ORIGINAL ARTICLE

Validation of Spectral Moisture Indexes Using Landsat 8 OLI/TIRS Images in a Vertisol

Validación de índices espectrales de humedad mediante imágenes del Landsat 8 OLI/TIRS en un Vertisol

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ABSTRACT: Remote sensing is a geomatic tool that has been used to determine soil moisture, a very important physical property in studies related to agricultural production. Particularly, the Vertisol present distinctive characteristics to other groupings of soils in Cuba in relation to water retention and the change of their properties. The objective of the research was validating the use of spectral moisture indexes through Landsat 8 OLI/TIRS images in a Vertisol. An area under natural grass, sugarcane and secondary forest of the Provincial Sugarcane Research Station in Guaro, Holguín was chosen. Three georeferenced random sampling points were established for each land use up to a depth of 30.0 cm, for the determination of gravimetric moisture, which was related by means of linear regression analysis with the spectral indexes of moisture and the calculation of parameters for validation. The use of remote sensing showed in the thematic maps obtained from the estimation of moisture with the different spectral indexes, the presence of homogeneous zones and their spatial variability in the moisture state of the Vertisol under the three land uses. ENDWI, MSI and EMSI indexes indicated a better estimation in the statistics used for the validation of the values obtained by remote sensing and *in situ* sampling of moisture, according to research related to the subject.

Keywords: Gravimetric moisture, Remote Sensing, Soil.

RESUMEN: La teledetección es una herramienta geomática que ha sido utilizada para determinar la humedad del suelo, propiedad física muy importante en estudios relacionados con la producción agropecuaria. Particularmente, los Vertisoles presentan características distintivas a otros agrupamientos de suelos en Cuba con relación a la retención de agua y el cambio de sus propiedades. El objetivo de la investigación se basó en validar el uso de índices espectrales de humedad mediante imágenes del Landsat 8 OLI/TIRS en un Vertisol. Se escogió un área bajo pasto natural, caña de azúcar y bosque secundario de la Estación Provincial de Investigaciones de la Caña de Azúcar en Guaro, Holguín. Se establecieron tres puntos de muestreo aleatorios georreferenciados por cada uso de la tierra hasta una profundidad de 30,0 cm, para la determinación de la humedad gravimétrica la cual, se relacionó mediante análisis de regresión lineal con los índices espectrales de humedad y el cálculo de parámetros para su validación. El uso de la teledetección mostró en los mapas temáticos obtenidos de la estimación de la humedad con los diferentes índices espectrales la presencia de zonas homogéneas y su variabilidad espacial en el estado de humedad del Vertisol bajo los tres usos de la tierra. Los índices ENDWI, MSI y EMSI indicaron una mejor estimación en los estadígrafos utilizados para la validación de los valores obtenidos por teledetección y muestreos *in situ* de la humedad, de acuerdo a investigaciones relacionadas con la temática.

Palabras clave: humedad gravimétrica, suelo, teledetección, índice espectral.

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INTRODUCTION

Soil moisture is crucial in the nexus that exists in the exchange of water, energy and carbon between the soil surface and the atmosphere. Several studies suggest the use of this physical property of the soil as an important factor to take into account when conducting studies on drought monitoring, evapotranspiration estimation, irrigation intervals, crop yield evaluation and forest management, among others (Qiu *et al.*, 2019).

Vertisol are of great importance in our country and are mostly used in the production of sugar cane and natural pastures for livestock. This group of soils occupies an area of 9060 km^2 divided into Chromic Vertisol (860 km^2) and Pélico Vertisol (8200 km^2), according to Hernández *et al.* (2015); Hernández (2021). They can also be very productive but with management restrictions when wet, with low infiltration rates and hydraulic conductivity, which can be susceptible to erosion and runoff. Their poor aeration make them very sticky and the excess of water in the soil makes tillage, sowing and harvesting operations difficult, as well as the traffic of agricultural implements. However, when they are dry they become very dense and hard, with high infiltration rates due to the presence of cracks that can be very large in width and depth (Wilson & Cerana, 2004).

Cid *et al.* (2016) state that the nature of the water-soil relationship in Vertisol has a notable effect on their water management, particularly when they are irrigated. The effect of cracks on infiltration and aeration and changes in apparent density with water content are characteristic of this type of soil that must be assessed together for proper water management.

The moisture present in the soil can be determined by point estimates, remote sensing or by simulation models. Each of these methods has some drawbacks, either in terms of the accuracy and precision of the estimates or in terms of their space-time scale, elements that are hardly reconcilable (Hernández-Pereira and Medina-González, 2012). Remote sensing methods for soil moisture estimation rely primarily on the relationship between soil moisture, dielectric characteristics of a specific target and radar receivers; which have the ability to acquire data under almost any weather condition and without an external source of lighting (Bao *et al.*, 2018). There are mainly three groups of models that apply remote sensing data to estimate soil moisture: backscatter models, statistical analysis techniques, and application of neural networks; which can be affected by vegetated surfaces, since active microwaves are strongly affected by surface roughness and vegetation (Zhan *et al.*, 2007; Zhang *et al.*, 2014; Champagne *et al.*, 2016).

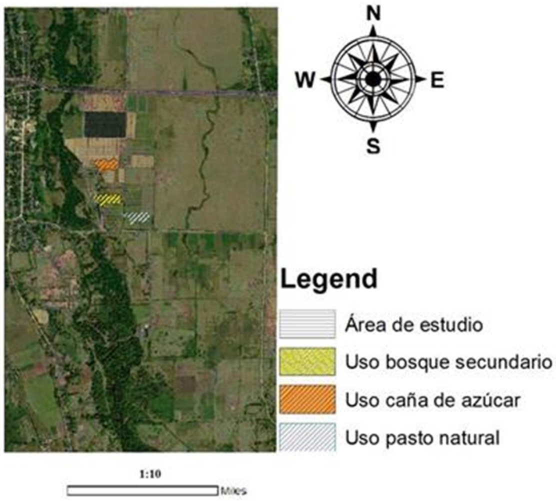

FIGURE 1. Location of the Guaro Experimental Block, belonging to the Provincial Sugarcane Research Station in Holguín taken from SAS Planet (SAS.Planet.Nightly.200718.10081/geojamal.com).

The Landsat 8 OLI/TIRS satellite of the United States Geological Survey presents 11 bands. Due to its cumulus and time, the Landsat images have a spatial resolution of 30 m, a temporal resolution of 16 days and a land coverage of 185 km. For the reasons stated above, the objective of the research was validating the use of spectral moisture index in a Vertisol with the use of Landsat 8 OLI/TIRS images.

MATERIALS AND METHODS

Soil moisture sampling was carried out in areas of Guaro Experimental Block, belonging to the Provincial Sugarcane Research Station (EPICA) of Holguín, in a moderately washed calcic and gleyic Chromic Vertisol (Hernández *et al.*, 2015). An area under three land uses (natural pasture, sugar cane and secondary forest) was chosen and three random sampling points were established by land use, which were georeferenced (Figure 1).

At each sampling point, a pit 30 cm deep was opened and undisturbed soil samples were taken with a 105.35 cm^3 cylinder, placed in weighing filters, the mass of moist soil was determined and they were placed in an oven at 105°, until they reached a constant weight (mass of dry soil). The gravimetric moisture was determined from the equation:

$$\theta_g = \frac{msh - mss}{mss} \quad (1)$$

Where θg is the gravimetric moisture; msh is the moist soil mass and mss is the dry soil mass.

To match as closely as possible to the date of sampling, an image (LC08_L1TP_011046_20190613_20190619_01_T1.tar) was downloaded from the www.usgs.gov site of the commercial Landsat 8 OLI/TIRS satellite in the WGS 84 UTM system, Zone 18 North, 011/046 Grid.

Radiometric correction and the calculation of the following spectral moisture indexes were performed on said image in the QGis 3.10 A Coruña software (Table 1).

For the validation of the spectral moisture indexes, a linear regression analysis was performed between the gravimetric moisture values and those estimated by the index using the Statgraphics Plus 5.0 software. For the validation of the mathematical models obtained, the methodology proposed by Singh *et al.* (2019) was taken into account with the use of the Landsat 8 OLI/TIRS satellite, which reduces the effects of vegetation cover on the reflected values of moisture by this sensor.

RESULTS AND DISCUSSION

Figure 2 shows the thematic maps obtained from the estimation of soil moisture for each spectral index and how this parameter varies in the area studied from the colors that the areas of highest, medium and low soil moisture values take. There are homogeneous areas in each thematic map, in addition to showing significant differences in the colors that the pixels take in each of the images obtained.

Silva *et al.* (2016) state that the land use in a production system is influenced by hydrophysical properties, hence the management of this soil must take into account water retention, because this characteristic modifies its structure and can be used in research to determine the impact of management on soil properties.

Investigations carried out on the state of humidity in Vertisol, refer to the need of carrying out studies at different depths where geostatistical tools are applied. That is because those carried out on this variable are fundamentally based on determining the moisture content of soil samples in two points of the territory to a depth of 60 cm with an auger, with a ten-year period, so an idea of how the values are distributed throughout the area is not offered (Cumbrera-González *et al.*, 2015).

Figure 3 shows the models of linear regression of the gravimetric moisture values respect to spectral moisture indexes where a linear distribution adjust was shown. The models describe a high positive association between the variables measured with a strong linear dependence between the dependent and the independent variables.

The use of remote sensing applied to soil moisture studies shows the relationship between the Near Infrared (NIR) and the Red (Red) electromagnetic bands, according to studies carried out by Amani *et al.* (2016). In their study, they validated two spectral indexes TSMI and MTSMI (Triangle Soil Moisture Index and Modified TSMI) with images from the Landsat 8 OLI/TIRS. They refer to a high relationship of 64% to 74% between the humidity determined by remote sensing with that sampled using the traditional method at a depth of 0 to 5 cm.

Based on multispectral images from the Sentinel-1 and Landsat 8 satellites, Alexakis *et al.* (2017) estimated soil moisture and obtained determination coefficients between 70% and 90%, which demonstrated the validation of this method in their research.

Table 2 shows the result of linear regression analysis of gravimetric moisture and spectral moisture indexes. A high determination is shown with values close to 100% as well as those of the positive correlation coefficient with values close to one, which is explained by the significance with Durbin Watson statistics less than a 95% confidence level in the mathematical models obtained. This statistical test also reflects that in the case of the gravimetric moisture models with the spectral indexes LSWI, MSI and ENDWI, the residuals present a positive interrelation with values close to zero; while the EMSI a value close to two, the residuals are uncorrelated.

The autocorrelation of the residuals is represented with values that vary from -1 to 1, which allows inferring that the structure of the models is correctly represented. The mean absolute error of the prediction explains that the dependent variables (spectral moisture indexes) explained were correctly chosen in each case, with values greater than zero, which indicates that the values were overestimated and adjust to the magnitude of the dependent variables.

The MSI and EMSI indexes showed better behavior in terms of the efficiency index with values closer to one, while the rest of the indexes have intermediate

TABLE 1. Calculated spectral moisture indexes

Moisture spectral index	Reference	Equation
LSWI (Index of Normalized Difference of Moisture in Vegetation and Soil)	Mohammadi *et al.* (2017)	$LSWI = \frac{NIR - SWIR1}{NIR + SWIR1}$ (2)
ENDWI (Improved Water Index)	Chen *et al.* (2005)	$ENDWI = \frac{NIR - SWIR2}{NIR + SWIR2}$ (3)
MSI (Moisture Deficiency Index)	Domínguez *et al.* (2017)	$MSI = \left(\frac{SWR1}{NIR}\right)$ (4)
EMSI (Improved Moisture Deficiency Index)	Domínguez *et al.* (2017)	$EMSI = \left(\frac{SWIR2}{NIR}\right)$ (5)

NIR: Near Infrared; SWIR1: Short wave infrared; SWIR2: Short wave infrared.

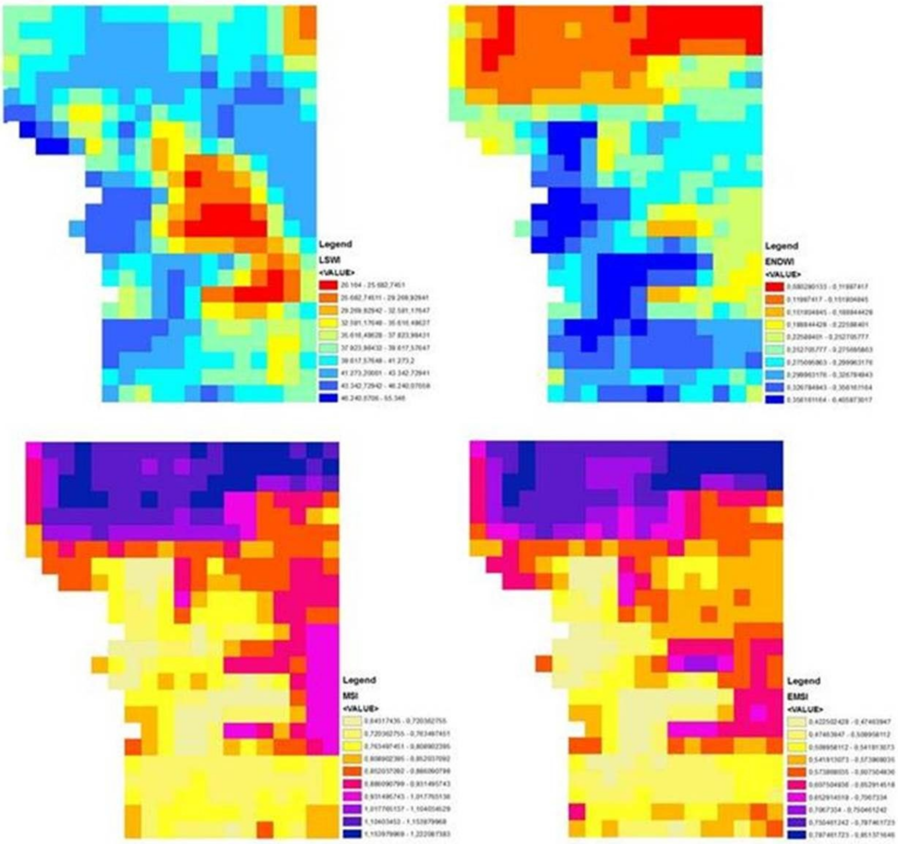

FIGURE 2. Thematic maps obtained from the estimation of soil moisture content from spectral indexes in the study area.

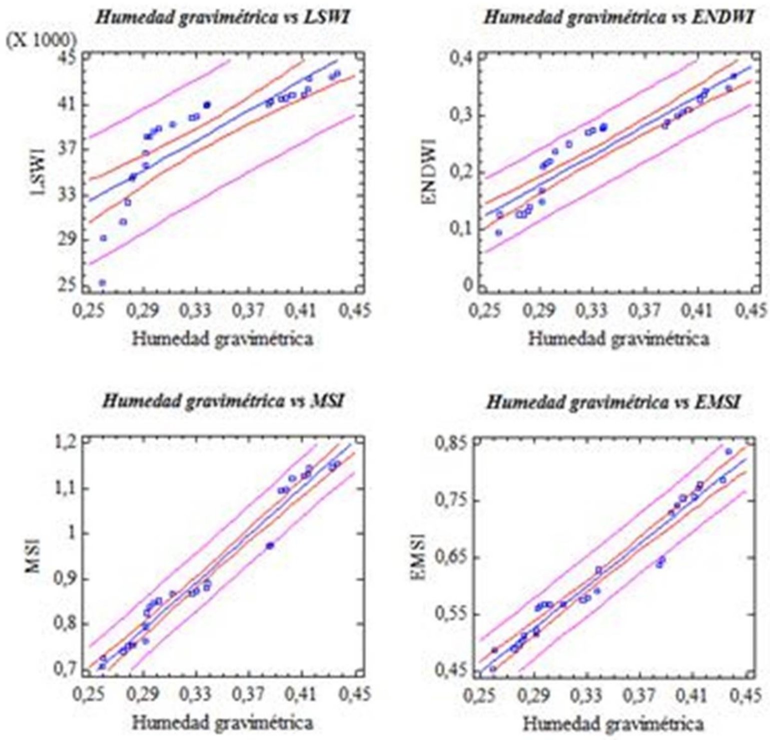

FIGURE 3. Linear regression analysis between gravimetric moisture and spectral moisture indexes

TABLE 2. Statistics of the linear regression analysis between gravimetric moisture and spectral moisture indexes

Statistics	Moisture spectral index			
	LSWI	ENDWI	MSI	EMSI
r^2	0,8402	0,9344	0,9814	0,9756
R^2	70,5933	87,318	96,3151	95,1765
EE	2569,6411	0,0299	0,0304	0,0253
EAM	1885,4722	0,0253	0,0250	0,0188
Durbin-Watson	0,2166 (P=0,0000)	0,3409 (P=0,0000)	0,8240 (P=0,0001)	1,2241 (P=0,0094)
RMSE	209,3115	1,6186	0,8476	0,6318
R-RMSE	0,9999	0,7794	0,6219	0,6910
%RMSE	48,3957	59,5995	78,8613	69,9638
NS	0,4312	0,6824	0,7185	0,8963
A.r	0,7031	0,7870	0,8816	0,8427
Equation of the model	LSWI = 15788,6 + 66790,8*θ_g	ENDWI = -0,2046 + 1,3181*θ_g	MSI = 0,0340 + 2,6103* θ_g	EMSI = -0,0209 + 1,8818*θ_g

R^2: Coefficient of determination; r^2: Correlation coefficient; SE: standard error; EAM: Mean Absolute Error; RMSE: Root Mean Square Error; R-RMSE: Root Mean Square Error Relative; % RMSE: Root Mean Percentage Square Error; NS: Efficiency of the model.

values for their estimation, which is consistent with what was stated by Hwan *et al.* (2012) for the validation of hydrological models through the use of efficiency indexes.

Qiu *et al.* (2019), when evaluating soil moisture under different land uses with the Landsat 8 OLI/TIRS satellite, found a correlation between this measurement and the moisture present in the soil, validated through the RMSE and r^2 statistics. From the use of remote sensing, Jalilvand *et al.* (2019) quantified the irrigated areas in Urmia Lake, Iran for which they validated the use of remote sensing in this study through the use of mathematical algorithms with a determination coefficient of 86%.

CONCLUSIONS

The use of remote sensing for the estimation of moisture in a Vertisol through spectral indexes related to this physical property and images from the Landsat 8 OLI/TIRS satellite, showed homogeneous areas with high, medium and low values in soil water content and its spatial variability in the thematic maps obtained. Based on the methodology used, the ENDWI, MSI and EMSI indexes indicated a better estimate in the statistics used for the validation of the values obtained by remote sensing and *in situ* moisture sampling.

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