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Comparison of soil moisture estimation based on LST-NDVI of Landsat 8 images with field soil sampling

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Abstract

Estimation of soil moisture is very important to soil and agricultural scientists and requires many attentions towards obtaining high and accurate results. So, satellite remote sensing data and images have been extensively used to determining soil moisture especially with the help of Landsat 8 OLI sensor images. In this research, 39 points were sampled for soil moisture at the same time of Landsat 8 satellite overpass. LST and NDVI indices were used for modelling. In order to estimate the accuracy of the results, the soil moisture obtained from the images was compared with the results obtained from the soil science laboratory. The results showed that the estimated moisture by the slope method of the Temperature Vegetation index (TVX) and the percentage of soil moisture measured by use of LST-NDVI indices has a correlation of R2=0.64. The validation results of soil moisture estimation model also showed that the model is able to predict surface soil moisture with RMSE of 3.14. Also, for the study area, the equation %SM=-0.936LST-0.515NDVI+36.7 was proposed to estimate the percentage of soil moisture

1. Introduction

Surface soil moisture and estimating its quantity is an important factor in the cycle of nature (Babaeian et al. 2019). This factor plays a key role in many hydraulic models (Wang et al. 2019). With the help of this role, the direction and extent of drought can be determined in regular intervals in areas with different climates (Palagiri and pal. 2023). Continuous monitoring of soil moisture in agricultural areas effectively helps to formulate policies and determine policies in the field of crop irrigation (Pramanik et al. 2022). Soil moisture is also used to identify areas prone to forest fires (Romano and Ursino. 2020). Therefore, it is important to monitor soil moisture in each region and at different times (Amani et al. 2016). Due to the diversity of environmental factors such as non-uniformity in soil physical characteristics, topography, land vegetation, evaporation and transpiration and rainfall, soil moisture is known as a variable factor in spatial and temporal intervals (Korres et al. 2015). ; Bidgoli et al. 2020). In addition, the relative humidity parameter plays a direct role in cases such as the ability of plants to access water, the penetration of runoff into the ground, the creation of runoff, temperature, control of soil salinity, the determining factor in smart agriculture, the creation and development of watershed plans. Ghazali et al. 2020; Ezenne et al. 2019). Therefore, its accurate, continuous and extensive estimation can be the basis for solving many problems. Since this phenomenon has a very variable spatial and temporal distribution (Mälicke et al. 2020), it is not possible to measure it only with fixed ground stations for all areas and hours, because in many areas there are as many permanent and active stations. There is not enough, and this issue makes relative humidity measurements face many challenges (Su et al. 2014; Acharya et al. 2021). On the other hand, the interpolation of the relative humidity parameter with the help of existing stations cannot solve the accuracy required for research activities and projects that require it. Therefore, it is necessary to have a method that can measure the relative humidity of the soil economically, continuously and for a very long time (Sadeghi et al. 2017; Xu et al. 2018). Remote sensing, having suitable capabilities and many applications in determining relative humidity, has attracted the attention of many researchers (Wang et al. 2020; Li et al. 2016). In this research, Landsat 8 satellite images is used to estimate soil relative humidity using NDVI and LST indices simultaneously.

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2. Method

2.1. Study area

The study areas include the research farm of the Faculty of Agriculture of Tehran University with an area of approximately 5 square kilometers from 35 degrees 48 minutes 40 seconds to 35 degrees 47 minutes 49 seconds north and 50 degrees 57 minutes 8 seconds to 50 degrees 57 minutes and 19 seconds east, and the research farm of the Ministry of Water and Soil with an area of approximately 3.5 square kilometers from 35 degrees 47 minutes 26 seconds to 35 degrees 67 minutes 45 seconds north and 50 degrees 56 minutes 17 seconds to 50 degrees and 56 minutes and 13 seconds east in Mohammad Shahr located in the southeast side of Alborz province. The climate of the region is temperate and semi-arid and has harsh winters and hot summers. Also, the region is subject to the Mediterranean Sea in terms of climate and is affected by the climate of this geographical region. The average rainfall of the province reaches 450 mm.

Figure 1. Iran and the study area

2.2. Data

In this research, various data were used, including Landsat 8 satellite image and field sampling of ground surface temperature and soil depth of 5 cm, as well as soil moisture at a depth of 5 cm. The number of selected samples is 39 in order to obtain field information. Then the coordinates of the points on the ground were implemented by two-frequency GPS. To increase the accuracy, sampling was done during the satellite overpass. After sampling, all samples were placed in plastic bag to preserve moisture and transferred to the laboratory to obtain moisture. In the laboratory, the weight of wet soil was measured with an accuracy of 0.01 and then it was placed in an oven with a temperature of 105 degrees Celsius for 24 hours to completely remove the soil moisture. Then the percentage of soil moisture was calculated per following sections.

Table 1. Specifications and image date

Sensor	OLI	Number of bands	11
Date	2016-04-24	Elevation angle	54.86
Local Time	11:30	Azimuth	142.54

$$\text{soil moisture}(\%)=\frac{\text{Wet soil weight}-\text{Dry soil weight}}{\text{Dry soil weight}}\times 100$$

2.3 Estimating temperature from emissivity based on NDVI

After calculating NDVI, a specific emissivity value was given to each NDVI interval based on different formulas presented in Table 3 (Zhang et al. 2006).

$$NDVI=\frac{band\,5-band\,4}{band\,5+band\,4}$$

Table 2. Division of NDVI ranges

NO	NDVI	Emissivity
1	-1<NDVI<-0.185	0.985
2	-0.185<NDVI<+0.157	0.955
3	+0.157<NDVI<0.727	1.0094 + 0.047ln(NDVI)
4	+0.727<NDVI<+0.8	0.99
5	+0.8<NDVI<1	0.99

2.4. Artis method

In order to obtain the temperature by this method, it is necessary to calculate the spectral radiance, the brightness temperature at the surface of the sensor, the normalized differential vegetation index and the emissivity, respectively. This method is also known as the Artis method (Farina, 2012; Feng et al, 2014).

$$L_\lambda=\text{gain}\times DN\times\text{offset}$$

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

$$T_{sensor}=\frac{K_2}{\mathrm{Ln}\left(\frac{K_1}{L_\lambda}+1\right)}$$

$$S_t=\frac{T_{sensor}}{1+\left(\lambda\times\left(T_{sensor}/\rho\right)\right)\mathrm{Ln}\varepsilon}$$

S=Kelvin-273.15

Table 3. Calibration coefficients for Landsat 8 thermal bands

Calibration factor	K_1	K_2
OLIBAND10	774.89	1321.08
OLIBAND11	480.89	1201.14

2.5. Extraction of surface soil moisture using temperature and vegetation index (slope of TVX relationship)

In this method, the NDVI index, the brightness temperature of bands 10 and 11, and the temperature of the earth's surface were extracted from the images, and the slope of the TVX relationship between NDVI, the temperature of the earth's surface, and also the values of the brightness temperatures were calculated. The TVX relationship uses the relationship between surface temperature and vegetation index to estimate the volumetric moisture content of the soil surface layer (Thomas et al., 2023).

3. Results

Through the combination of reflective and thermal data, this study has estimated the moisture of the surface layer of the soil according to the state of the natural vegetation of the area. The obtained results indicate the relative position of this method in predicting the moisture of the surface layer of the soil using the slope of TVX in the study area. The TVX method uses the relationship between surface temperature and vegetation index to estimate the moisture content of the soil surface layer. Table 3 shows the amount of RMSE and R^2 (Table 4, Figure 2).

Table 4. The model estimated from examining the relationship between moisture percentage and LST-NDVI method

Model	Equation	R^2	RMSE
LST-NDVI	%SM=-0.936LST 0.515NDVI+36.7	0.64	3.14

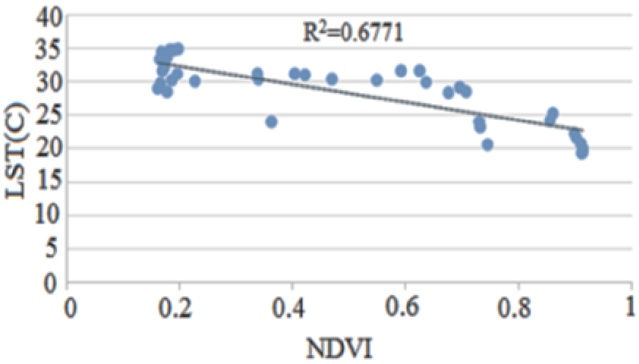

Figure 2. The relationship between land surface temperature and NDVI index in the studied samples

Correlation tests were conducted to determine the relationship between the slope of the TVX relationship and the observed soil moisture data. Figure 4-4 shows the slope regression diagram of the TVX relationship resulting from the correlation of LST and NDVI with the moisture percentage of the surface layer of the soil during the study period (Figure 3).

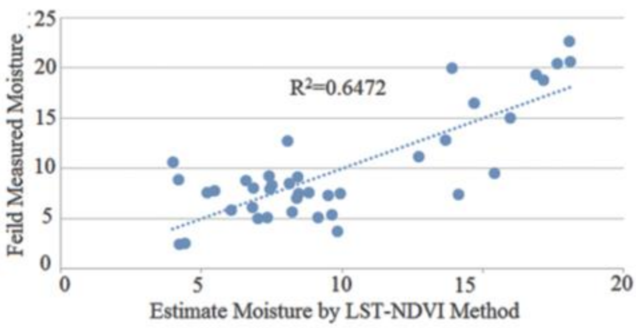

Figure 3. Moisture estimated by the slope method of the TVX relationship (LST-NDVI) against the measured soil moisture percentage

4. Discussion

The results obtained from this research showed that the model derived from the slope of the TVX relationship (LST-NDVI model), the model derived from the linear regression relationship between soil moisture values and NDVI and LST index values have a significant correlation with soil surface layer moisture. And they can provide a good estimation of soil surface layer moisture in arid, semi-arid and moderate semi-arid regions (Figure 4, Table 5 and 6).

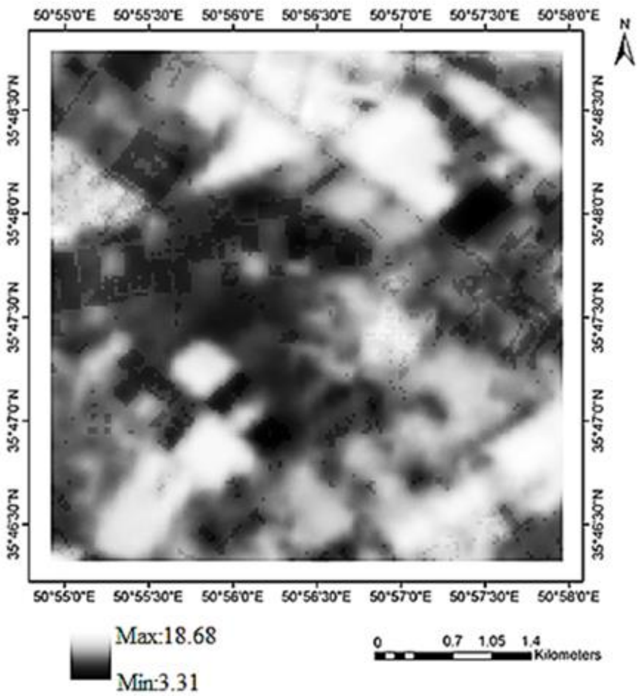

Figure 4. Soil moisture percentage obtained from TVX model (LST-NDVI)

Table 5. The results of the normality test of the indices used in the soil moisture estimation model

N		39
Normal Parameters	Mean	9.95
	Std.Deviation	4.26
Most	Extreme Absolute	0.194
Differences	Positive	0.194
	Negative	-0.090
Kolmogorov-Smirnov Z		1.215
Asymp.sig. (2-tailed)		0.105

Table 6. Validation of methods using T-test

Sig	0.890
T	0.139-

5. Conclusion

The science and technological methods are always transforming and progressing, and every day we see the improvement of the previous methods and the replacement of technology and methods of obtaining data and information from various phenomena on the surface of the earth. New sources of information and optimal methods have also been effective in estimating and measuring soil surface layer moisture. By using Landsat 8 images and performing various stages of data processing and correction, it is now possible to extract indicators such as normalized vegetation difference

(NDVI) and land surface temperature (LST). In order to determine the accuracy of the obtained model, real soil moisture data is needed at the same time as the satellite passes. In this way, by using the indices obtained from Landsat 8 images and the actual values of soil moisture, it is possible to analyze the data in order to obtain soil surface layer moisture estimation models.

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