International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:11, No:9, 2017

The Use of Thermal Infrared Wavelengths to Determine the Volcanic Soils

Levent Basayigit, Mert Dedeoglu, Fadime Ozogul

Abstract**—**In this study, an application was carried out to determine the Volcanic Soils by using remote sensing. The study area was located on the Golcuk formation in Isparta-Turkey. The thermal bands of Landsat 7 image were used for processing. The implementation of the climate model that was based on the water index was used in ERDAS Imagine software together with pixel based image classification. Soil Moisture Index (SMI) was modeled by using the surface temperature (Ts) which was obtained from thermal bands and vegetation index (NDVI) derived from Landsat 7. Surface moisture values were grouped and classified by using scoring system. Thematic layers were compared together with the field studies. Consequently, different moisture levels for volcanic soils were indicator for determination and separation. Those thermal wavelengths are preferable bands for separation of volcanic soils using moisture and temperature models.

Keywords**—**Landsat 7, soil moisture index, temperature models, volcanic soils.

I. Introduction

SOIL moister is an significant characteristic as color, texture, structure, mineralogy, organic matter, free carbonates, and salinity in the study of soil description and determination of distribution [1]. These properties can be predicted by spectral reflections obtained from remote sensing data [2], used with multivariate calibrations [3]. All of these in addition to remote sensing methods facilitate thematically mapping soil properties by reducing the need for extensive time-consuming and costly field surveys. Soils moister content influences spectral signature of soils through the absorption processes in middle infrared (MIR) and thermal infrared region (TIR). Soil water exhibits absorption peaks at about 1450 nm, 1880 nm, and 2660 nm [4]. In recent years, satellite-based techniques with thermal infrared remote sensing methods, have been used in many studies for the determination of surface soil moisture by using different moisture index [5]. The most common remote sensing data used for this purpose are Landsat, ASTER, and MODIS images which have been used for retrieving the surface variables required as inputs for energy balance modelling [6]-[8]. A linear relationship between soil moisture and surface temperature [9] is at the basis of the studies. Similarly, SMI uses land surface temperature (LST) and vegetation density to determine soil moisture, thus different values have been obtained for different soils [10]. LST reflects the water effects of the soil properties, and the vegetation index shows the complex conditions of the underlying surface. Many studies applied these two variables to study the SMI calculated through different remotely sensed data sources [5], [11]. Although remote sensing and soil spectroscopy have been recognized as a potentially effective and cost-efficient technology, they are not yet routinely used in soil surveys [8]. Our purpose of this research is to develop a new approach for determination of volcanic soils using SMI map that produced Landsat 7 ETM+ image. For this purpose, volcanic and other geological properties of soils have been utilized.

L. Basayigit is with Süleyman Demirel University, Agriculture Faculty, Soil Science and Plant Nutrition Department, Isparta Turkey, (phone: +90-246-2118589; fax: +90-246-2118696; e-mail: leventbasayigit@hotmail.com)

M. Dedeoglu is with Selçuk University, Agriculture Faculty, Soil Science and Plant Nutrition Department, Konya Turkey.

F. Özoğul is with Süleyman Demirel University, Graduate School of Natural and Applied Sciences, Isparta Turkey.

II. Material and Methods

A. Study Area and Data

The study area which is called Golcuk Formation was located in Isparta, Turkey, approximately 3450 hectares. Position of the area is upper left longitude 30° 27′ 27″ and latitude 37° 44′ 56″, lower right longitude 30° 31′ 47″and latitude 37° 42′ 2″ (Fig. 1), it includes different geological formations such as alluvion, limestone, volcanic tuff, and Golcuk Lake.

The study was carried out on the LANDSAT-7 Enhanced TM data in 2011 August. The data include the spatial resolution of thermal band (1.040 – 1.250 μm) with 60 m also spatial resolution of visible (630 – 690 μm for Red) and NIR (770 – 900 μm) band with 30 m.

B. SMI Calculation

SMI (1) is based on empirical parameterization of the relationship between LST and normalized difference vegetation index (NDVI) and it is calculated using (1) [12]-[15].

$$SMI = (LSTmax – LST) / (LSTmax – LSTmin) \quad (1)$$

where LSTmax and LSTmin are the maximum and minimum surface temperature for a given Landsat 7 Thermal Band (Band 6), and LST is the LST (2), the surface temperature of a pixel calculated from using Landsat Product Equals [16].

$$LST = BT / 1 + w * (BT / p) * \ln (e) \quad (2)$$

where, BT = At Satalite Temperature, w = wavelength of emitted radiance (λ → 11.45 μm), p = h * c / s ($1.438 * 10^{-2}$ mK) → p = 14380, c = light speed ($c = 2.9979\times10^{8}$ m/s), h = Planck' s Constant ($6.626 * 10^{-34}$ Js), s = Boltzmann Constant

$(1.38 * 10^{-23}$ J/K).

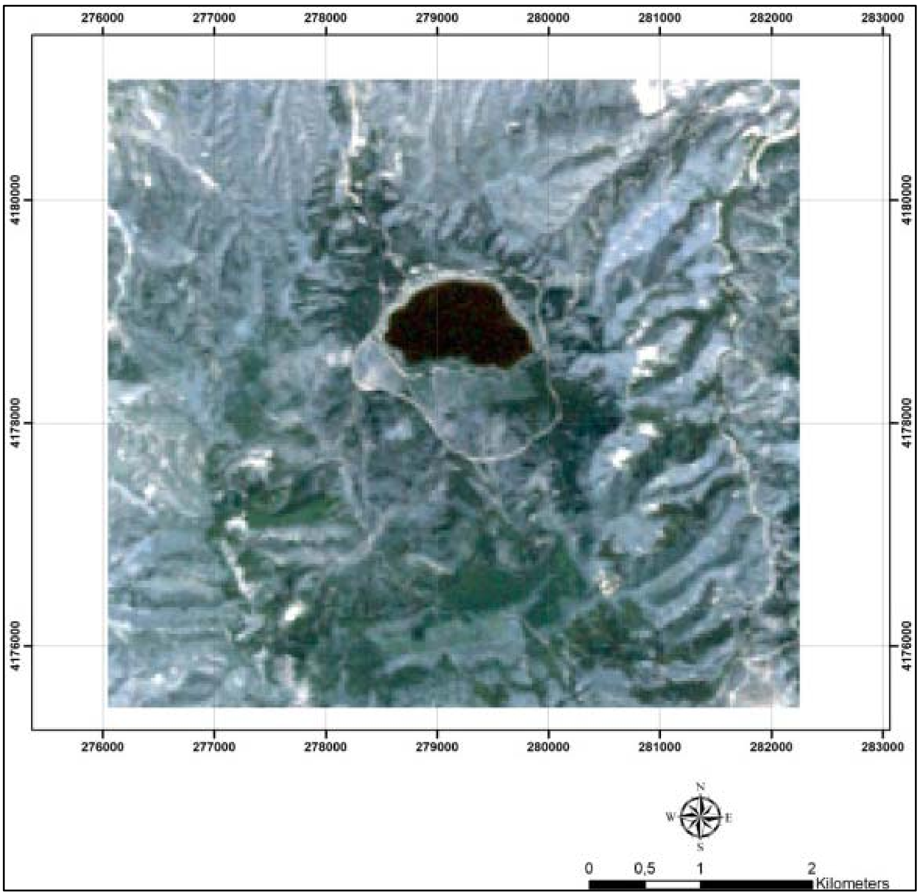

Fig. 1 Landsat 7 ETM + imagery from 2011 August

TABLE I
RADIOMETRIC RESCALING PARAMETERS OF ML AND AL

Radiometric Rescaling	Band 6
M_L	0.055375
A_L	1.18243

TIRS band data must be converted to TOA (Top of Atmosphere) spectral radiance using the radiance rescaling factors provided in the metadata file. To calculate brightness temperature from Landsat thermal bands, at first, we need to convert Landsat thermal band DN values to spectral radiance (3). The formula for converting DN to Top atmosphere spectral radiance is

$$L\lambda = M_L Q_{cal} + A_L \quad (3)$$

where; L_λ = TOA spectral radiance (Watts/(m^2 * srad * μm)), M_L = Band-specific multiplicative rescaling factor from the metadata. (RADIANCE_MULT_BAND_x, where x is the band number), A_L= Band-specific additive rescaling factor from the metadata, (RADIANCE_ADD_BAND_x, where x is the band number), Q_{cal} = Quantized and calibrated standard product pixel values (DN)

The values of M_L and A_L for band 6 for our study area are extracted from the metadata and are presented in Table I.

The spectral radiance can be converted to brightness temperature in Celsius using (4),

$$T = K_2 / \ln [(K_1 / L_\lambda) + 1 \quad (4)$$

where, T = At – Satellite Brightness Temperature (K), L_λ = TOA spectral radiance (W/ m^2 * srad * μm), K_1 and K_2 = Band – specific thermal conversion constant from the metadata.

The values K_1 and K_2 for band 6 for our study area were obtained from the metadata (Table II).

TABLE II
THERMAL CONSTANTS PARAMETERS OF K_1 AND K_2

Thermal Constants	Band 6
K_1	607.76
K_2	1260.56

Land Surface Emissivity (LSE) methods are properly applicable for LST retrieval from Landsat imagery. SMI can be determined using surface soil temperature and NDVI data obtained from Landsat 7 satellite image [17]. Differentiation of volcanic soils and their identification can be performed on the basis of the level of surface moisture. LSE average emissivity of an element of the surface of the Earth is calculated from measured radiance and LST [18]. LSE is a proportionality factor that scales blackbody radiance (Planck's law) to predict emitted radiance, and it is the efficiency of transmitting thermal energy across the surface into the atmosphere [19]. In this sense, LSE must be known in order to estimate land-surface temperature accurately from radiance measurements. We used the USGS equality to calculate for the LSE (5). This equality uses the NDVI Normalized Difference Vegetation Index (NDVI) algorithm (6) for determining land-surface temperatures [20].

$$LSE = 0.004P_V + 0.986 \quad (5)$$

where, P_V = Proportion of Vegetation, P_V = (NDVI – NDVImin) / (NDVI max – NDVI min)^2.

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (6)$$

NDVI for Landsat 7 (Band 4 – Band 3) / (Band 4 + Band 3).

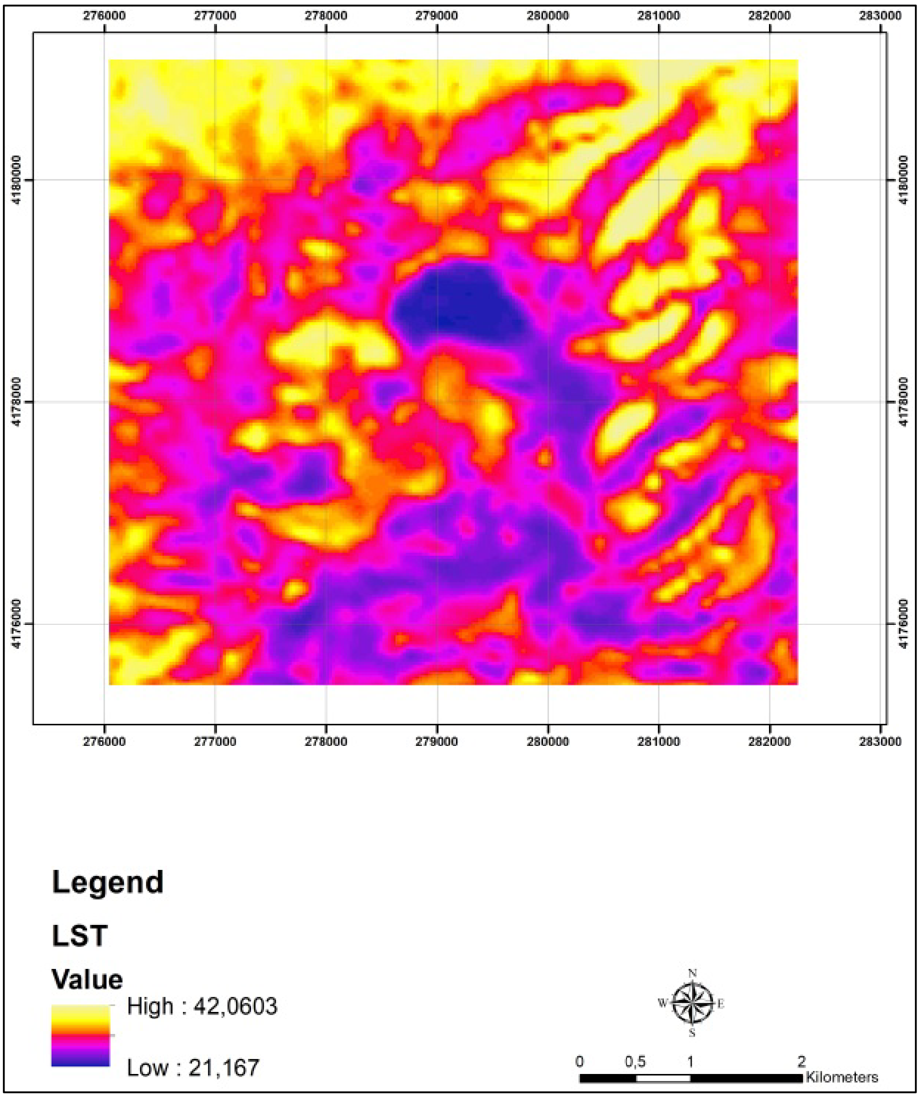

Fig. 2 LST map

We used ArcGis 9.3 software to perform NDVI analysis, store data, raster calculations, and generate thematic maps [21].

C. Determination of Volcanic Soils

Soils formed in volcanic ejecta have unique physical, chemical, and mineralogical properties that are rarely found in soils derived from other parent materials. These properties are largely attributable to the formation of noncrystalline materials (e.g. allophane, imogolite, ferrihydrite) containing variable charge surfaces, and the accumulation of organic matter [22]. In particular, the content of organic matter and the water retention capacity are decisive in the separation of the soil from other formations by using infrared spectroscopy [23]. When these properties are taken into consideration, they will be distinguished with their moisture values from other soil formations using SMI.

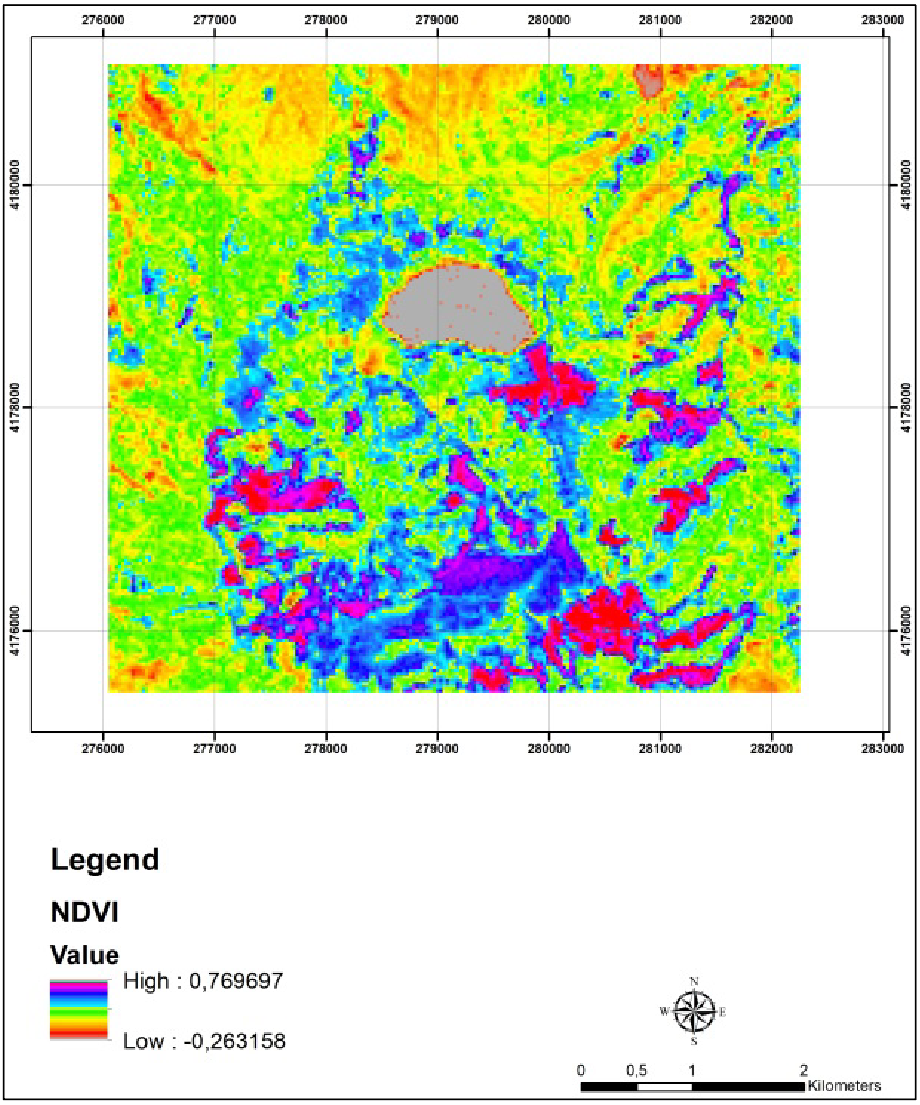

Fig. 3 NDVI map

III. Result and Discussions

In the study, LST data (Fig. 2) are derived by using NDVI (Fig. 3) and Thermal Band data from Landsat 7 ETM + satellite image. Descriptive statistics of the determined data are presented in Table III.

TABLE III
Descriptive Statistics of NDVI and LST

Variable	Mean	St. Dev	SE Mean	Min.	Max.
NDVI	0.251	0.298	0.002	-0.263	0.769
LST	32.035	5.755	0.523	21.167	42.060

According to the determined values, NDVI values change between -0.263 and 0.769 from the Golcuk Lake surface to intensive vegetation cover, while LST values show a regular distribution between 21.167 °C and 42.060 °C from the Golcuk Lake surface to bare soils which is the limestone in the area. Also, the soil moisture map determined as thematically depending on the LST is presented in Fig. 4. It was determined that soil moisture content decreases as the temperature increases when LST is compared with moisture content. It is indicated in the research that there is an inverse relationship between the surface temperature and moisture content [12], [14].

There is a strong correlation between surface temperature values calculated by TIR Emission and NDVI, and these parameters are directly related to soil moisture depending on Al – Fe humus complexes and plant cover [24]-[30]. Especially, the heat flow from the lake surface is lower than the bare soil as plant surface. Therefore, when the surface temperatures are determined, the humidity conditions of the vegetation covered areas are considered as a plant reflection factor. In this way, the water content of the plant and the surface temperature are combined to produce real results about the moisture status of the soil surface [5], [17], [30].

As a result, soil moisture levels can be determined by deriving from surface soil temperature and NDVI data using Landsat 7 satellite image. Volcanic soils separation and identification depending on the level of surface moisture can be done in areas other than soil formations

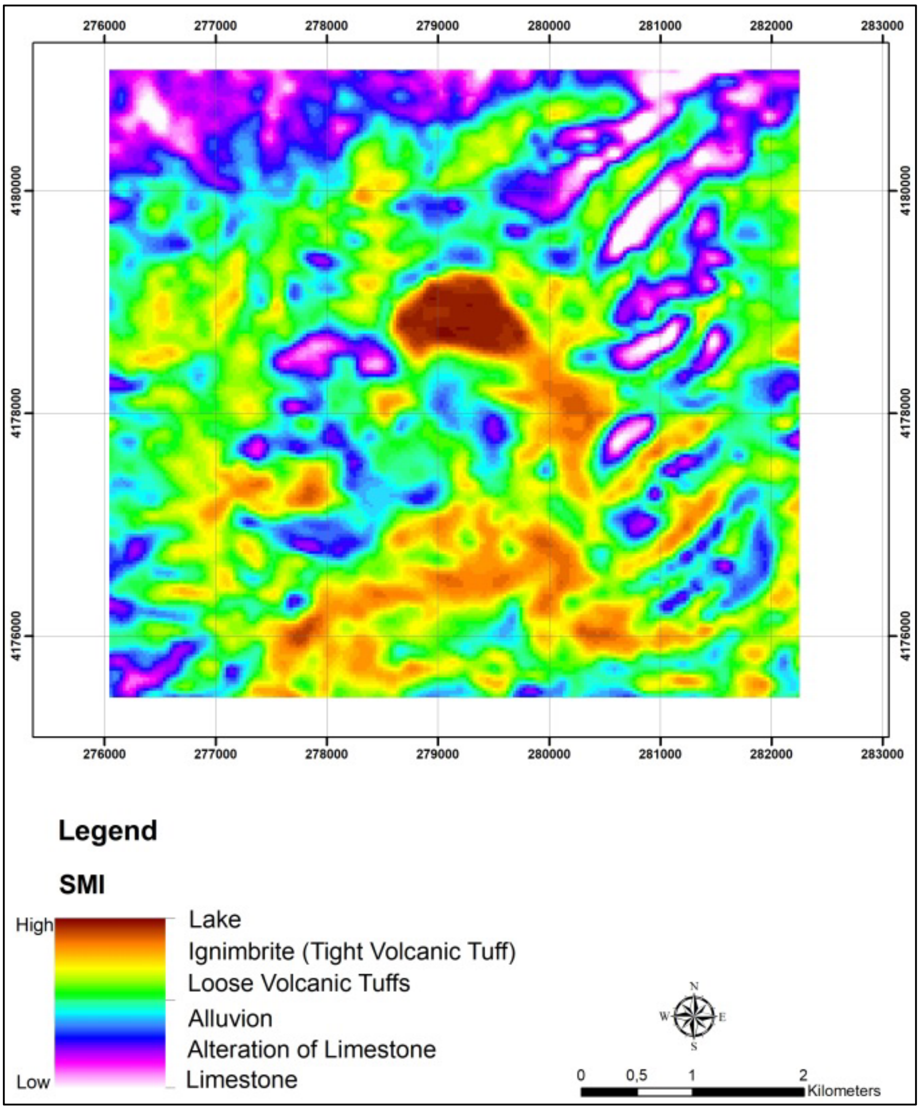

Fig. 4 Soil moisture map

IV. Conclusion

The estimation of SMI from the radiative transfer equation-based method using band 6 has the very high potential for the establishment of different soil formation. This result has brought a different perspective to the use of TIRS data for the studies of volcanic soils.

Acknowledgment

We would like to acknowledge the financial support of The Scientific Research Council of Suleyman Demirel University (SDÜBAP), Project No 4353-YL2-15.

References

[1] Manchanda, M. L., Kudrat, M., & Tiwari, A. K. (2002). Soil survey and mapping using remote sensing. Tropical ecology, 43(1), 61-74.
[2] Guerrero, C., Viscarra Rossel, R. A., & Mouazen, A. M. (2010). Diffuse reflectance spectroscopy in soil science and land resource assessment. Special Issue Geoderma, 158, 1−2.
[3] Rossel, R. V., & Chen, C. (2011). Digitally mapping the information content of visible–near infrared spectra of surficial Australian soils. Remote Sensing of Environment, 115(6), 1443-1455.
[4] Hoffer, R.M. 1978. Biological and physical considerations in application computer aided analysis techniques to remote sensing. pp 237-286. In:

P.H. Swain & S.M. Davis (eds.) Remote Sensing: Quantitative Approach. McGraw-Hill International Book Co.

[5] Zhang, D., Tang, R., Zhao, W., Tang, B., Wu, H., Shao, K., Li, Z. L., 2014. Surface soil water content estimation from thermal remote sensing based on the temporal variation of land surface temperature. Remote Sens., (6), pp. 3170-3187.

[6] French, A.N., et al., 2005. Surface energy fluxes with the Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) at the Iowa 2002 SMACEX site (USA). Remote Sens. Environ. 99 (1–2),55–65.

[7] Su, H., McCabe, M.F., Wood, E.F., Su, Z., Prueger, J.H., 2005. Modeling evapotranspiration during SMACEX: comparing two approaches for local- and regional-scale prediction. J. Hydrometeorology 6 (6), 910–922.

[8] Mulder, V. L., De Bruin, S., Schaepman, M. E., & Mayr, T. R. (2011). The use of remote sensing in soil and terrain mapping—A review. Geoderma, 162(1), 1-19.

[9] Moran, M.S.; Clarke, T.R.; Inoue, Y.; Vidal, A. Estimating crop water deficit using the relation of between surface air temperature and spectral vegetation index. Remote Sens. Environ. 1994, 49, 246–263.

[10] Whiting, M.L.; Li, L.; Ustin, S.L. Predicting water content using Gaussian Model on soil spectra. Remote Sens. Environ. 2004, 89, 535–552.

[11] Petropoulos, G.; Carlson, T.N.; Wooster, M.J.; Islam, S. A review of Ts/VI remote sensing based methods for the retrieval of land surface energy fluxes and soil surface moisture. Prog. Phys. Geog. 2009, 33–250.

[12] Zeng Y., Feng Z. and Xiang N. (2004). Assessment of soil moisture using Landsat ETM+ temperature/vegetation index in semiarid environment. Geoscience and Remote Sensing Symposium, IGARSS '04. Proceedings. 2004 IEEE International, Volume: 6, 4306 – 4309. doi: 10.1109/IGARSS.2004.1370089.

[13] Parida B. R., Collado W. B., Borah R., Hazarika M. K., and Samarakoon L. (2008). Detecting Drought-Prone Areas of Rice Agriculture Using a MODIS-Derived Soil Moisture Index. GIScience & Remote Sensing, 45, No. 1, p. 109 – 129. doi: 10.2747/1548-1603.45.1.109.

[14] Wang L. and Qu J. (2009). Satellite remote sensing applications for surface soil moisture monitoring: A review. Front. Earth Sci. China 3: 23.

[15] Potić I, Bugarski M, Matić-Varenica J., 2017. Soil Moisture Determination Using Remote Sensing Data For The Property Protection And Increase Of Agriculture Production. 2017 Annual World Bank Conference On Land And Poverty, Washington DC, March 20-24, 2017.

[16] USGS, 2017. Landsat 7 Science Data Users Handbook. Department of the Interior, U. S. Geological Survey. https://landsat.gsfc.nasa.gov/wp-content/uploads/2016/08/Landsat7_Handbook.pdf.

[17] Yu, X., Guo, X., & Wu, Z. (2014). Land surface temperature retrieval from Landsat 8 TIRS—Comparison between radiative transfer equation-based method, split window algorithm and single channel method. Remote Sensing, 6(10), 9829-9852.

[18] Norman, J. M., & Becker, F. (1995). Terminology in thermal infrared remote sensing of natural surfaces. Remote Sensing Reviews, 12(3-4), 159-173).

[19] Sobrino, J. A., Jiménez-Muñoz, J. C., Sòria, G., Romaguera, M., Guanter, L., Moreno, J., Martínez, P. (2008). Land surface emissivity retrieval from different VNIR and TIR sensors. IEEE Transactions on Geoscience and Remote Sensing, 46(2), 316-327.

[20] ERDAS, 2002. Basic and advanced user manual.

[21] ESRI, 2010. User's guide, http://www.esri.com, 2010.

[22] Dahlgren, R. A., Saigusa, M., & Ugolini, F. C. (2004). The nature, properties and management of volcanic soils. Advances in Agronomy, 82.

[23] Fidencio, P. H., Poppi, R. J., & de Andrade, J. C. (2002). Determination of organic matter in soils using radial basis function networks and near infrared spectroscopy. Analytica Chimica Acta, 453(1), 125-134.

[24] Goward, S. and Hope, A., 1989. Evapotranspiration from combined reflected solar and emitted terrestrial radiation: Preliminary FIFE results from AVHRR data. Advances in Space Research, (9), pp. 239-249.

[25] Nemani, R., Pierce, L., Running, S. and Goward, S., 1992. Developing satellite-derived estimates of surface moisture status. Journal of Applied Meteorology, (32), pp.548-557.

[26] Goetz, S., 1997. Multi-sensor analysis of NDVI, surface temperature and biophysical variables at a mixed grassland site. International Journal of Remote Sensing, (18), pp. 71-94.

[27] Sandholt, I., Rasmussen, K. and Andersen, J., 2002. A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. Remote Sensing of Environment., (79), pp. 213-224.

[28] Wang, C., Qi, S., Niu, Z. and Wang, J., 2004. Evaluating soil moisture status in China using the temperature-vegetation dryness index (TVDI). Canadian Journal of Remote Sensing, (30), pp. 671-679.

[29] Yue, W., Xu, J., Tan, W. and Xu, L., 2007. The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat 7 ETM+ data. International Journal of Remote Sensing, (28), pp. 3205-3226.

[30] Zhang, F., Gao, Z. and Zuo, L., 2007. Study on relationship of soil moisture and land cover: a case in Lijin County, Shangdong Province. Remote Sensing and Modeling of Ecosystems for Sustainability IV. Ustin, L. (eds). Proceedings of SPIE 6679, 667918, SPIE, Bellingham, WA.