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Analysis of Soil Salinization in the Aghjabadi District Using Various Indices

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Abstract. *This study aims to assess the level of soil salinization in the Aghjabadi district and to analyze the spatial distribution dynamics of salinized areas. Although the Aghjabadi district, located in the Aran region of Azerbaijan, holds strategic importance for agriculture, it faces significant challenges due to soil salinization. Elevated salinity levels contribute to decreased agricultural productivity, degradation of soil fertility, and negatively impact the sustainable use of agricultural lands. Consequently, the application of scientifically grounded approaches is essential for accurate monitoring and effective land management.*

The primary objective of the research is to precisely determine the degree of soil salinization in Aghjabadi, map salinized areas, and compare the effectiveness of various salinity indices. For this purpose, satellite imagery was analyzed using remote sensing and Geographic Information Systems (GIS) technologies. Landsat 8 satellite images were used to calculate several salinity indices, including Salinity Index 1, Salinity Index 2, Salinity Index 3, and the Normalized Difference Salinity Index (NDSI). Each index reflects different aspects of soil salinity, enabling the generation of detailed soil salinization maps for the region.

As a result of the study, the compatibility of different salinity indices with the ecological and climatic conditions of the Aghjabadi district was evaluated, and the most suitable index was identified. This approach contributes to effective soil monitoring, planning of cultivated areas, and the development of soil management strategies. Furthermore, the research holds both scientific and practical significance in terms of ecological sustainability, optimal use of agricultural resources, and the prevention of soil degradation.

Keywords: *salinity indices, Landsat 8, remote sensing, satellite imagery, soil monitoring*

Introduction

Soil salinization is one of the major ecological and economic challenges that reduces agricultural productivity, particularly in arid and semi-arid climate regions (Allbed et al., 2014, pp. 91–102). The accumulation of soluble salts in the soil layer leads to the deterioration of its physico-chemical properties, disruption of soil structure, and a decline in the plants' ability to absorb water and nutrients. As a result, crop yields decrease significantly. This process has long-term consequences, contributing to a decline in soil fertility, salinization of water resources, and degradation of ecosystems (El-Basyoni & Ibrahim, 2018, pp. 104–113; Jones & Pethick, 2006, pp. 1–14).

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Although the Aghjabadi district, located in the Aran economic region of Azerbaijan, holds significant importance for agriculture, widespread soil salinization issues are observed in the area. Improper management of irrigation systems, the rise of groundwater levels, and climatic factors are among the main causes contributing to increased soil salinity. Therefore, accurate assessment and mapping of soil salinization dynamics represent one of the essential scientific bases for ensuring the sustainable development of agriculture in the region (Omomov et al., 2022).

In recent years, alongside traditional soil analyses, the application of remote sensing and Geographic Information Systems (GIS) technologies has gained significant momentum in the study of soil salinization. These methods enable the assessment of soil salinity over large areas in a rapid, cost-effective, and highly accurate manner. Various salinity indices derived from spectral data obtained through satellite imagery allow for both visual and analytical evaluation of soil salinity levels (Rana & Mishra, 2014; Scudiero et al., 2014).

In this study conducted for the Aghjabadi district, the assessment of soil salinity levels was carried out using Landsat 8 OLI/TIRS satellite imagery. Four main indices were applied during the analysis: Salinity Index 1, Salinity Index 2, Salinity Index 3, and the Normalized Difference Salinity Index (Scudiero et al., 2014; Xia et al., 2017). The results obtained for each index were compared, and maps reflecting soil salinity distribution were generated accordingly.

The research results indicated that, under the ecological and climatic conditions of the Aghjabadi district, the SI2 and NDSI indices provided more accurate assessments of soil salinity. This confirms the reliability of remote sensing data as a valuable source of information for monitoring and managing soil salinization (Abbas et al., 2013; Rahmati & Nabiollahi, 2020).

The objective of this study is to assess the level of soil salinity in the Aghjabadi district using satellite observations, to analyze the applicability of various salinity indices, and to determine the most effective assessment methodology for the region.

Methods

This study was conducted to assess the soil salinization status in the Aghjabadi district using Landsat-8 satellite imagery. Remote sensing technologies, particularly Landsat 8 OLI/TIRS satellite images, provide high temporal resolution capabilities for large-scale monitoring and mapping of soil salinity conditions. The satellite images utilized in this research were acquired from 2024 and were georeferenced accordingly. Various salinity indices—Salinity Index 1 (SI1), Salinity Index 2 (SI2), Salinity Index 3 (SI3), and Normalized Difference Salinity Index (NDSI)—were calculated from the images. These indices were employed to evaluate the level of soil salinity based on the spectral bands obtained from Landsat 8 satellite imagery (Omomov et al., 2022; Abbas et al., 2013).

Field measurements were conducted within the study area to evaluate soil salinization. Using a Progress 1T device, soil electrical conductivity and temperature were measured, and based on these data, the degree of salinization was determined at three different depth intervals (0–20 cm, 20–50 cm, and 50–100 cm). In total, 214 measurements were taken, which served as the basis for calculating the salinization degree (Tavakkol & Ghorbani, 2021).

Regression analysis was employed to establish correlations between the satellite-derived data and the field-measured electrical conductivity. These equations formed the foundation for generating salinization maps. Using ArcGIS software, salinization maps were produced, and the effectiveness of different salinity indices was compared.

Pixel brightness values and vegetation indicators were calculated from various spectral bands of the satellite images. This process ensured an accurate assessment of salinization and enabled the spatial representation of salinity levels across different areas of the Aghjabadi district on the maps.

Results

The results indicate that soil salinity and salinization risk in the study area were evaluated based on data from 2023. The spatial distribution maps generated using salinity indices reveal five distinct salinity classes, with index values ranging from 0 to 1, representing non-saline to saline conditions (Fig. 1a). The salinity map produced using the alternative SI2 index exhibits a similar classification pattern and value range, confirming the spatial differentiation between saline and non-saline areas (Fig. 1b). The regression models derived from Landsat 8 imagery acquired in 2023 further support the identification of salinity patterns across the study area (Allbed et al., 2014, pp. 91–102; Scudiero et al., 2014). The following map presents the spatial distribution of soil salinization in the Aghjabadi district based on the Salinity Index 1 (SI1) (Figures 1, 2, 3, 4). The salinity levels on the map are classified into five distinct categories:

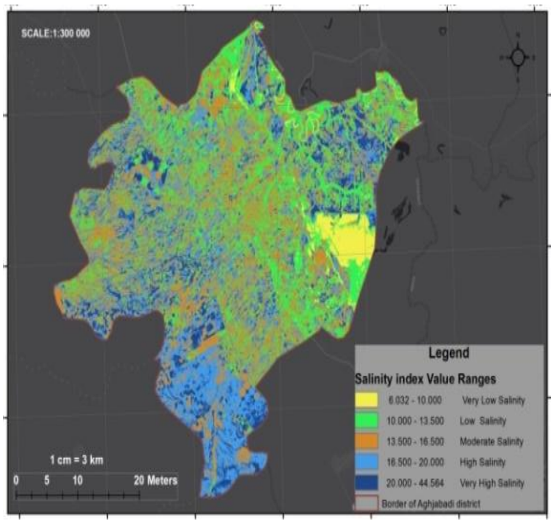

Figure 1. Range of Salinity Index Values (SIVR) in the Soils of Aghjabadi District

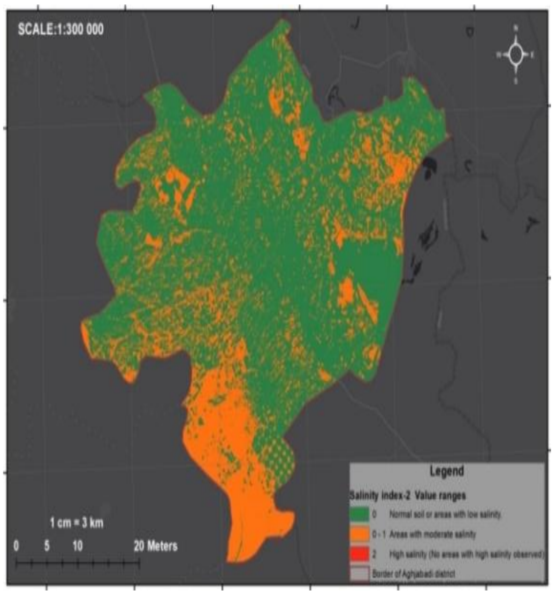

Figure 2. Spatial Distribution of Salinity Index 2 (SI2) in the Soils of Aghjabadi Distric

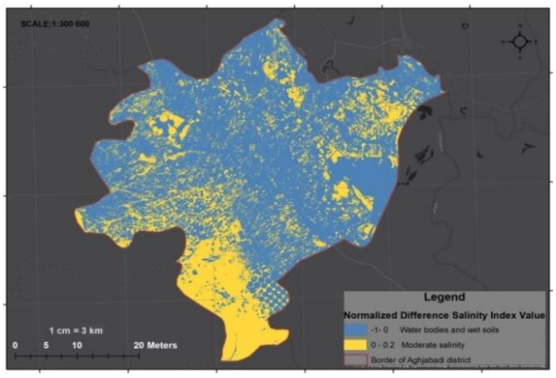

Figure 3. Spatial Distribution of the Normalized Difference Salinity Index (NDSI) in the Soils of Aghjabadi District

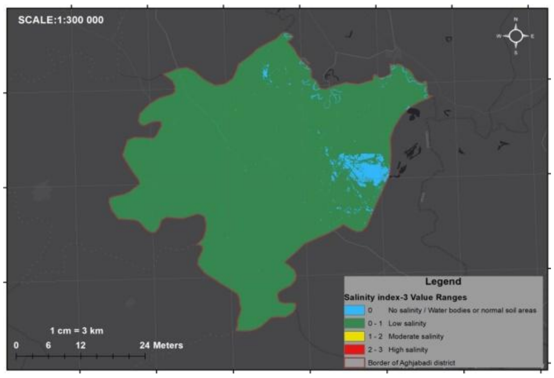

Figure 4. Spatial Distribution of Salinity Index 3 (SI3) in the Soils of Aghjabadi District

The Salinity Index SI-1 map represents soil salinization across five main classes: very low salinity, low salinity, moderate salinity, high salinity, and very high salinity. This map reflects varying salinity levels over a broad range, allowing for a more precise determination of salinization intensity across different areas. In particular, the "very high salinity" class, ranging from 20,000 to 44,584, provides a more complex and detailed differentiation of salinity on the map. The map is designed to identify regions with high salinity over an extensive geographic area, as the very high salinity category (20,000–44,584) covers a large spatial extent (Rahmati & Nabiollahi, 2020; Ismayil et al., 2025).

Salinity Index 2 (SI-2): In the Salinity Index 2 classification, salinization is described in only three levels: 0 (normal soils or very low salinity), 1 (moderately saline soils), and 2 (highly saline soils). This index provides a simpler classification by identifying the main salinity levels but does not provide information on higher salinity intensities. Notably, although the "2" class exists on the Salinity Index 2 map, areas of very high salinity are not represented, indicating that the map has more limited capability in depicting zones of high salinity intensity.

Normalized Difference Salinity Index (NDSI): The NDSI map illustrates a narrower range of salinized soils. Values between -1 and 0 on this map represent water bodies or moist soils, while the range from 0 to 0.2 indicates moderately saline soils. The primary focus of this map is on water bodies and moist soils. The NDSI map demonstrates less extensive salinization and a prevalence of water-related soil areas. Since it does not cover a broader range of salinity levels, it provides more limited information confined mostly to water and moist soils.

Salinity Index 3 (SI-3): The SI-3 map displays four main classes of salinity: 0 (normal soils or water bodies), 1 (low salinity), 2 (moderate salinity), and 3 (high salinity).

However, the "3" class is not represented across large areas; only a small region is depicted with the "2" class. This indicates that the SI-3 map provides limited information on high-intensity salinization, with most areas falling into the moderate salinity category.

When evaluating the intensity and distribution of salinization, the Salinity Index 1 map reveals broader and more intensive salinized areas, particularly reflecting regions of very high salinity (20,000–44,584). In contrast, Salinity Index 2 and Salinity Index 3 provide simpler classifications and depict only limited zones of high salinity. The Normalized Difference Salinity Index (NDSI) highlights relatively less extensive salinization and emphasizes the significance of water bodies.

Field measurements and regression analysis used in the study serve as essential tools to enhance the accuracy of the indices. These measurements analyzed soil electrical conductivity and temperature across three different depth intervals, which were then correlated with satellite imagery to generate salinity maps. Data obtained from Landsat 8 satellite images were processed with high precision, especially for salinity analysis. Furthermore, the maps created using ArcGIS software were compared with actual field conditions to assess their reliability. Electrical conductivity measurements provide precise evaluation of salinity levels. For instance, measurements conducted using the Progress 1T device proved highly effective for analyzing soil salinity, and integrating this data with satellite imagery facilitated the production of salinity maps with improved accuracy (Ismayil et al., 2025).

Discussions

Table 1.
Formulas of the Four Salinity Indices Used in the Study

Name	Formula	**Spectral Bands Used**
Salinity index (S1)	$SI = \sqrt{R \times SWIR1}$	Band 4 (Red), Band 6 (Shortwave Infrared 1)
Salinity index (S2)	$SI2 = \frac{SWIR1}{NIR}$	Band 6 (Shortwave Infrared 1), Band 5 (Near Infrared)
Salinity index (S3)	$SI3 = \frac{SWIR1}{G}$	Band 6 (Shortwave Infrared 1), Band 5 (Near Infrared)
Normalized Difference Salinity Index (NDSI)	$NDSI = \frac{(R - NIR)}{(R + NIR)}$	Band 4 (Red), Band 5 (Near Infrared)

According to the table 1, a brief explanation of each index is provided below:

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

- **SI** – Salinity Index, representing the soil salinization index
- **R** – Reflectance of the Red band (Band 4) in Landsat 8 satellite imagery
- **SWIR1** – Reflectance of the Shortwave Infrared 1 band (Band 6) in Landsat 8 satellite imagery

This index is used to measure soil salinity levels based on remote sensing data. The calculation of the salinity index involves the use of the Green (G) and Red (R) bands.

Alternative Salinity Index (SI2):

$$SI2 = \frac{SWIR1}{NIR}$$

- **SI2** – Salinity Index 2
- **SWIR1** – Reflectance of the Shortwave Infrared 1 band (Band 6) in Landsat 8 satellite imagery
- **NIR** – Reflectance of the Near Infrared band (Band 5) in Landsat 8 satellite imagery

This index is used to evaluate the level of soil salinization on the soil surface by analyzing the spectral data from satellite images for the identification of soil salinity.

Salinity Index (SI3):

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

- **SI3** – Salinity Index 3
- **SWIR1** – Reflectance of the Shortwave Infrared 1 band (Band 6) in Landsat 8 satellite imagery
- **G** – Reflectance of the Green band (Band 3) in Landsat 8 satellite imagery

This index is particularly applied for assessing soil salinity, especially to identify areas with high salinity levels.

Normalized Difference Salinity Index (NDSI):

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

- **NDSI** – Normalized Difference Salinity Index
- **R** – Reflectance of the Red band (Band 4) in Landsat 8 satellite imagery
- **NIR** – Reflectance of the Near Infrared band (Band 5) in Landsat 8 satellite imagery

Various spectral bands and their corresponding indices play a significant role in environmental monitoring and soil cover analysis. Using satellite data, particularly images from the Landsat series, the condition of soil cover and vegetation is analyzed through different spectral bands (Huang & Li, 2020; Jafari & Fathian, 2019).

Conclusion

This study investigated the effectiveness of various salinity indices for assessing soil salinization in the Aghjabadi district. The analysis revealed that Salinity Index 1 demonstrated the highest sensitivity and accuracy, effectively identifying areas of high salinity intensity and providing a wide range of detailed information. Salinity Index 2 illustrated the overall salinization status but was unable to fully capture areas of high salinity. Salinity Index 3 primarily represented moderately saline zones and provided limited information on high-intensity salinization. The Normalized Difference Salinity Index (NDSI) was particularly useful for identifying water bodies and moist soils, but it had certain limitations in evaluating areas with high salinity intensity.

The results indicate that the Salinity Index 1 (SI1) is considered the most effective indicator for the accurate assessment of soil salinization, as it provides both high sensitivity and a broad range of data.

The study also emphasizes that the SI1 index serves as an important scientific and practical tool for agricultural planning, soil management, and evaluating salinization risks in the region.
Based on these findings, the study presents the following recommendations:

- Salinity maps developed using the SI1 index should be utilized to identify priority areas in soil management and irrigation policy-making.
- Future research should incorporate high-resolution satellite imagery (e.g., IKONOS and Sentinel-2) alongside Landsat 8 to produce more precise and detailed salinity maps.
- Efficient methodologies should be developed for long-term soil monitoring and agricultural planning by combining multiple salinity indices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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