

The Use of Thermal Infrared Wavelengths to Determine the Volcanic Soils

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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 moisture 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 moisture 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.

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].

$$SMI = (LST_{max} - LST) / (LST_{max} - LST_{min}) \quad (1)$$

where LST_{max} and LST_{min} 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 ($\lambda \rightarrow 11.45 \mu\text{m}$), $p = h * c / s$ ($1.438 * 10^{-2} \text{ mK}$) $\rightarrow p = 14380$, $c = \text{light speed}$ ($c = 2.9979 \times 10^8 \text{ m/s}$), $h = \text{Planck's Constant}$ ($6.626 * 10^{-34} \text{ Js}$), $s = \text{Boltzmann Constant}$

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

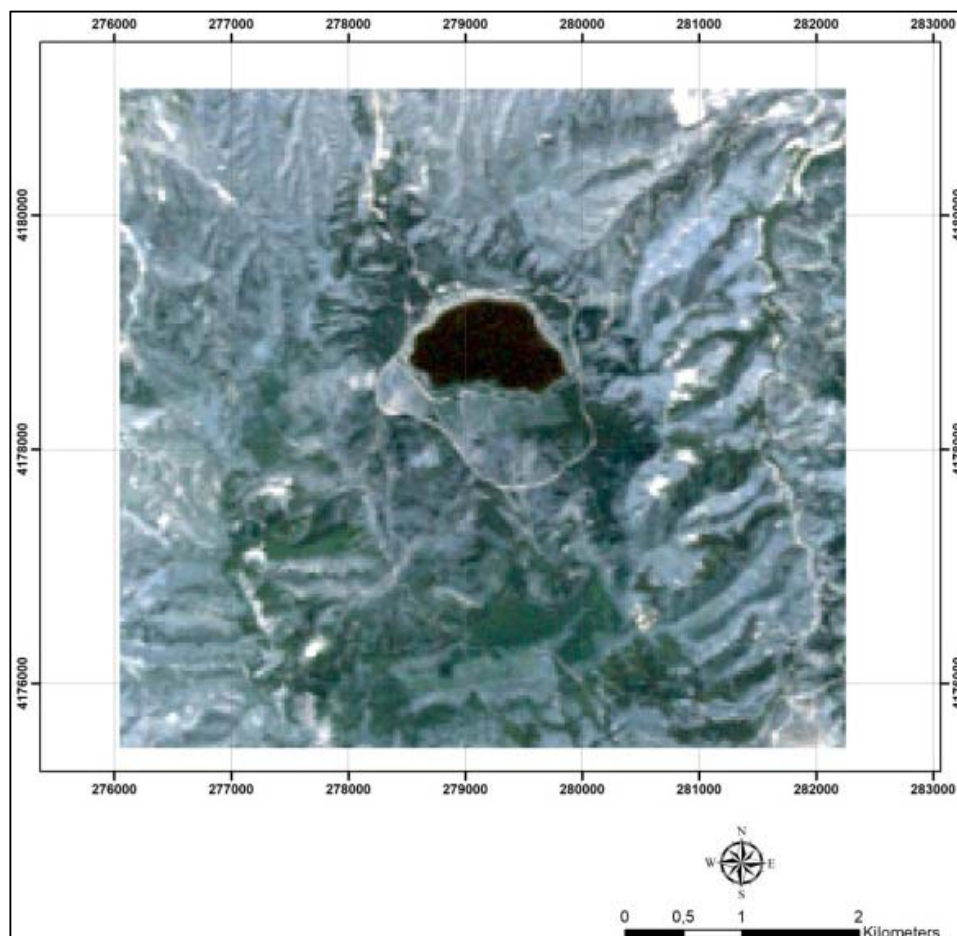


Fig. 1 Landsat 7 ETM + imagery from 2011 August

TABLE I
 RADIOMETRIC RESCALING PARAMETERS OF M_L AND A_L

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 ($\text{Watts}/(\text{m}^2 * \text{srad} * \mu\text{m})$), 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 ($\text{W}/\text{m}^2 * \text{srad} * \mu\text{m}$), 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, $P_V = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})^2$.

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

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

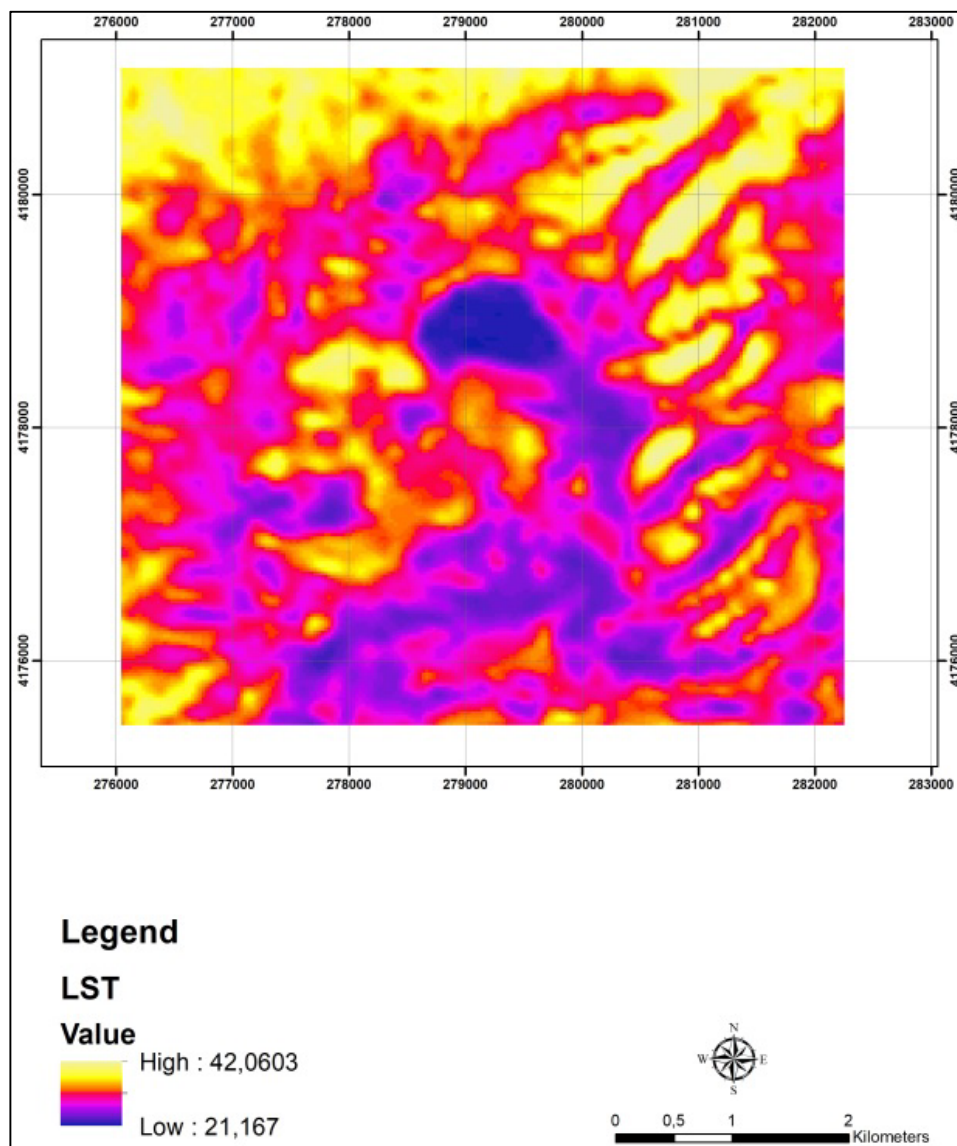


Fig. 2 LST map

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.

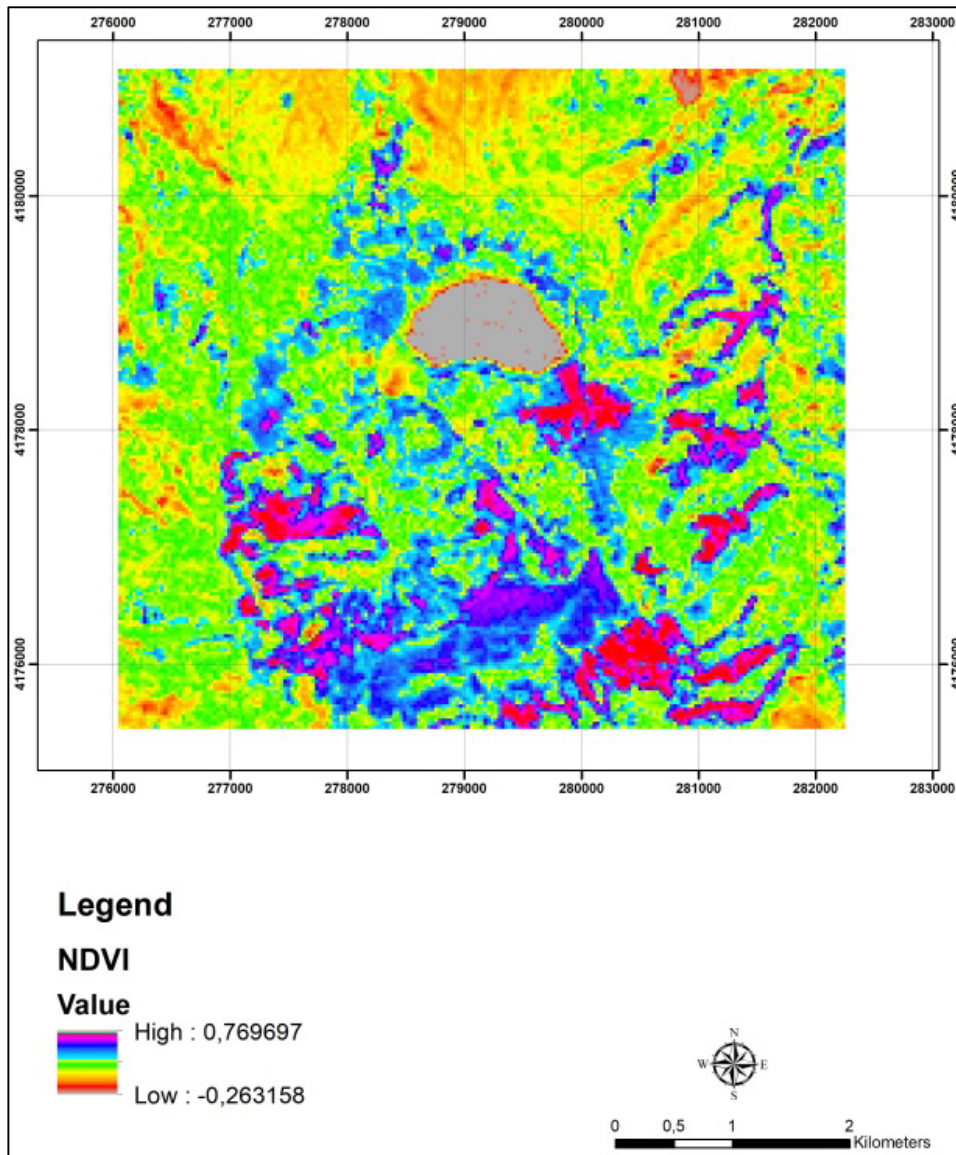


Fig. 3 NDVI map

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

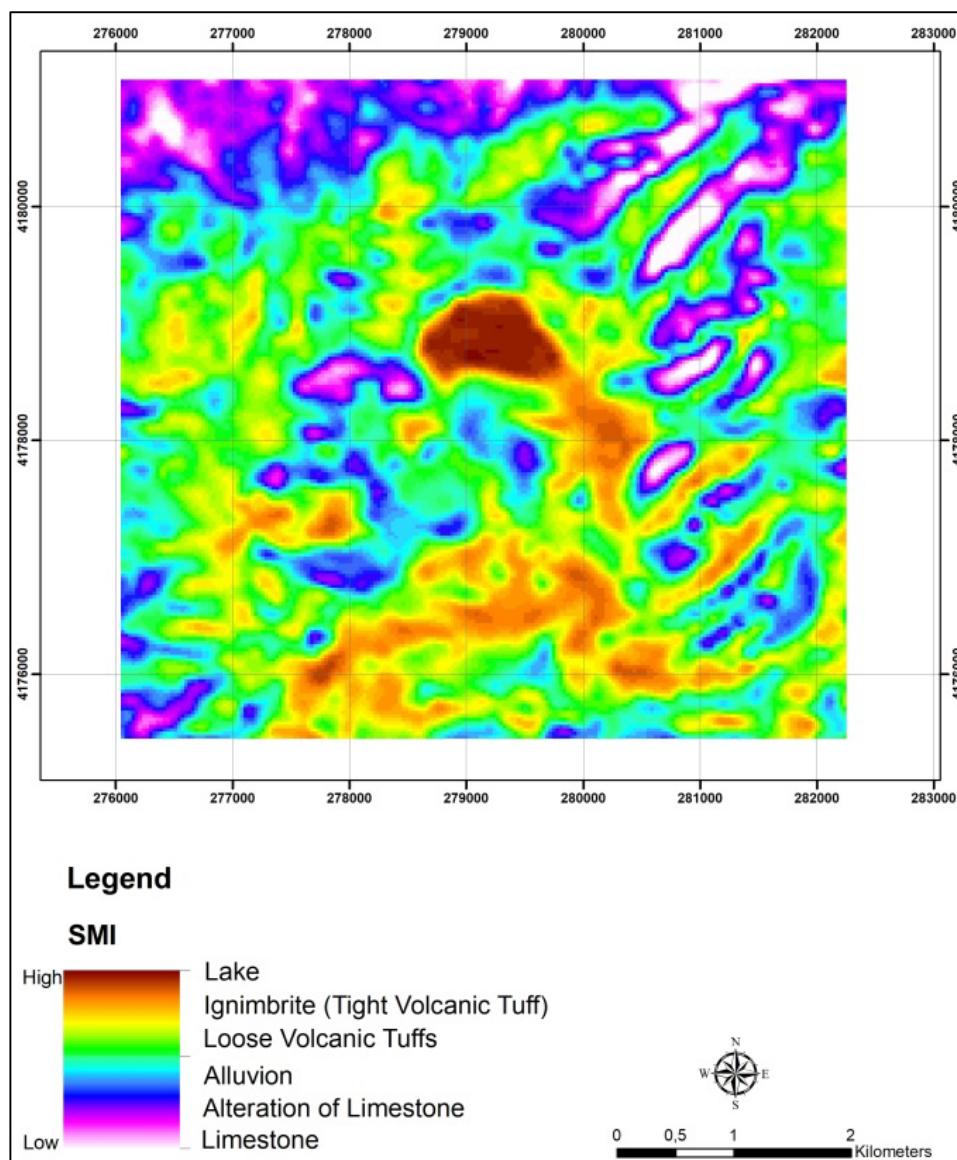


Fig. 4 Soil moisture map

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.

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