ENVIRONMENT SENSITIVITY MAPS OF LAND DEGRADATION AND DESERTIFICATION USING MEDULAS MODEL AND REMOTE SENSING IN SHIRQAT CITY/IRAQ

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ABSTRACT
This research of aims to study environment sensitivity of desertification and land degradation using MEDULAS project and remote sensing in AL-Shirqat City/Salahadin/Iraq. A 10 soil pedons were chosen from study area depending on difference in soil properties, landuse and causes of desertification and degradation as (Salinity, Erosion, Gypsum and vegetation cover). Soil profile description, soil samples and GPS were conducted. The physical (texture) and chemical (CaCO₂, CaSO₄, 2H₂O, O.M, EC and pH) properties were determined. The Soil were classified as Torrifluvents in the (P₁, P₂, P₃), Calcigypsids in the (P₄ and P₅), Calcids in the P₆ and Calcids in the P₇. The landsat 8 image at 20sep. 2019 and 19 sep. 2013 were acquired in the spectral indices calculate and spatial maps by using ERDAS 15 and GIS 10.2. The result show contrast in soil proprieties as sand, clay, soil gypsum, CaCO₃, OM and EC that reflect on Soil Quality Index (SQI) which were (60)% poor quality and (40)% moderate quality degradation. While (19.10)% that moderate quality and 80.90% that poor quality for Vegetation Quality Index. The results show that 0.1% of the study area is classified as C1; 25.35% as C2; 74.55% of the areas were C3. The spectral indices as LAI, SI5, OSAVI were appropriate for monitor of desertification and degradation. While (19.10)% that poor quality, 0.1% that moderate quality and 80.90% that poor quality for Vegetation Quality Index. Add, spatial change in the spectral indices as NDVI and LAI. The results shown that MEDALUS model is a important model in the areas disposed to desertification and degradation. Key word: Remote sensing, MEDULAS project, NDVI, Desertification, LAI.

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INTRODUCTION
Desertification is important phenomena in arid and semi-arid environments. In the context of the EC MEDALUS (Mediterranean Desertification and Land Use), the focus here is primarily on European Mediterranean environments where physical loss of soil by wind erosion, water erosion, salinization, overgrazing and loss of nutrient status in soil. Wind erosion, salinization and drought are more problems affected in arid and semi-arid. Land degradation is among the most serious environmental problems at global, regional, and local scales (13) which leads to a depletion of soil fertility and productivity loss. One third of the world's drylands have already lost more than 25% of their productive capability. Each year the world loses 10 million ha of land for desertification and approximate 30% of the Earth's surface area is at risk of desertification affecting one billion people worldwide almost two billion people are located over the dryland (22). The more studies are depend on medulas project in evaluation of soil degradation, land degradation and desertification at the large scales (2,6,13,15,16,19,20,27). Assessment of the sensitivity of the soil in the rural area of Čukarica municipality to the processes of degradation is considered. The results obtained show that 41.54% of the study area is classified as critical; 22.34% of the surface as fragile; 8.47% of the areas are potentially endangered and 9.58% not threatened to degradation processes (18). Kadović et al., 2016 was used MEDALUS for detection and evaluation of land degradation in Deliblato sands. Remote sensing technique has great value in monitoring desertification and land degradation. use of remote sensing (RS) and Geographic Information System (GIS) for Change Detecting Spatial and Temporal Variability of Soil Salinity in Al-Latifiya Project, Iraq (9), depending more than satellite images and spectral indices as (NDVI, VI, TNDVI, SAVI, MSAVI, IPVI) in northern Iraq and the results ensured on the possibility of using of technique remote sensing as a device active and accurate in estimated size of area of degradation and desertification which extended to rangelands especially in the last few years (3). The determine soil deterioration degree based on NDVI to that were in the range of moderate to severe deterioration. Some physical deterioration as represented by soil texture, coarse sand texture, and chemical deterioration due to high level of salinity on some locations. The high level of gypsum and biological deterioration indicated by low level of organics and missed plant cover (26). The present study aimed to assess the environmental sensitivity of desertification and land degradation in the Shirqat district in Salah Al-Din Governorate / Iraq using the Medulas model and remote sensing.

MATERIALS AND METHOD
Study area. The Shirqat district is located between longitudes (42°52'31.77"E and 42°58'43.756" E) and two latitudes (35°39'41.352"N and 35°15'27.392” N) in the northern part of Salah Al-Din Governorate / Iraq. Its area is approximately (1577) km² and had the population 220000. An study area of 214.99 km² was chosen for the study, based on the variation in soil properties according to the physiographic units (Alluvial soils, mountain and Al- desert Jazeera soils but according to Soil Survey Staff (2006) are classify Torrifluvents (P₁, P₂, P₃), Torripsamments(P₅, P₇), Calcigypsids(P₆, P₁₀) and calcids(P₈, P₀). It suffers from several causes of desertification phenomena as (wind erosion, water erosion, salinization, sand movement, overgrazing and gypsum content). As well as, agricultural exploitation, the quality of irrigation water and mismanagement. Average annually rainfall ranges between 150 - 250 mm, average maximum temperatures range between 13.5 - 42.50° C°, and minimum temperatures range between 3.3 - 26.2° C° the mean temperature is increase in July and August, and lowest in January and February. The several locations were selected which involve (10) ten pedon and its morphological description was done according to the (Soil Survey Staff 2006). In addition, the coordinates of the study location were determined using GPS. Soil samples were taken and transferred for laboratory, and the soil physical (Soil Texture) and chemical properties (OM, CaCO₃, CaSO₄.2H₂O) were determined in the Department of Soil Science and Water Resources at the Tikrit University. Slope was analyzed using the DEM Digital Elevation Model and ArcGIS Ver 10.2 software and ranged between 0-19.5% as (Fig.1).
Medalus project. The environment sens-itivity to land degradation and desertification are defined using the Environmental Sensitive Area Index (ESAI) according to the model data (Kosmas et al., 1999; Kosmas et al. 2014, Kadović, 2016; Lamqadem, 2018; Zambon, 2017; Mostafa, 2020). The Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI) were used. Spatial distribution maps of Soil quality indices, vegetation quality indices and environment sensitivity were conducted using ArcGIS Ver 10.2. The areas of environmental sensitivity classes of land degradation and desertification were calculated using the inverse distance method.

Soil quality index

For the soil quality estimation one topographic (slope) and seven soil properties (soil texture, EC, organic matter, calcium carbonate, soil gypsum, rock fragment of surface layer and soil Albedo) were selected. Soil quality index (SQI) was calculated as following equation:

Soil Quality Index-SQI=(X1×X2 ……Xn)^1/8

(1) then X= Soil properties as mentioned in table (1) respectively.
Table 1. Classes, description, and assigned weighting indices for the parameters.

| Parameter          | Class   | Description            | Susceptibility class | Weight index |
|--------------------|---------|------------------------|----------------------|--------------|
| Soil Texture       | 1       | Good                   | L, SCL, SL, LS, CL   | 1            |
|                    | 2       | Moderate               | SC, SiL, SiCL        | 1.2          |
|                    | 3       | Poor                   | Si, C, SiC           | 1.6          |
|                    | 4       | Very Poor              | S                    | 2            |
|                    | 5       | Very poor              | S                    | 2            |
| OM %               | 2       | Slightly               | 2-4                  | 1.2          |
|                    | 3       | Moderate               | 4-8                  | 1.5          |
|                    | 4       | Sever                  | 8-15                 | 1.8          |
|                    | 5       | Very sever             | >15                  | 2            |
| Slope %            | 1       | Level                  | <6%                  | 1            |
|                    | 2       | Gentle                 | 6-18                 | 1.2          |
| (DEM), ArcGIS      | 3       | steep                  | 18-35                | 1.5          |
|                    | 4       | Very steep             | >35%                 | 2            |
|                    | 5       | Very low               | <3%                  | 1            |
| CaCO₃ %            | 3       | Moderate               | 10-25                | 1.5          |
|                    | 4       | High                   | 25-50                | 1.8          |
|                    | 5       | Very high              | >50%                 | 2            |
| ROCK FRAGMENTS     | 2       | Very stony             | >60                  | 1            |
|                    | 3       | Bare to slightly       | <20                  | 2            |
|                    | 4       | Low                    | <2                   | 1            |
| CaSO₄. 2H₂O        | 2       | moderate               | 2-10                 | 1.5          |
|                    | 3       | High                   | 10-25                | 1.8          |
|                    | 4       | Very high              | >25                  | 2            |
| Soil Brightness    | 1       | Dark                   | 0-0.20               | 1            |
|                    | 2       | Moderate dark          | 02-0.25              | 1.5          |
| Lamqadem, 2018     | 3       | Lighte                 | 0.25-1               | 2            |

Vegetation quality Index

The main factors affecting vegetation status in the area are erosion (wind and water), plant cover (necessary in reducing wind affect and fertility layer loss) and drought condition. Erosion protection, drought resistance and vegetation cover criteria. Different vegetation classes and scored were derived using the equation formula as following (table 2):

\[
VQI = (VgC\% \times Erosion \times Drought)^{1/3}
\]  

Vegetation Cover - VgC %

The equation mentioned by (Puredorj, 1998) was used to calculate the percentage of vegetation cover in the study area which range 0 -100%. Vegetation green Cover (VgC%) was calculated using ArcGIS Ver. 10.2. The ERDAS program Ver. 15 was used to calculate the NDVI, which expresses the vegetation density and its values between -1,+1, as the closer to 1 the higher the plant density. The index represents the difference between the near infrared (B5), in which the plant has a high reflectance, and the red wavelength in which the plant has a strong absorption and represents the chlorophyll absorption area as following.

\[
VgC\% = 0.65 \times (-4.337-(3.733 \times NDVI) +161.968 \times (NDVI)^{0.5}
\]  

Where, NDVI-Normalized Difference Vegetation Index.

\[
NDVI= (NIR-R)/(NIR+R)
\]

Where, NIR-Near Infrared (B5 at the OLI, landsat 8 according to aquire R-RED (B4 at the OLI, landsat 8).

Erosion. The index for soil erodibility is express the product of multiplying the wind erosion, water erosion, and soil crust index

\[
E = EF \times WEF \times SCF
\]

Where, EF Wind erodible Fraction, WEF-Water erodibility and SCF-Soil Crust Factor as following:

Erodible Fraction-EF. The wind erosion hazard is severe in regions of low precipitation and high temperatures and wind velocity
where soil is bare. The risks of wind erosion are exacerbated by wind blowing across long, bare fields on soils of single-grain or weak structure and having a loamy texture (Lal et al., 2004). It depends in its calculation on soil characteristics that decrease soil erodibility to wind erosion as (organic matter and clay) or increase soil erodibility to wind erosion as (sand content and structurless) as following equation (Fryrear et al., 2000). According to Dregne (1983) criteria were classified as Slight-tly, Moderate, Sever, and very sever degradation.

\[ EF = 29.09 + (0.31 \times \text{sand}\% + 0.17 \times \text{silt}\% + 0.338 \times \text{sand/clay}\% - 4.66 \times \text{OM}\% - 0.95 \times \text{CaCO}_3\%)/100 \ldots \] \tag{6}

**Water erodibility Index – WEF:** Sandy soils have larger macropores and absorb water more rapidly than clayey soils. Under low intensity rains, sandy soils produce less runoff than clayey soils. Most of the rain falling on clayey soils is into runoff due to the small micropores, which decrease water infiltration. (Blanco and Lal, 2008). It depends in its calculation on soil texture as following:

\[ \text{WEF} = (0.37 \times (\text{silt} + \text{vfsand}\%) \times (0.28 \times \text{Clay}\%)+14.87)/100 \] \tag{7}

**Surface Crust Index – SCF:** Soil crust index is inversely proportional to the clay content. The higher the clay content, the lower the soil crust rate and in turn, the lower the degree of protection of the soil surface from the effect of erosion. Crusts are more thick, firm, and strong to erosion than uncrusted soils. The rate at which crusts are degraded depends on the degree of the abrasive forces of the wind. It depends in its calculation on soil clay content as following:

\[ \text{SCF} = 1/(1+0.0049 \times (\text{CLAY})^2 \] \tag{8}

**Lang Factor:** Richard Lang established a climate classification based on a ratio factor between precipitation and temperature. The Lang climate factor \((L)\) is calculate using the following formula:

\[ L = \frac{P}{T} \] \tag{9}

Where, \(P\): Annual total precipitation (mm), \(T\): Annual temperature mean (°C).

**Table 2. Classes, description, and assigned weighting indices for the parameters**

| Parameter       | Class | Description | Susceptibility | Weight |
|-----------------|-------|-------------|----------------|--------|
| Erosion         | 1     | Low         | <0.039         | 1      |
|                 | 2     | Moderate    | 0.039-0.053    | 1.3    |
|                 | 3     | High        | 0.053-0.066    | 1.8    |
|                 | 4     | Very High   | >0.066         | 2      |
| VgC%            | 1     | Very dense  | 100-81         | 1      |
|                 | 2     | dense       | 80-61          | 1.2    |
|                 | 3     | moderate    | 60-41          | 1.5    |
|                 | 4     | poor        | 40-21          | 1.8    |
|                 | 5     | Very poor   | 20-0           | 2      |
| Aridity Index   | 1     | Humid       | >160           | 1      |
|                 | 2     | Semi Humid  | 160-40         | 1.5    |
|                 | 3     | dry         | 40-10          | 1.8    |
|                 | 4     | Very dry    | 10-0           | 2      |

**Climate quality.** The data were obtained from Iraq Meteorological through period 1980-2019. Climate quality is assessed by using parameters that influence water availability to the plants such as amount of rainfall, air temperature and aridity, as well as any climate threats as frost which might inhibit or even prohibit plant growth. Annual precipitation is classified in three classes considering the annual precipitation of 280 mm as a critical value for erosion and plant. As result of the calculation on Soil texture as following:

\[ \text{WEF} = (0.37 \times (\text{silt} + \text{vfsand}\%)) \times (0.28 \times \text{Clay}\%)+14.87)/100 \] \tag{7}

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\[ L = \frac{P}{T} \] \tag{9}

Where, \(P\): Annual total precipitation (mm), \(T\): Annual temperature mean (°C).

Climate quality index (CQI) was calculated according to formula:

\[ \text{Climate Quality Index} = (\text{Rainfall} \times \text{BGI})^{1/2} \] \tag{11}

Where, CQI=1.67
ESAI (Environmentally Sensitive Areas Index). Environment Sensitivity Area Index to desertification and land degradation using multiply (soil quality, climate quality and vegetation quality). Classifying the area into four main classes and eight classes as mentioned in (table 4).

\[
\text{ESAI} = (\text{SQI} \times \text{CQI} \times \text{VQI})^{1/3}
\]

Where, SQI: Soil Quality Index, CQI: Climate Quality Index, and VQI: Vegetation Quality Index.

Table 4. ESA, Soil, Vegetation, Climate Quality index

| Quality     | SOI   | VOI   | CQI  |
|-------------|-------|-------|------|
| high        | <1.13 | <1.13 | 1.15 |
| moderate    | 1.13-1.45 | 1.13-1.45 | 1.15-1.81 |
| Low         | >1.45 | >1.45 | >1.81 |

Table 3. Classes, description, and assigned weighting indices for CQI

| Parameter     | Class | Description | Susceptibility class | Weight index |
|---------------|-------|-------------|----------------------|--------------|
| Rainfall (mm) | 2     | Humid       | >650                 | 1            |
|               | 3     | Dry-humid   | 650-280              | 1.5          |
|               | 4     | Dry         | <280                 | 2            |
| BG Index      | 1     | Very humid  | <50                  | 1            |
|               | 2     | Humid       | 50-75                | 1.1          |
|               | 3     | Humid-Dry   | 75-100               | 1.2          |
|               | 4     | Semi dry    | 100-125              | 1.4          |
|               | 5     | Dry         | 125-150              | 1.8          |
|               | 6     | Very dry    | >150                 | 2            |

N: Non affected; P: Potential; F: Fragile; C: Critical

Spectral Indices
The satellite image at 26 Sep 2019 and 20 Sep 2013 were used. The ERDAS imagem Ver. 15 in the processing, interpretation and change detection was used and in indices calculate as follows:

Leaf Area Index (LAI): The Leaf area index (LAI) is a dimensionless measure of the one-sided area of canopy foliage (m²) per unit ground surface area (m²) (Scurlock and Hicke, 2003; Garrigues et al., 2008). Leaf area index (LAI) was calculated using spectral reflectance and SAVI as follows:

\[
\text{LAI} = \ln \left( \frac{0.69 - \text{SAVI}}{0.59} \right) / 0.91
\]

Soil Adjective Vegetation Index (SAVI): It indicates the effect of the interaction between soil reflectivity and vegetation cover as in the following equations.

\[
\text{SAVI} = \frac{(1 + L)(B5 - B4)}{(L + (B5 + B4))}
\]

\[
\text{OSAVI} = \frac{(B5 - B4)}{((B5 + B4 + 0.16)}
\]

\[
\text{GOSAVI} = \frac{(B5 - B3)}{((B5 + B3 + 0.16)}
\]

Soil Salinity Index (SIS)

\[
\text{SIS} = \frac{\text{BLUE}}{\text{RED}}
\]

\[
\text{where the B5 = Near Infrared band; B4 = Red Band and B3 = Green band with landsat8}
\]

RESULTS AND DISCUSSION

Soil Quality Index-SQI
The spatial variation in soil characteristics reflects its sensitivity to desertification and land degradation processes in arid and semi-arid regions. Soil characteristics results indicate that P5 and P7 had a high sand content, reaching more than 70%. While P1, P2 and P8 were suffering from salinity, it reached more than 15 dSm⁻¹ in the surface layer of soil. The results indicate that the locations P6, P8 and P10 suffer from high gypsum content in the soil, reaching 25.00, 11.05 and 9.95%, respectively. The results show that soil quality index ranged between (1.23 and 1.52) as it reached the lowest value at P5, which is located within alluvial plain, for plant growth and the highest organic matter content compared to other sites. The highest value is for the fifth pedon, P5 and P7, which have a very fragile structure and loose as a result of the sandy texture, sparse vegetation cover and low organic matter. The indices within the soils of moderate and poor quality, as the result is an interrelated result of many physical, chemical and morphological
characteristics. Figures (2) indicate the spatial distribution of the soil quality index, as the percentage of poor soil quality index reached 67%, which includes P5, P6, P7, P8, P10 and other sites fall within the moderate quality, which constitutes 33% of area study.

Fig. 2. Soil Quality Index maps

Vegetation Quality Index-VQI

Erosion Index: Soil erosion is one of the most important criteria in evaluating desertification and land degradation, due to detachment soil particles, reduce its fertility, and effect on agricultural crops. The results indicate the variation in the wind soil erodibility, which is related to its calculation on important soil characteristics that have the ability to aggregate soil particles more than 1 mm that increase its resistance. Wind soil erodibility was increased at P3 and P7 (0.75 and 0.62), while the decrease in the alluvial plain locations at P1, P2, and P3, which have the good structure, higher organic matter and lower content of sand. According to Dregne (1983) criteria that refer to the effect of wind erosion on soil degradation which classify to Slightly, Moderate, severe and very severe degradation was its area 134.01, 54.78, 18.04 and 8.16 km² and as percent(62.33, 25.48, 8.39 and 3.80 )%. The P7 and P3 locations, which is suffer from very sever degradation, while most location was at moderate and slightly. The results refer to that locations with high sand content, weak structure and dispersed vegetation cover have higher erodibility to wind erosion. Sandy soils are less cohesive than clayey soils and thus aggregates with high sand content are more easily detached. The results of Figure (3) showed water soil erodibility ranged between 0.23-0.40 for each of the P2 and P5, respectively. May be relate to the content soils from cementing materials between soil particles, which leads to the formation of large aggregates and a cohesive structure. The soil organic matter is one of the key factors that control the aggregates stability. It physically, chemically, and biologically cement primary particles into aggregates. The soil ability to erosion depends on its structure. Soils with weak soil structure are more detachable. According to figures (3) that indicate the water soil erodibility, that the location soils of the alluvial plain P1, P2, and P3 are the most water erosion range 0.35 - 0.39. According to Dregne criteria, they occurred within lands of degradation The area was severe degradation formed an area of 80.63km² and a percentage of 37.50%, while the sites P3 and P7 were the least exposed to water erosion because water infiltration is positively correlated with an increase in coarse soil particles and decrease in fine particles (25). Sandy soils have larger macropores and absorb water more rapidly than clayey soils. Macropores conduct water more rapidly than micropores.
The results of Figure (4) that the SCF index was relatively high in the sites P5, P6, P7 reached 0.984, 0.984 and 0.799 because weak structure, high gypsum and sand content. According to Dregne (1983) that P5 and P7 is within area of Very sever degradation formed 13.81 km² (6.42) %. While the area of moderate degradation and slightly degradation was 39.66 km² and 39.66 km² (18.45 and 54.78)%. Thus, the crust is one of the indicators that protect the soil surface from the intensity of winds and raindrops on the occurrence of erosion and its degradation, and this crust depends on the content of the clay.
Figure 5 indicates soil erodibility ranged between 0.016 - 0.167 at P1 and P3 respectively, and it was found that the sites P5, P6 and P7 had the highest erosion potential (> 0.06) according to Medulas model and it was within the 4 class (very high) which formed an area of 24.16 km² (11.24%). In contrast, P3, P4, P8, and P10 were within the moderate erodibility, ranging 0.039-0.053, which formed an area of 116.44 km² (54.16%). According to Dregne (1983) criteria, the P5, P6 and P7 within very severe degradation. As for the sites P3, P4, P8 and P10, they are within moderate degradation. Thus, wind erosion and soil crust factor have a higher degree of impact than water erosion, which led to the effect of wind erosion in the AL-Jazeera region which suffer from sand dune movement, strong wind, Gypsiferous soil, sandy to loam texture and mismanagement.

Vegetation green Cover-VgC %. The vegetation cover usually ranged between 32.7 and 50.40 %. According to the obtained data that P1, P2 and P3 had relatively higher vegetation cover and was within the class 3 (medium density), while the other pedons (68.09%) within the class 4 (low) density). Thus, according to the medulas criteria, the area of land with moderate vegetation 68.59km² (31.91) %. While, land with poor vegetation, equivalent to 146.39km² (Figure 6).
According to the obtained data from spatial distribution maps, that the P9, P3, P2, P1 within the moderate quality, which appears (71.06) km² (19.10) %. As for the rest of the pedones, which are P10, P8, P7, P6, P5, with an area of 143.93 km² (80.90) % within low quality (Fig. 7). Vegetation cover is one of the most important indicators to monitor of desertification and protect the soil surface from external factors, improves its internal system such as water, air, organic matter, organism activity, soil temperature, humidity, and permeability.

Desertification Environment Sensitivity (ESAI). Most of the sites were within the class C and varied according to a subclass and they were within the class C1, which occupied a very small area of 0.22 km² (0.10)%, and an area under C2 was 54.50 km² (25.35)% , which included the sites P1, P2, P4 and P9 respectively, where their values were limited range 1.41-1.53. The subclass C3, so it was modified in this study to other classes (C31, C32, C33). Therefore, the sites P5, P6 and P7 were within the higher class C33 environmental sensitivity to desertification, range 1.62-1.68, its area was 34.45 km² (16.03)% , and the area of subclass C32, ranged 1.53-1.56, occupied a large part of the study area, reaching 87.70 km² (40.79)%. In general, the C3 class total area occupied 74.55% of the area of the study area(Figures 8, 9).
According to the obtained data, 123.65 km$^2$ (57.51%) is suffering from very severe degradation at 19 Sep. 2013 and decrease an area at 20 Sep. 2019 which occupies 63.39 km$^2$ (29.48%) and change area between 2019 and 2013 was 60.25 km$^2$. While, the areas of severe degradation about 120.86 km$^2$ of the total area (56.22%) at 20 Sep. 2019 while 80.86 km$^2$ of the total area (37.61%), and change area was 39.99 km$^2$ (40%) may be increase in rainfall totally and management practices (figures 10).

The Area Leaf Index (LAI) is one of the important vegetative indicators that express the state and health of vegetation cover. According to fig. (12), very severe degradation...
is occupies large area which reach 75.74 km$^2$ and 192.44 km$^2$ at 2019 and 2013 respectively, compared with other degree, 18.03km$^2$ for sever degradation(Fig.12).

![Fig. 12. Area Leaf Index maps of study area](image)

The OSAVI and GOSAVI vegetation indicators ranged between 0.090 - 0.198 and 0.17 - 0.29 for the year 2013, and they ranged between 0.10 - 0.15 and between 0.14 - 0.22 for the year 2019. This variation in the values of the spectral indices is a result of the influence of soil and atmosphere on the reflectivity of vegetation. The SI5 salinity index ranged between 0.67 - 0.89, and the maximum height was reached in soils with high salinity levels such as P$_1$, P$_2$, and P$_8$ sites. This may be due to poor management and quality of irrigation water.
Table 13. Vegetation and soil indices of study area

| Loc. | Statistical | 
|------|-------------|
|      | OSAVI      | GOSAVI     | SI5  |
|      | 2013 | 2019 | 2013 | 2019 | 2013 | 2019 |
| $P_1$ | Min | 0.135 | 0.100 | 0.199 | 0.152 | 0.726 | 0.810 |
|      | Max | 0.180 | 0.177 | 0.242 | 0.248 | 0.746 | 0.835 |
|      | Mean | 0.157 | 0.150 | 0.219 | 0.218 | 0.735 | 0.823 |
| $P_2$ | Min | 0.160 | 0.093 | 0.238 | 0.120 | 0.681 | 0.886 |
|      | Max | 0.208 | 0.180 | 0.271 | 0.257 | 0.723 | 0.913 |
|      | Mean | 0.173 | 0.151 | 0.246 | 0.218 | 0.700 | 0.8995 |
| $P_3$ | Min | 0.190 | 0.094 | 0.287 | 0.135 | 0.602 | 0.618 |
|      | Max | 0.206 | 0.114 | 0.307 | 0.162 | 0.632 | 0.737 |
|      | Mean | 0.198 | 0.100 | 0.299 | 0.146 | 0.618 | 0.678 |
| $P_4$ | Min | 0.084 | 0.109 | 0.176 | 0.192 | 0.618 | 0.674 |
|      | Max | 0.109 | 0.145 | 0.207 | 0.218 | 0.660 | 0.739 |
|      | Mean | 0.093 | 0.121 | 0.187 | 0.199 | 0.637 | 0.712 |
| $P_5$ | Min | 0.086 | 0.092 | 0.191 | 0.170 | 0.595 | 0.670 |
|      | Max | 0.093 | 0.140 | 0.199 | 0.206 | 0.612 | 0.795 |
|      | Mean | 0.090 | 0.115 | 0.195 | 0.192 | 0.601 | 0.715 |
| $P_6$ | Min | 0.084 | 0.109 | 0.169 | 0.189 | 0.674 | 0.627 |
|      | Max | 0.090 | 0.133 | 0.175 | 0.236 | 0.698 | 0.733 |
|      | Mean | 0.085 | 0.122 | 0.172 | 0.205 | 0.686 | 0.696 |
| $P_7$ | Min | 0.088 | 0.095 | 0.182 | 0.182 | 0.630 | 0.684 |
|      | Max | 0.097 | 0.110 | 0.198 | 0.189 | 0.682 | 0.740 |
|      | Mean | 0.092 | 0.102 | 0.192 | 0.185 | 0.651 | 0.710 |
| $P_8$ | Min | 0.097 | 0.077 | 0.197 | 0.134 | 0.653 | 0.881 |
|      | Max | 0.159 | 0.150 | 0.227 | 0.266 | 0.756 | 0.876 |
|      | Mean | 0.121 | 0.112 | 0.207 | 0.200 | 0.698 | 0.879 |
| $P_9$ | Min | 0.099 | 0.107 | 0.199 | 0.161 | 0.596 | 0.661 |
|      | Max | 0.191 | 0.165 | 0.252 | 0.254 | 0.771 | 0.761 |
|      | Mean | 0.120 | 0.130 | 0.225 | 0.217 | 0.631 | 0.711 |
| $P_{10}$ | Min | 0.102 | 0.102 | 0.187 | 0.187 | 0.618 | 0.840 |
|      | Max | 0.222 | 0.222 | 0.266 | 0.266 | 0.737 | 0.926 |
|      | Mean | 0.134 | 0.134 | 0.225 | 0.225 | 0.694 | 0.885 |

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