

SOIL SALINIZATION IN UJAR REGION OF AZERBAIJAN WITH INDEX APPLICATION AND VARIOUS METHODS COMPARISON

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Abstract

This study analyzes the application of various salinity indices (SI, SI2, SI3, NDSI) to assess the level of soil salinity in Ujar region. Based on the data obtained using remote sensing and GIS technologies, the areas of soil salinity distribution were determined. By comparing different indices, the extent to which each method showed different levels of salinity was analyzed. The obtained results provide important indicators for determining the risk of salinization in the soils and the use of these data in agriculture and nature management. This approach is an important tool for accurate assessment and analysis of soil salinity. Conducting soil monitoring in the Ujar region, which is the region that best meets the needs of agriculture in the Azerbaijan Republic, is a very pressing issue. The highest regression accuracy for all points and separately for crops was obtained for images for May 13, 2023, low – for July 16, 2023 and for November 2, 2023. On May 13, almost all crops were actively growing, and on November 2, the surface of the fields was open. The best regressions were obtained for the period of active vegetation of crops. The southwestern and central parts of Ujar are more exposed to salinity.

Key words: soil salinization, salinization indices, GIS, spatial images, salinization analysis

Introduction. Soil salinity significantly limits crop production. In arid areas, yield losses can range from 19% to 45% due to unfavourable conditions caused by high salt content. Secondary salinization is one of the main processes of land degradation, which negatively affects ecosystems and biodiversity [1]. This phenomenon is associated with the accumulation of water-soluble salts, which inhibit plant growth and change the chemical composition of the soil. Proper distribution of water resources can reduce the level of salt accumulation in soils [3].

Soil salinization is a serious threat to agriculture and ecosystems, especially in regions with semi-arid and arid climates. At present, the most promising are the use of satellite data and automated methods for deciphering soil salinity. These studies are actively being developed in many countries [4, 5]. In Azerbaijan, especially in areas such as Ujar region, this problem creates unfavourable conditions for agriculture and vegetation, causing high salt accumulation in the soil as a result of drought and failure to apply proper irrigation methods. Salinization reduces soil productivity and poses problems for long-term agricultural activities and water management [6, 7].

This study differs from previous studies in that it analyzes the application of the latest salinity indices (SI1, SI2, SI3, NDSI) to assess the soil salinity levels of Ujar. Soil salinization occurs mainly due to high concentrations of salts (NaCl, MgCl₂, NaHCO₃, Na₂CO₃, CaSO₄, MgSO₄, Na₂SO₄), which negatively affects plant growth and can lead to a decrease in yields [8].

The middle quaternary alluvial and undifferentiated eolian deposits that come to the surface are represented by sands and sandy loams with lenses and layers of loams and clays. Salinity is somewhat absent to a depth of 30–50 cm, below which the salt content increases sharply. Solonchak soils are formed on flat depressions. The main innovation of the study is to conduct a detailed analysis of salinity by different indices, both by area and by salinity intensity, and to show in a comparative form how each index reflects the risk of salinity.

The soils are depleted of nutrients, low in humus (< 1%), and are characterized by complete lack of structure and the ability to become waterlogged after irrigation and form a dense crust. Under the influence of irrigation, salt migration processes in the soil profile are activated. Meadow soils are characterized by high alkalinity. The content of carbonates reaches high values and increases with depth. Winter wheat (*Triticum aestivum* L.), alfalfa (*Medicago* L.), rice (*Oryza sativa* L.), and oats (*Avena sativa* L.) are grown on the irrigated area.

Unlike other studies, the aim of this work is not only to determine the risk of salinity, but also to show in practice how this risk can be assessed for agriculture and the environment. Potential applications for the use of the results and proposals for the development of methods to combat salinity will be made [9].

Methods. The satellite images used in the research work were Landsat 8 OLI data. The data was obtained from the USGS Earth Explorer platform. The images were adjusted to take into account the boundaries of the area, and the indices were

calculated using the Arctoolbox-Spatial Analyst-Map Algebra-Raster Calculator command. Remote sensing technologies, such as Landsat 8 satellite imagery, offer promising opportunities for monitoring and mapping soil salinity at large spatial scales with high temporal resolution [10].

The research focused on Ujar research station (47°38'2.844"N, 40°27'44.078"E) of Kur-Araz lowland. In order to assess the salinization status of the Ujar soils, a study was conducted using satellite images. The images were first cropped and aligned to the corresponding coordinates. Then, indices were applied.

In this research work, various salinity indices (SI1, SI2, SI3, NDSI) were used and analyzed. These indices were calculated using spectral bands obtained from satellite images. The index values were calculated in ArcGIS 10.8 software and the salinity level of the territory was determined.

Using the Progress 1T field salinity meter, the electrical conductivity and temperature of the soils were determined, and the degree of salinity was calculated based on these data. The degree of salinity was determined in the following depth ranges: 0–20, 20–50, 50–100 cm. A total of 216 determinations were made.

Salinity maps were constructed based on regression analysis – creating regression equations between space imagery data and electrical conductivity measured in the field. Using GIS, pixel brightness values were extracted for all spectral channels of Landsat 8 satellite images and the values of pixel brightness ratios in different channels and vegetation indices were calculated (Tables 1 and 2).

T a b l e 1
The formula of four indices used in the study

Name	Formula
Salinity index (S1)	$SI = \sqrt{R \times SWIR1}$
Salinity index (S2)	$SI2 = \frac{SWIR1}{NIR}$
Salinity index (S3)	$SI3 = \frac{SWIR1}{G}$
Normalized Difference Salinity Index (NDSI)	$NDSI = \frac{(R - NIR)}{(R + NIR)}$

Below is a brief explanation of each index according to the table:

Salinity Index (SI1): $SI = \sqrt{R \times SWIR1}$

This index is used to measure soil salinity based on remote sensing data. Green (G) and red (R) bands are used to calculate the salinity index.

Alternative Salinity Index (SI2): $SI2 = \frac{SWIR1}{NIR}$

This index is used to estimate the salinity level on the land surface by analyzing spectral image data to determine soil salinity.

Alternative SI3: $SI3 = \frac{SWIR1}{G}$

This index is used to assess soil salinity, especially to identify high salinity levels.

NDSI:
$$NDSI = \frac{(R - NIR)}{(R + NIR)}$$

NDSI is a normalized difference index used to estimate salinity. It uses red (R) and NIR bands.

Table 2 lists the wavelengths of the various ranges and the indices in which these ranges are used.

T a b l e 2
Compliance with Landsat 8 bands and salinity indices

Band	Name	Wavelength (µm)	Use in indexes
Band 2	Blue (B)	0.45–0.51	(Generally not used)
Band 3	Green (G)	0.53–0.59	Important for SI3
Band 4	Red (R)	0.64–0.67	Important for SI, NDSI, SI2
Band 5	NIR (Near infrared)	0.85–0.88	Important for SI2, NDVI, SAVI
Band 6	SWIR1 (Shortwave infrared)	1.57–1.65	Important for SI, SI2, SI3, NDSI
Band 7	SWIR2 (Shortwave infrared 2)	2.11–2.29	(Mainly shows saline soils more clearly)

Results. In the data analysis stage, since only data for 2023 were used, changes in soil salinity and salinity risks in the area were assessed over a certain period of time. The map in Fig. 1a shows the spatial distribution of soil salinity based on the salinity indexes. The salinity level is divided into five different classes. It takes values from 0 to 1, indicating saline and non-saline areas (Fig. 1a). A map using the alternative SI2 is shown below. It takes values from 0 to 1, indicating saline and non-saline areas (Fig. 1b). The regressions based on Landsat 8 images was constructed using images from 2023.

The presented salinity map (Fig. 1c) represents values from −1 to 0. Green colour indicates areas of low salinity, and blue colour indicates areas of salinity that is present or poorly estimated. This map shows that salinity in the Ujar is not clearly visible and the NDSI index is not suitable for this region.

Figure 1d shows a salinity map based on the SI3. The SI3 index estimates the level of soil salinity using the ratio between band 6 (SWIR) and band 3 (G). The map shows three main classes:

- Slightly Saline (ECe range: 2–4 dS/m) (0–0.66): Represents areas with minimal or non-saline (ECe range: < 2 dS/m) soils.
- Moderate Salinity (ECe range: 4–8 dS/m) (0.66–1.33): These are regions with moderate salinity, where the soil contains a certain concentration of salts.

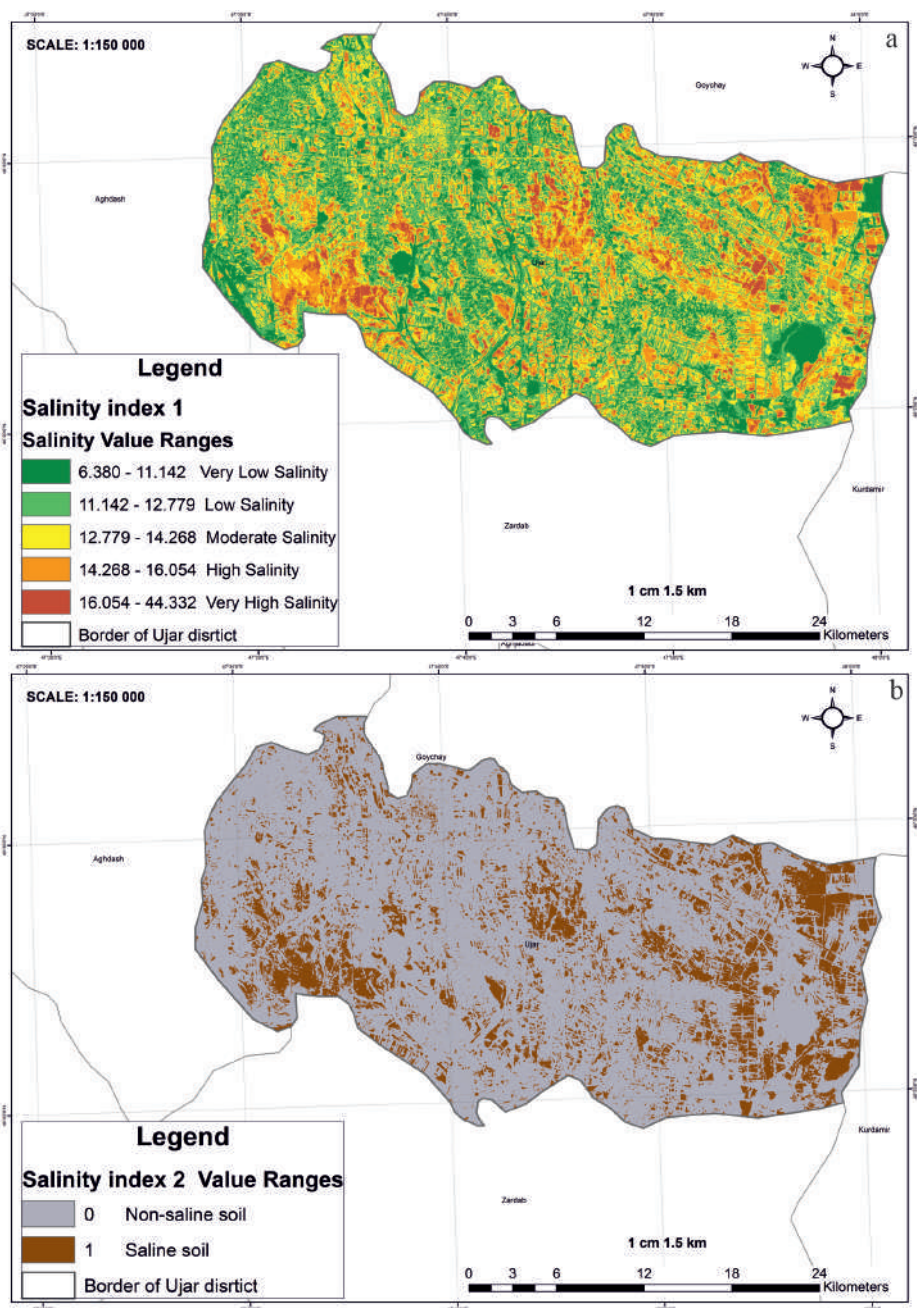


Fig. 1. Salinity maps of Ujar region using different indices (Using ArcGIS 10.8). The map was prepared by the authors (2023) in order to more clearly show the intensity of soil salinization in the region and its geographical distribution.

a. SI1 map of Ujar region; b. SI2 map of Ujar region

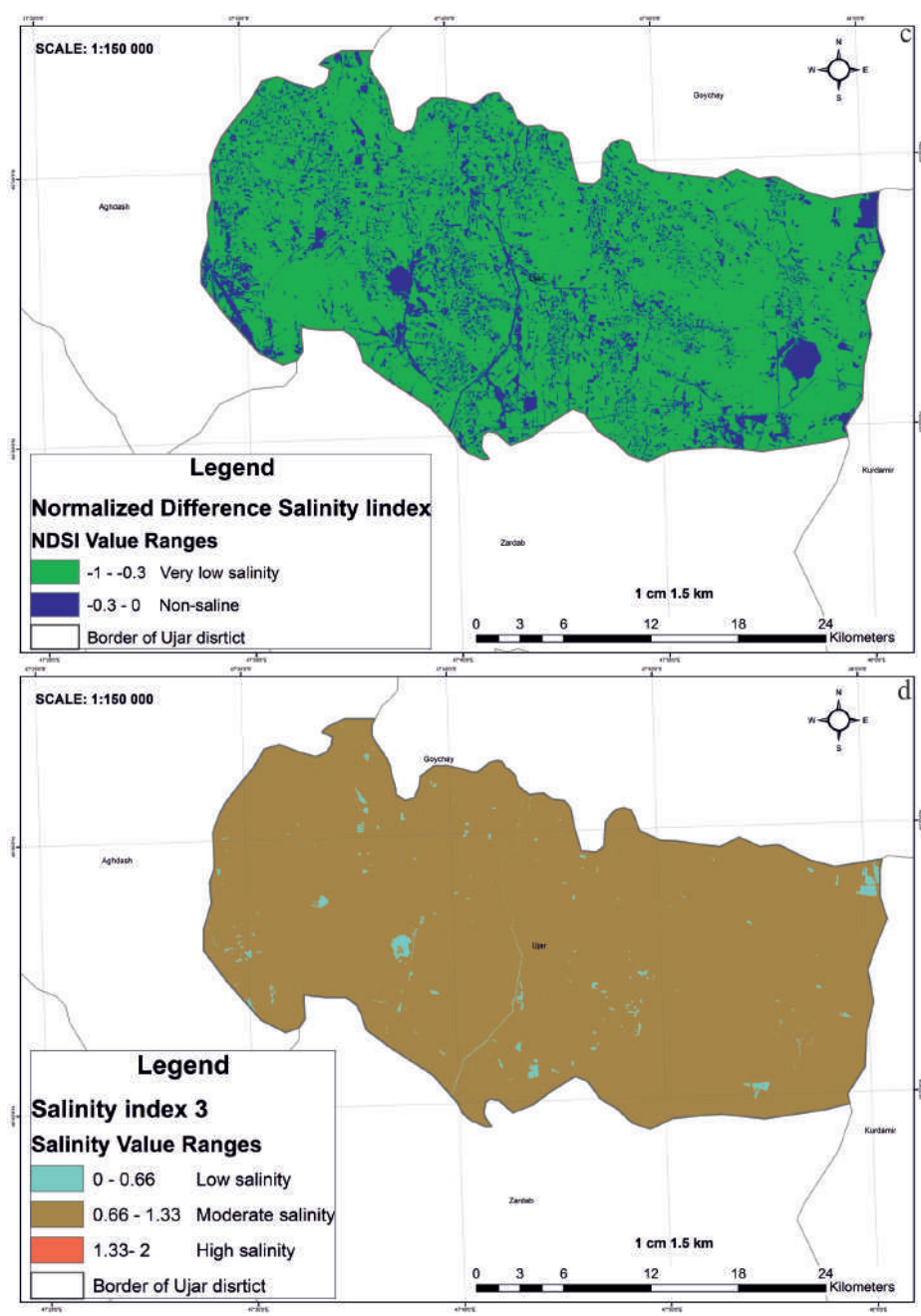


Fig. 1. c. NDSI map of Ujar region; d. SI3 map of Ujar region

- High Salinity (ECe range: 8–16 dS/m) (1.33–2): Very few land areas are shown in this class because areas with high salinity are rare.

SI1 had the widest range, dividing soil salinity into five levels (very low, low, medium, high, and very high). The values ranged from 6380 to 44.33 μm , showing different levels of salinity distribution in the region. This index can be considered one of the most suitable methods for Ujar, as it allows for a more accurate assessment of the degree of salinity.

The SI2 is a value that ranges from 0 (non-saline) to 1 (saline). The main advantage of this index is its simplicity, it has limitations in distinguishing between degrees of salinity. Although SI2 shows the general distribution of salinity, it does not provide sufficiently accurate information for a detailed analysis of its intensity.

The SI3 values were within the range of 0–0.66 (low salinity), 0.66–1.33 (medium salinity) and 1.33–2 (high salinity). However, this indicator is not considered effective for the region, since high salinity values are not noticeable in Ujar. It was noted that it is not suitable enough to assess the dynamics of the salinization process.

NDSI values varied from -1 to 0 and allowed classification of predominantly slightly saline or non-saline areas. Since it does not accurately reflect high salinity levels, it was insufficient to assess the actual soil salinity situation in the Ujar region.

According to the satellite image, the most significant results of the regression analysis ($R^2 > 0.3$) were obtained only for the fields sown with alfalfa.

Conclusion. The SI1 is the most suitable indicator for assessing soil salinity in the Ujar region because this index, in addition to reflecting the characteristics of the region, allows for a more accurate identification of salinity levels. Although SI2 is useful to some extent, it is not suitable for detailed analysis because it only provides information on salinity. SI3 and NDSI were ineffective and limited in use for assessing the salinity status of the region.

These results show that the selection of a suitable index is important for accurate salinity analysis, and a combination of different indices may provide more reliable results. Deciphering the salinity of the region's soils from the image of their open surface is less successful than from the image of crops. The most informative was the state of crops in the first half of the growing season.

SI1 is the most effective method; SI2 reflects the general state of soil salinity, that is, it separates saline and non-saline soils; SI3 is not effective for Ujar, the values obtained do not provide complete information about salinity; NDSI also reflects very low salinity and generally non-saline areas.

As a result of the four indices, we can say that SI1 provides the most accurate and complete information for Ujar because here the classification by salinity degree is correctly reflected and is consistent with the studies conducted on the ground. The southwestern and central parts of Ujar are more exposed to salinity.

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