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Evaluation of Land Degradation Status of Soil Series Using Geomatics Techniques

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ABSTRACT

This study aimed assessing the land degradation status of some soil series of the North Tikrit Agricultural Project using remote sensing data. Part of the project area (246,555) km^2 was selected based on variations in soil characteristics and agricultural crops. The study area is located between the longitudes of 43˚ 12′ 30″ and 43˚ 27′ 30″ E and the latitudes of 35˚ 15′ 00″ and 35˚ 0′ 00″ N. This project area includes five soil series: Hatra, Jareesh, Safa, Seneyah, and Shurqat. Forty-four soil samples covering these five soil series were collected from the surface layer (0-30 cm). The chemical properties of these samples were determined, including pH, Electric Conductivity (EC), calcium carbonate content, gypsum content, cation exchange capacity, and organic matter content. Two Landsat satellite images were employed for calculation of soil and vegetation spectral indices. One of these two images was acquired on 15 June, 2002 while the other was acquired on 25 June, 2022. The spectral indices of concern encircled three vegetation indices (Advanced Vegetation Index (AVI), Specific Leaf Area Vegetation Index (SLAVI), and Structure Insensitive Pigment Index (SIPI)) and three soil spectral indices (Bare Soil Index (BSI), Modified Bare Soil Index (MBSI), and Normalized Difference Bare Soil Index (NDBSI)). The results show that there are variations in the values of the various computed soil and vegetation spectral indices during the two study periods and that the values were, in general, lower in 2022 than in 2002. It was found that the soils were degraded and that, consequently, the plant density declined during the study period. This had negative impacts on the fertility and productivity of the soils in the study area. The results also showed differences in the soil spectral reflectivity curves, especially at the wavelengths of water absorption; 1.4, 1.9, and 2.2 µm, due to the presence of gypsum at high concentrations in the soils.

تقييم حالة تدهور الاراضي لبعض سلاسل الترب باستخدام التقانات الجيومكانية

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الخلاصة

هدفت الدراسة الى تقييم حالة تدهور الاراضي لبعض سلاسل ترب مشروع شمال تكريت الزراعي باستخدام معطيات التحسس النائي. تم اختيار جزء من مساحة المشروع(246.555) كم^2 على أساس التغاير في صفات التربة والحالة الإنتاجية للمحاصيل الزراعية، اذ تقع منطقة الدراسة عند خطي طول (0′ 0′ 45°) و(0′ 0′ 40°) شرقاً ودائرتي عرض (0′ 0′ 35°) و(0′ 0′ 30°) شمالاً. والتي اشتملت على خمس سلاسل تربة ومن ثم استحصلت 44 نموذج تربة من الطبقة السطحية 0 − 30 سم موزعة على سلاسل التربة وتسجيل بعض الملاحظات والمعلومات الحقلية. تم تقدير الصفات الكيميائية (درجة تفاعل التربة والايصالية الكهربائية وكاربونات الكالسيوم والجبس والسعة التبادلية الكاتيونية والمادة العضوية). تم استخدام مرئيتين فضائتين مكتسبة بتاريخ 15 حزيران 2002 و25 حزيران 2022 ومن خلالها تم حساب المؤشرات الطيفية للتربة SBIو MSBI وNDBSI والمؤشرات النباتية SLAVI و AVI وSIPIو GCI. توصلت النتائج الى وجود اختلاف وتباين في قيم الأدلة الطيفية للتربة والنبات وللعامين 2002 و2022 اذ تبين ان الترب متدهور وضعيفة التغطية النباتية وهذا ينعكس على الحالة الخصوبية والإنتاجية لترب منطقة الدراسة.

الكلمات المفتاحية: الدلائل الطيفية للتربة والنبات، SBI، MSBI، SIPI، GCI.

INTRODUCTION

Remote sensing is one of the modern sciences that developed remarkably quickly because of its ability to provide accurate information about the Earth and atmosphere by using satellites and aircrafts. It has become one of the basic sciences that are employed in solving many environment problems, through the amount and quality of information that multitemporal and multispectral satellite images provide continuously (Canada Centre for Remote Sensing, 2010). Remote sensing provides an effective and reliable way of collecting the required information in order to obtain a map of the types and areas of crops and the soil types and distribution in any area of interest. The outputs of processing of the remote sensing data can be used as an input to the Geographic Information System (GIS) so as to convert relevant information derived from satellite images into a database for the areas of interest (Canada Centre for Remote Sensing, 2010).

The soil spectral reflectance properties are fundamental for agricultural research. Ben-Dor *et al.*, (1997) indicated that soil spectral reflectance properties are essential for many remote sensing applications in the soil sciences since soil spectral reflection data can be obtained in the laboratory or in the field and from satellite images. The soil spectral reflectance helps in determining soil characteristics without the need for soil sample collection and analysis and, thus, without disturbing the soil column and affecting its biological, chemical, and physical properties (Khalaf, 2021). Najib (2008) clarified that the reason for the increase in the spectral reflectivity of the salt land cover is its high content of white salt crystals, especially those of NaCl and $CaSO_4.2H_2O$. In the meantime, the increases in the organic matter and moisture contents are due to reduce the soil spectral reflectivity. In this respect, Hamad (2009) highlighted the possibility of distinguishing and separating soil units (soil series) through the spectral reflectivity values using satellite images.

The spectral reflectance properties of the plants too are critical for agricultural research. The spectral reflectances of crops in the field change with changes in crop growth, vigor, health, and density at the different stages of the crop lifecycle and it's healthy. Al-Bakri and Abu-Zanat (2007) clarified that the most important measures are the reflective spectral properties and the Normalized Difference Vegetation index (NDVI), which help greatly in monitoring the state of vegetation cover and estimating its health condition. Leblon (2009) spotlighted that the Modified Soil Adjusted

Vegetation Index (MSAVI) reduces the effect of soil reflectivity on the vegetative covers. However, Muhameed and Abbas (2010) pinpointed ineffectiveness of the MSAVI due to the lack of vegetation cover in it. Rondeaux *et al.*, (1996) presented the Optimized Soil Adjusted Vegetation Index (OSAVI) based on the spectral reflectivity values of visible spectral bands and near infrared wavelength by introducing the soil adjustment coefficient value of 0.16 as an optimal value for reducing the effect of soil reflectivity. In a study of the temporal variation of land cover in Baghdad Governorate using remote sensing methods and the GIS (Ali and Muhimeed 2016). Soil Adjusted Vegetation Index (SAVI) can be helpful in detection of the agricultural lands and that its use produced similar results to the results of supervised classification. Khalaf *et al.*, (2018) used remote sensing and GIS to monitor changes in movement and stabilization of sand dunes and their effect on land degradation and environmental pollution based on indices spectral indices: Bare Soil Index (BSI), Chlorophyll Index (CI), Infrared Percentage Vegetation *Index* (*IPVI*), Land Degradation *Index* (*LDI*), MSAVI, Normalized Differential Sand Dune Index (NDSDI), NDVI, Shadow Index (SI), Transformed Normalized Difference vegetation *index* (*TNDVI*), and Vegetation Index (VI). The results demonstrate that the values of the vegetation indicators (NDVI, VI, TNDVI, SAVI, MSAVI, IPVI, and CI) increase in the non-active sand dunes. Khalaf and Hussien (2021) employed the three spectral indices: Leaf Area Index (LAI), Salinity Index (SI5), and OSAVI to monitor desertification and land degradation in Al-Shirqat City in the governorate of Salahuddin in Iraq. Due to the importance of the spectral indices in assessing and monitoring the land degradation.

This study aimed at employing specific spectral indices that are use for the first time in Iraq for evaluating land degradation and desertification in the North Tikrit Agricultural Project. The indices encompassed three vegetation indices (the Advanced Vegetation Index (AVI), Specific Leaf Area Vegetation Index (SLAVI), and Structure Insensitive Pigment Index (SIPI)) and three soil indices (the Bare Soil Index (BSI), Modified Bare Soil Index (MBSI), and Normalized Difference Bare Soil Index (NDBSI).

MATERIALS AND METHODS

Study Area

Part of North Tikrit Agricultural Project area was selected for the study of soil and land degradation and desertification using carefully-selected soil and vegetation spectral indices. North Tikrit Agricultural Project is implemented in the governorate of Salahuddin in Iraq. Part of the area of this project was chosen for study based on variability in it in soil characteristics, agricultural crop productivity, and soil series. The study area has a land area of 246,555 km^2 and is located between the longitudes of 43˚ 12′ 30″ and 43˚ 27′ 30″ E and the latitudes of 35˚ 15′ 00″ and 35˚ 0′ 00″ N (Figure 1).

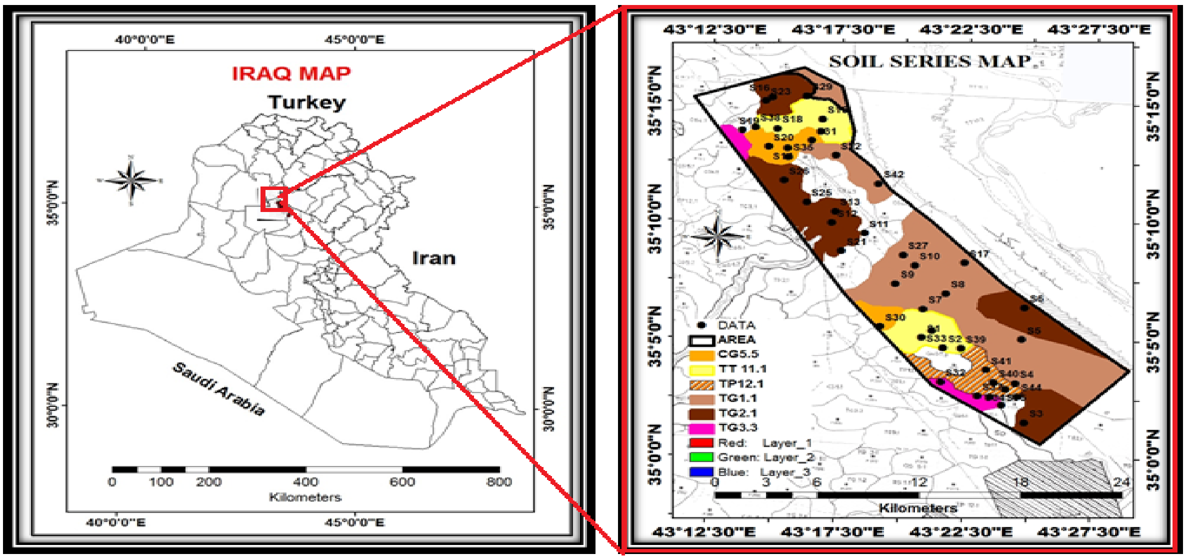
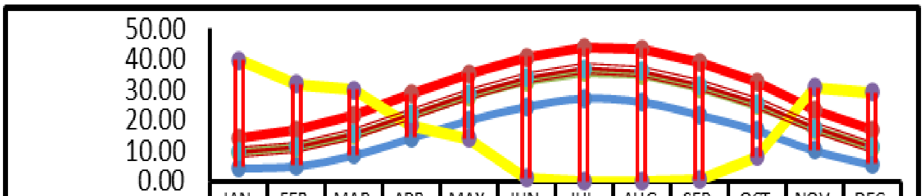


Figure (1): Map of North Tikrit Agricultural Project.

Weather data have been collected for the study area during the period 1980-2020 from Baiji Weather Station (Iraq) and pooled over this period (Figure 2). The mean minimum monthly temperature pooled over this period ranged from 4.46 ºC in January to 27.30 ºC in July. In addition, the average mean maximum monthly temperature during the same period ranged from 14.40 ºC in January to 43.86 ºC in July. Meanwhile, the mean monthly rainfall depth pooled over this time period ranged from 0.0 mm in July and August to 39.63 mm in January. The mean monthly soil temperature, on the other hand, ranged from 9.58 ºC in January to 36.98 ºC in July (Figure 2).



	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Taverage	9.43	11.00	15.12	21.45	27.71	32.66	35.58	34.76	30.56	24.75	16.92	11.13
Tmin	4.46	5.15	8.75	14.38	20.16	24.62	27.30	26.11	21.92	16.82	10.28	5.56
Tmax	14.40	16.85	21.49	28.52	35.25	40.70	43.86	43.42	39.20	32.68	23.55	16.69
Rainfall(mm)	39.63	31.89	30.01	18.47	14.05	1.07	0.00	0.01	0.49	7.98	30.75	29.06
TSoil (c°)	9.58	11.22	15.54	22.17	28.73	33.92	36.98	36.13	31.72	25.63	17.42	11.35

Figure 2. Climate data for Baiji station over the period 1980-2020.

Digital processing of Landsat 9 and Landsat 7 satellite images.

Surface reflectivity is defined as the ratio of the reflected radiation flux to the incident radiation flux. In the case of Landsat 9 images, it is calculated using the following equation (Salifu *et al.*,, 2011):

$$p_\lambda = \frac{M_p * Q_{Cal} + A_p}{\sin(\theta_{SE})} \quad \ldots\ldots (1)$$

where

p_λ = The Top-of-Atmosphere (TOA) reflectance.

M_p = The band-specific multiplicative rescaling factor.

Q_{Cal} = The quantized and calibrated standard product pixel digital number (DN) value.

A_p = The band-specific additive rescaling factor.

θ_{SE} = The local Sun elevation angle.

In the case of Landsat 7 images, surface reflectivity is calculated using the following equation:

$$L_\lambda = \left(\frac{L_{Max.\lambda} - L_{Min.\lambda}}{Q_{CalMax.} - Q_{CalMin.}}\right) * (Q_{Cal.} - Q_{CalMin.}) + L_{Min.\lambda} \quad \ldots\ldots (2)$$

$$p_\lambda = \frac{\pi * L_\lambda}{ESUN_\lambda * \cos\theta * d_r} \quad \ldots\ldots (3)$$

where

p_λ : Spectral reflectivity of a surface.

L_λ : Spectral radiance for each band.

$ESUN_\lambda$: The mean solar exo-atmospheric irradiance for each band

DN: The numeric number of the sensor at each band.

$L_{Max.}$: The highest value in the MTL file.

$L_{Min.}$: The lowest value in the MTL file.

$\cos\theta$: The cosine of the solar irradiance angle
d_r: The inverse squared relative Earth-Sun distance in astronomical units.

Spectral indices for assessing soil degradation and vegetation

There are many spectral indices that are relevant for assessment of the status of soil and vegetation. As was highlighted earlier, this study considered six indices, namely, AVI, SLAVI, SIPI, BSI, MBSI, and NDBSI. In the following paragraphs, the researchers define each of these indices and explicates how it is calculated.

Vegetation Spectral indices

1- Advanced Vegetation Index (AVI). This is a numerical indicator based on the near infrared (NIR) and red (RED) bands of electromagnetic radiation. It is useful in monitoring space-time variations of crops, forests, and rangelands. It is, therefore, highly important for the characterization of vegetation species and the extraction of phenolic parameters(GU, 2019). It is calculated using Equations 4 and 5:

$$\text{AVI (Landsat 8 - 9)} = [B5 \times (1 - B4) \times (B5 - B4)]^{1/3} \quad \text{……………….……………….…………. (4)}$$
$$\text{AVI (Landsat 4 – 7)} = [B4 \times (1 - B3) \times (B4 - B3)]^{1/3} \quad \text{………………………….………… . (5)}$$

2- Structure Insensitive Pigment Index (SIPI). This index is good for the analysis of vegetation cover with different plants and different ratios of carotenoids to chlorophyll. The value of this index increases with plant stress and is, hence, the highest for the highly-stressed plants. It is calculated as the ratio of the difference between the NIR band, which reflects the health of vegetation, and the band to their sum (Equation 6). The difference between these two bands ranges from 0 to 2 (EOS, 2019).

$$SIPI = \frac{NIR - Blue}{NIR - Red} \quad \text{…………………………………………………….…………. (6)}$$

3- Specific Leaf Area Vegetation Index (SLAVI). This index represents the area of one face of the leaves divided by their dry weights. Thus, change in the specific leaf area index is associated with plant leaf surface modifications such as capillary growths on the leaf surface Trichomes and the wax and salt bladders, which increase of reflectance in the green and red wavelength.

$$SLAVI = \frac{NIR}{RED + SWIR2} \quad \text{…………………………....……..………….………. …. (7)}$$

Soil Spectral Indices

1- Bare Soil Index (BSI). This index is a numerical indicator associated with the blue, red, and infrared (IR) wavelengths. The short and red wavelengths are used to predict the mineral composition of soil, while the NIR and blue wavelengths are used to detect vegetation.

$$BSI\ (Landsat\ 9) = \frac{(B6 + B4) - (B5 + B2)}{(B6 + B4) + (B5 + B2)} \quad \text{………...…………… . (8)}$$

$$BSI\ (Landsat\ 7) = \frac{(B5 + B3) - (B4 + B1)}{(B5 + B3) + (B4 + B1)} \quad \text{………………………………….…...………… . (9)}$$

2- **The Normalized Difference Bare Soil Index (NDBSI).** This index was proposed to improve detection of the bare soil, wastelands, and vegetation cover with a degree of response to the reflection of the soil on the vegetation cover. The short-wave infrared (SWIR) band is used to determine properties of the exposed or barren soils such as surface roughness, moisture content, organic matter content, and the sand, silt, and clay proportions in the soil (Roy *et al.*,, 1997). A value of −0.2 is necessary, but not sufficient, for indicating the presence of barren areas (Baraldi *et al.*,, 2006).

$$NDBSI = \frac{SWIR - NIR}{(SWIR + NIR)} - 1 \quad \epsilon(-1, +1) \quad (10)$$

3- Modified Bare Soil Index (MBSI). This index is a modified version of the Bare Soil Index (BSI). In this index (Equation 11), the NIR band has been added to reduce the impact of vegetation. Although all features of the land cover have negative MBSI values (approximately −2 to less than 0). An additional factor (*f* = 0.5) was added to redistribute the values of this index, both the negative and positive values. The MBSI values range from −0.5 to +1.5. Positive values denote barren soils while negative values indicate plants and water bodies. Values of this index are computed according to Equation 11:

$$MSBI = \left(\frac{SWIR1 - SWIR2 - NIR}{SWIR1 + SWIR2 + NIR} \right) + 0.50 \quad (11)$$

RESULT AND DISCUSSION

Soil Spectral indices: In this study, the researchers employed certain indices that are appropriate for monitoring soil degradation, especially in the arid and semi-arid regions. The results of analysis (Figure 3) bring to notice that there were differences in the values of the NDSBI between the years 2002 and 2022. In 2002, the NDSBI values ranged in the study area from 0.028 to 0.093 while in the year 2022, the values ranged from -0.104 to 0.068. Moreover, the mean NDSBI values for the five soil series that prevail in the study area (Hatra, Seneyah, Safa, Jareesh, and Shurqat) were 0.062, 0.057, 0.056, 0.054, and 0.051, respectively. In the year 2022, the mean NDSBI values decreased in the following sequence: Seneyah >Jareesh > Shurqat > Safa > Urban. This temporal variation in the NDSBI values in the study area may be related to many factors like drought, wind, dust storms, and desertification because all these factors have direct or indirect impacts on the characteristics of the soil such as its nutrient content (Li and Chen, 2014; Chen *et al.*,, 2004). The positive NDSBI values indicate barren soil and lack of vegetation whereas the negative NDSBI values indicate vegetation (Roy *et al.*,, 1997; Baraldi *et al.*,, 2006). The BSI is an index that indicates soil differences. It is based on the NIR, SWIR1, and SWIR2 bands and it enables distinguishing between barren soils and other types of ground covers (Nguyen *et al.*,, 2021). Additionally, it can be employed to predict the mineral composition of the soil. Its values ranged from 0.085 to 0.130 in the study area in 2002 and from −0.014 to 0.123 in 2022. Figure 3 points out temporal and spatial variations in the values of this index, which ranged in 2002 from 0.114 for the Shurqat soil series to 0.119 for the Geresh series. In 2022, however, the lowest and highest BSI values were 0.095 (Hatra series) and 0.114 (Seneyah series (Figure 3)). The positive values of this index denote deterioration of the soil. Rasul *et al.,* (2018) and Yan *et al.,* (2015) confirmed that values of the BSI depend on soil composition, moisture content, and the vegetative covers surrounding them. Furthermore, Rasul et. al. (2018) clarified that performance of the BSI varies according to climatic conditions, both the wet and dry conditions.

The MBSI is one of important indicators that are frequently employed to monitor soil degradation and desertification. The positive values of this index refer to the barren soils while the negative values indicate water bodies and plants. In 2002, the MBSI values for the Seneyah, Hatra, Safa, Jareesh, and Shurqat were 0.241, 0.240, 2.238, 0.236, and 0.236, respectively (Figure 3). In 2022, however, the values were 0.225 (Geresh series), 0.244 (Seneyah and Shrqat series), 0.233 (Saffa), and 0.219 (Hatra series). These results underscore that most of the soils in the study area are barren because all the reported MBSI values are positive, which indicate barren soils and low (or declining) vegetative cover. Thus, the values of the three aforementioned soil spectral indices that have been used in the current study to assess land degradation and desertification decreased over the study period (2002-2022), especially in the rangeland and Al-Jazeera areas, by effect of a number of factors, mainly including wind erosion, overgrazing, early grazing, low organic matter content of soil, low nutrient content, high content of gypsum, weak soil structure, and sand dunes. In this regard, climatic changes and drought have play role in the growth and development of plants, which decline with an increase in temperature and a drop in rainfall frequency and depth (Liao *et al.*,, 1999; CUI, 2008; Al-Dulaimi, 2012; Al-Nuaimi, 2021).

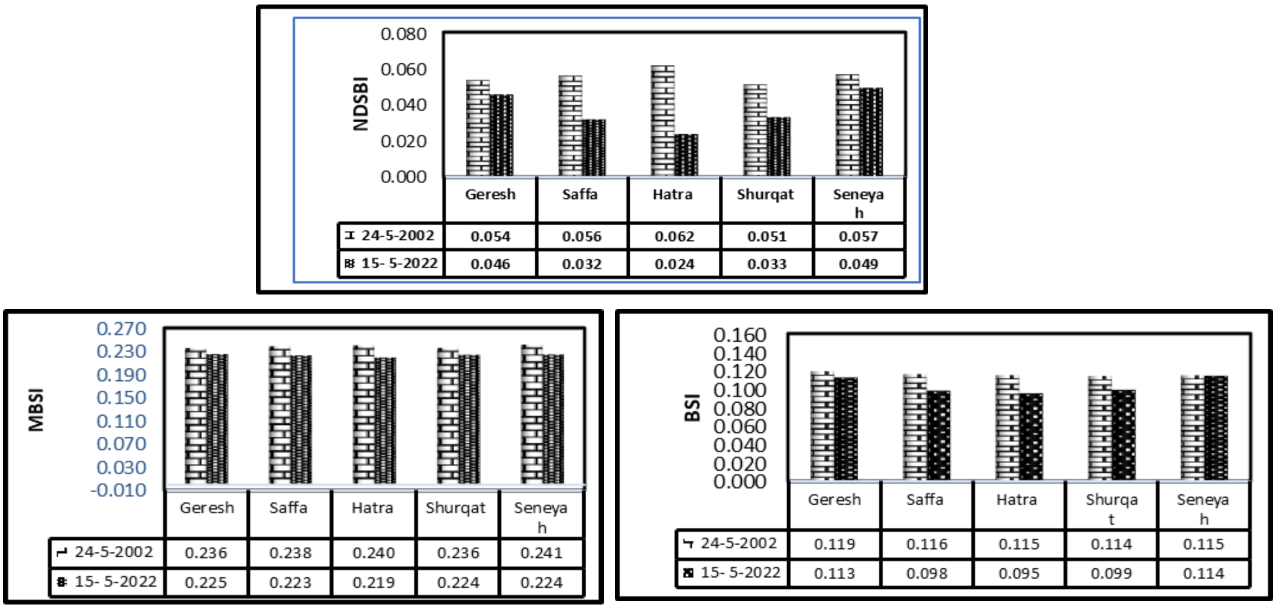


Figure 3. The mean values of soil spectral indices in the study area in 2002 and 2022.

Vegetation spectral indices

Many spectral indices can be derived from images of satellites such as Landsat, MODIS, and SPOT and used for assessment and monitoring of plant health based on its density, phenotypic characteristics, the composition of the vegetative system, or canopy. The SLAVI, which was first proposed by Lymburner *et al.*, (2000), is the ratio of the area of one face of the leaves to their dry weight. The results (Figure 4) indicate that, in 2002, the SLAVI lowest value was 0.541 whereas the highest value was 0.598. On the other hand, its values ranged in 2022 from 0.558 to 0.763. This difference depends on the spatial relationship between leaf area index and spectral reflectance of the NIR band. As to AVI, in 2002, the five soil series under consideration (Shurqat, Seneyah, Hatra, Jareesh, and Safa) had the values of 0.253, 0.249, 0.248, 0.248, 0.116), respectively (Figure 4). In 2022, the Hatra, Shurqat, Jareesh, Seneyah, and Saffa had the AVI values of 0.286, 0.280, 0.279, 0.272, and 0.098, respectively. The AVI values depend on the wavelength of NIR, which increases with density of the vegetation cover. So, this index has spatial relationship with the soil fertility and concentrations of nutrients in it. The SIPI is a good indicator for estimating the ratio of carotenoids to chlorophyll in plants. It is noticed that the SIPI values are generally low in the study area (Figure 4). Specifically, the results of the present study (Figure 4) bring to surface that the values of this index ranged in the study area from 0.229 to 0.311 in the year 2002 and from 0.188 to 0.350 in the year 2022. Calculation of this index takes into account the red band of electromagnetic radiation, which expresses the chlorophyll absorption band and the NIR band. As plant density increases, reflection increases in the NIR region and decreases in the red region of the light spectrum. Consequently, as chlorophyll content of the plant decreases, reflection in the red region increases, thus resulting in a decrease in the value of the SIPI. Since the values of this index usually fall in the range of 0-2, the higher the SIPI, the higher the carotenoids content and the lower the chlorophyll content of the plant, which reflect exposure of the plant to environmental stressors like plant diseases and limited supply of nutrients.

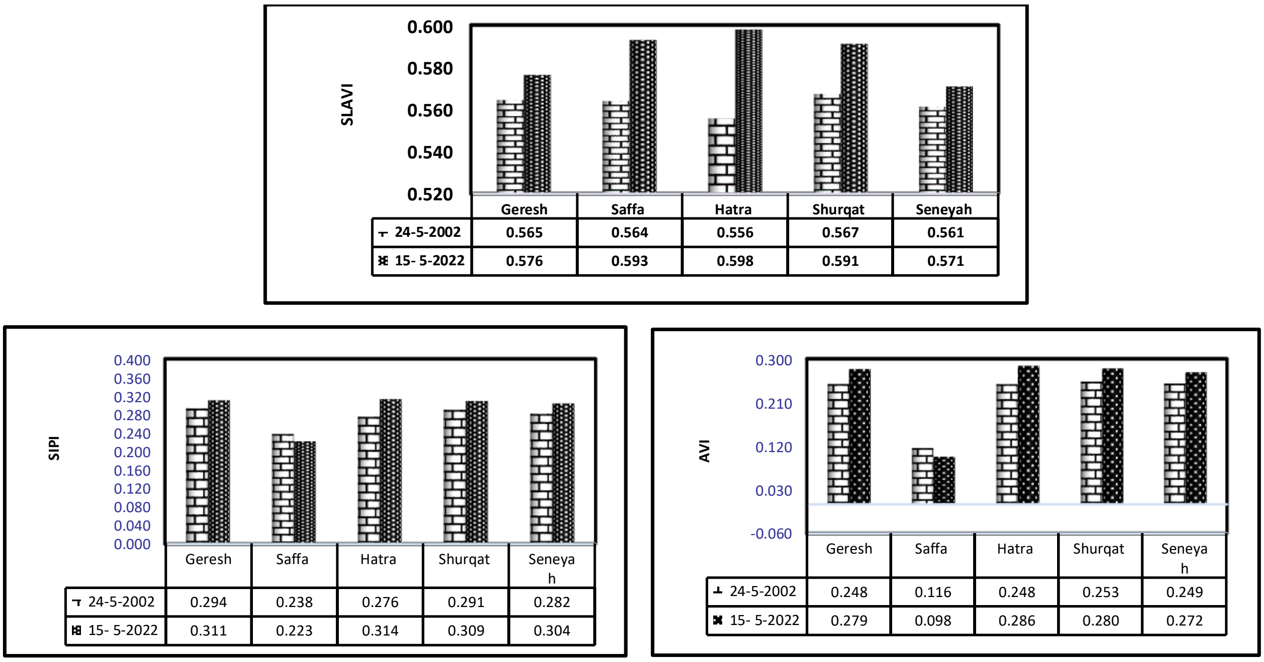


Figure 4. The mean values of vegetation spectral indices in the study area in 2002 and 2022.

Table 1 presents descriptive statistics of soil and vegetation spectral indices that confirm that soil and and vegetation in the study area suffer from environmental degradation. Thereupon, a suitable land management plan must be drawn for the study area that takes onto consideration, amongst others, reduced groundwater exploitation expansion of horizontal agriculture, protection of grazing lands and pastures, improvement of soil fertility and soil structure. Inter-, and intra-correlations between the six soil and vegetation indices under consideration have been examined. The correlation analysis outcomes are given in table 2. It can be seen that SLSVI has high correlations with NDBSI, BSI, and MBSI. Meantime, the AVI has high correlation with SIPI and NDBSI has medium-strength correlations with BSI and MBSI. All other correlations are negligible (very low in strength (≤0.20)).

Table (1). Descriptive Statistics of Soil and Vegetation Spectral Indices.

Descriptive Statistics	Vegetation Spectral Indices					
	SLAVI	AVI	SIPI	SLAVI	AVI	SIPI
	2002			2022		
Standard Error	0.002	0.009	0.003	0.007	0.013	0.006
Median	0.563	0.244	0.280	0.572	0.275	0.306
Mode	0.563	0.243	0.277	0.571	0.279	0.313
Standard Deviation	0.011	0.059	0.023	0.045	0.083	0.040
Kurtosis	1.481	-	-0.838	7.696	0.573	-0.256
Skewness	0.607	-	-0.621	2.871	-1.326	-1.027
Range	0.057	0.170	0.082	0.205	0.352	0.162
Minimum	0.541	0.105	0.229	0.558	-0.014	0.188
Maximum	0.598	0.275	0.311	0.763	0.338	0.350
Descriptive Statistics	Soil Spectral Indices					
	2002			2022		
	NDBSI	BSI	MBSI	NDBSI	BSI	MBSI
Standard Error	0.056	0.116	0.238	0.035	0.102	0.223
Median	0.002	0.001	0.001	0.006	0.005	0.001
Mode	0.055	0.117	0.237	0.047	0.115	0.223
Standard Deviation	0.049	0.118	0.233	0.046	0.112	0.223
Kurtosis	0.011	0.008	0.009	0.040	0.033	0.009
Skewness	2.042	5.503	11.239	6.406	6.029	8.557
Range	0.567	-	2.723	-2.670	-2.619	-2.551
Minimum	0.065	0.045	0.052	0.172	0.137	0.052
Maximum	0.028	0.085	0.228	-0.104	-0.014	0.187

Table 2. The coefficients of correlation (*r*) between the spectral indices.

r	SLA	AVI	SIPI	NDB	BSI	MBSI
Landsat 7, 2002						
SLA	1.00					
AVI	-0.01	1.00				
SIPI	0.20	0.89	1.00			
NDB	-0.90	-0.06	-0.20	1.00		
BSI	-0.61	-0.09	-0.02	0.56	1.00	
MBSI	-0.44	-0.05	-0.17	0.67	-0.04	1.00
Landsat 9, 2022						
SLA	1.00					
AVI	-0.09	1.00				
SIPI	0.02	0.98	1.00			
NDB	-0.99	0.05	-0.04	1.00		
BSI	-0.99	0.08	-0.02	0.99	1.00	
MBSI	-0.78	0.02	-0.05	0.79	0.75	1.00

CONCLUSION

The spectral indices are important for monitoring soil degradation, vegetation changes, and desertification, particularly in the arid and semi-arid regions. This study found that values of all the spectral indices under consideration decreased in the study from 2002 to 2022. The decreases in index values reflect severity of drought and desertification in this area during the study period. In addition, the values of the coefficients of correlations (*r*) between the soil spectral indices and vegetation spectral indices were negative. The correlations between AVI and SIPI were positive 0.89 in 2002 and 0.98 in 2022. Meantime, the correlations between SLAVI and NDBSI were negative -0.99 in 2002) and -0.99 in 2022.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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