emissivity and Fractional vegetation cover (Pv)

The VCM is model for the Land syurface emissivity (LSE) of a pixel that provides the effective emissivity of a heterogeneous and rough surface,ε,as

$$\varepsilon = \varepsilon_v P_v + \varepsilon_g (1 - P_v) + 4\delta\varepsilon P_v (1 - P_v) \quad \ldots(3)$$

Where ε_V represents vegetation emissivity, P_V is the fractional vegetation cover, ε_g is bare soil emissivity and $\delta\varepsilon$ is the cavity term that is related to the radiance emitted indirectly through internal reflections occurring between crop walls and the ground [10]. Emissivity values for vegetation and bare soil can be measured in the field [22] or obtained from a database [23].Weighted value ($\delta\varepsilon$) of 0.015 has been adopted in present study from literature [10]. For the calculation of emissivity values, the term ε_V and ε_S, i.e., the emissivity values of pure vegetation and soil pixels are taken as 0.985 and 0.960 respectively from literature [10].

Determination of the fractional vegetation cover is calculated using the NDVI, with the following expression [10]:

$$P_v = \frac{\left(1 - \frac{NDVI}{NDVI_g}\right)}{\left(1 - \frac{NDVI}{NDVI_g}\right) - K\left(1 - \frac{NDVI}{NDVI_v}\right)} \quad \ldots.\ (4)$$

where $NDVI_g$ and $NDVI_V$ represent the minimum and maximum values of the NDVI image, respectively, which, provided that the area is large enough, will correspond with areas with no vegetation (bare soil) and with full vegetation coverage.

The K parameter for a Landsat TM is calculated as
[10]:

$$K = \frac{\rho_{4v} - \rho_{3v}}{\rho_{4g} - \rho_{3g}} \quad \ldots\ldots.(5)$$

Where, ρ_{4v} and ρ_{3v} are the reflectances in the near infrared (TM band 4) and in the red (TM band 3) for the area with full vegetation cover and ρ_{4g} and ρ_{3g} the reflectance in near infrared and red for the area without vegetation (bare soil).

Estimation of Land surface Temperature

The thermal radiance values were converted to surface temperatures using the pre-launch calibration constants [24.The surface temperature for Landsat TM is estimated using,

$$Ts = \frac{K_2}{Ln\left(\varepsilon * \left(1 + \frac{K_1}{L\lambda}\right)\right)} \quad \ldots\ldots(6)$$

Where,
Ts = Effective at-sensor brightness temperature (in Kelvin)
K_2 = Calibration constant 2 (in Kelvin) [1260.56 for Landsat 5 TM and 1282.71 for Landsat 7 ETM+]
K_1 = Calibration constant 1 [W/ (m^2 sr μm)], [607.76 for Landsat 5 TM and 666.09 for Landsat 7 ETM+]
Lλ = Spectral radiance at the sensor's aperture [W/ (m^2 sr μm)]
LN = Natural logarithm

RESULT AND DISCUSSION

Characteristics of LST, NDVI and vegetation Fraction

Fig.2 (a) shows the spatial distribution of NDVI value that varies from -0.130 to 0.86. Spatial variation of NDVI is not only subject to the influence of vegetation amount but also to topography, slope, solar radiation availability and other factors [23]. NDVI image displays the dark areas in south and centre part corresponding to soil and settlement. Bright area of high NDVI values were found along the Ghaggar River which indicate the high vegetation amount in the area while medium grey tones shows the cotton and other crops.

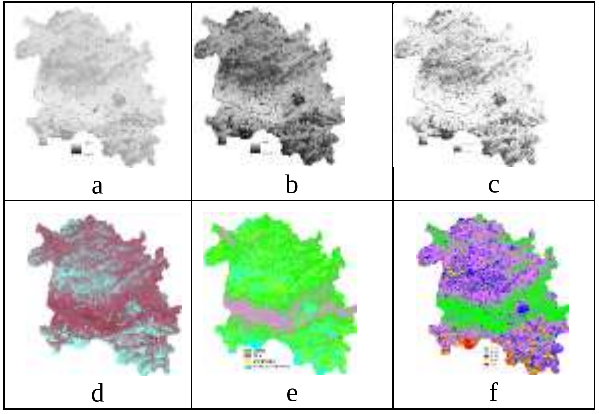

Fig.2: Spatial distribution of NDVI (a), Vegetation fraction (b), emissivity (c), FCC (d), Classified (e) and land surface temperature (f).

Similar spatial distribution pattern can be seen in the vegetation fraction image Fig.2(b) and emissivity image Fig.2(c) which has range between 0.960 to

0.990 respectively, Since a blackbody absorbs all the energy that reaches it, radiates a maximum heat flux compatible with its internal temperature and has a radiant temperature equal to its internal body temperature. Emissivity value increases as vegetation amount increases. Emissivity value of fully vegetated areas is 0.990 while soil has 0.960 because of thermal conductivity difference between vegetation and soil. Similar values have been found by [24]. Correlation between NDVI and vegetation fraction images is 0.99 while with emissivity of 0.98 indicating a positively strong correlation.

Similarly correlation between NDVI and LST is -0.87, This indicates that as vegetation amount increase, surface temperance goes down to maintain vegetation temperature. Using this relationship, we can estimates the surface temperature of individual pixel which will help to assess the water stress in crops and its timely recovery.

Fig.2 (d) shows the false color composite image of the study area while Fig.2 (e) shows land cover of the study area. Rice is cultivated along the Ghaggar river while cotton is cultivated in major area. Other crops in Sirsa district is cluster bean, sorghum and fodder.

Fig. 2(f) shows the spatial distribution of surface temperature in study area. Surface temperature ranged from 26.62 to 49.78 ^{0}C. High temperature lies in south part of study area because of dry soil (red color) with standard deviation of 4.29 ^{0}C, indicating the dry and wet soil temperature difference .Along the Ghaggar river temperature range lies between 25-30 ^{0}C, indicating rice grown area and shown as green color in map. Average temperature of the rice grown area is 27.98 ^{0}C with standard deviation of 0.36 ^{0}C; this shows that surface temperature almost remains same throughout the rice grown area. While standard deviation value of surface temperature for other crops was (1.11^{0}C) indicating the mixed proportion of soil and vegetation in the study area. The other vegetation is mostly cluster bean which have very sparsely populated here. Lowest temperature was found in rice grown areas (26.62 ^{0}C) while highest temperature was in dry soil (49.78 ^{0}C). Table 1 indicates the statistical information of different land covers. Average temperature and standard deviation value of surface temperature for cotton was 30.77 ^{0}C and 0.78 ^{0}C, respectively, indicating the full vegetation cover is having less variation in surface temperature.

Table 1. Descriptive statistics of biophysical parameters of land cover types

Land Cover	Mean NDVI (SD)	Mean VF (SD)	Emissivity (SD)	Mean LST (SD)
Rice	0.75 (0.015)	0.73 (0.024)	0.990 (0.00029)	27.98 (0.36)
Cotton	0.66 (0.023)	0.60 (0.029)	0.986 (0.00103)	30.77 (0.78)
Other	0.54 (0.031)	0.46 (0.033)	0.983 (0.00249)	33.74 (1.11)
soil	0.13 (0.040)	0.09 (0.030)	0.960 (0.00595)	41.96 (4.29)

Relationship between LST and Vegetation abundance:

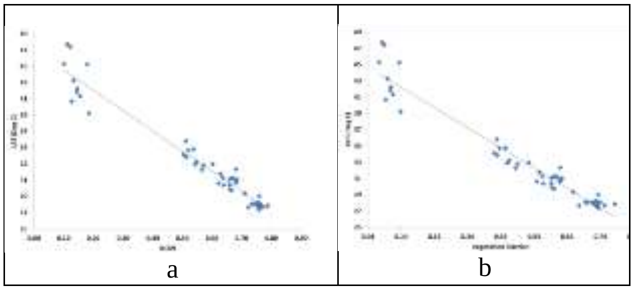

Fig.3 shows relationship between NDVI and vegetation fraction.

Strong correlation between surface temperature and NDVI including soil and vegetation promise a potential success for using regression models to predict the surface temperature. Similar relationship was found between surface temperature and vegetation fraction. Strong correlation between surface temperature and vegetation abundance (NDVI, Vegetation fraction) shows a potential to predict the surface temperature if NDVI or vegetation fraction is known. Multiple coefficient of determination R^2 is 0.9499, indicating that the predictor NDVI account for 94.99 % of variance in surface temperature, the adjusted R^2 is 0.9489. If the vegetation fraction (P_v) is used a predictor the multiple coefficient of determination R^2 would be 0.9433 and adjusted R^2 would be 0.9421.These results suggest that both vegetation fraction (P_v) and NDVI can be used as predictor of surface temperature. These results show the strong relationship between surface temperature and vegetation abundance (vegetation fraction and NDVI).

Table 2: Linear regression model for predicting surface temperature

Model	Coefficient of Determination,R^2	Adjusted, R^2
$LST = 45.69 - 24.76 * VF$	0.943	0.942
$LST = 47.04 - 24.91 * NDVI$	0.949	0.948
$LST = 46.86 - 21.22 * NDVI - 3.69 * VF$	0.950	0.948

Vegetation abundance is one of the most influential factors in controlling LST measures through partitioning solar radiation into fluxes of sensible and latent heat and by limiting the proportions of vegetation and ground. Results show that the unmixed vegetation fraction provides a slightly stronger negative correlation with LST for all land cover types. The results demonstrate that the interplay between thermal and vegetation dynamics creates unique signatures of these biophysical parameters in each land cover type and produce correlations among the images of LST, NDVI, and vegetation fraction.

CONCLUSION

In this paper, Vegetation Cover Method (VCM) has been applied in order to retrieve land surface emissivity which uses visible and near infrared data, Predicting surface emissivities from visible and near-infrared data provides high spatial resolution map of vegetation farction, emissivity and surface temperature. High resolution emissivity estimation can be useful to understand variation of radiant temperature of different land covers. One of the major advantage of VCM is that this is a simple way of emissivity estimation from proportion of vegetation and require only red and near infra-red band. Emissivity of vegetation and soil close to emissivity of vegetation and soil cited in literature. Surface temperature and vegetation abundance shows strong negative relationship.NDVI or vegetation farction can be used as predictor to estimate the surface temperature of different land covers. High spatial resolution surface temperature helps in assess land cover and also to monitor the vegetation condition in term of water and disease stress.

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