

MAPPING OF SOIL SALINITY IN ABSHERON SOIL BASED ON SENTINEL-2 USING LightGBM

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Abstract

This paper reflects the results of assessing the degree of salinity of Absheron soils based on remote sensing technologies. The research was conducted in Sungayit, Guzdek down station, and Yashma districts located in Absheron region of Azerbaijan. Certain areas of the Absheron region are ecologically clean areas with high tourism potential in the future. Classification of soils by salinity degree was performed using indices calculated from data in Sentinel-2 spectral channels. Previously obtained field measurements and ground observations using LightGBM machine learning algorithm were used to confirm the degree of soil salinization in the areas identified on satellite images. Based on a comparative analysis of machine learning and remote sensing methods, it was found that they provide similar results for soil salinity assessment when the study area does not cover a large area of land. This work has important implications for understanding soil salinity dynamics and could be used in further research on land and agricultural management at the regional level. For a country like Azerbaijan, the result obtained by the staff of the Soil Institute is of a local nature.

Key words: spectral index, LightGBM, Sentinel-2, soil salinity, remote sensing, NDVI, DSM

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Introduction. Soil salinization, a critical determinant of agricultural productivity, poses serious challenges to sustainable land management in arid and semi-arid regions. Soil protection and its rational use for arable land is one of the important tasks in agriculture. Remote sensing technologies, such as Sentinel-2 satellite imagery, offer promising opportunities for monitoring and mapping soil salinity at large spatial scales with high temporal resolution. Soil salinity refers to the concentration of soluble salts in the soil, which can significantly affect agricultural productivity and soil health. This is a critical environmental problem, especially in arid and semi-arid regions where the rate of water evaporation is high, leading to salt accumulation. Soil salinization is a complex process in which sulphates, chlorides, and carbonates accumulate in the soil in quantities exceeding the norm. As a result, the soil changes its properties, and all plants growing in this soil die. The content of more than 0.1% of these compounds from the mass of dry soil makes the land unsuitable for agriculture [1, 2]. Some soil properties, such as soil structural fractions (sand, silt, and clay content), do not change significantly over shorter time scales of a year or a decade compared to other characteristics, such as soil organic carbon (SOC) or soil water content. Space photography produces a clearer picture than traditional aerial photography, but its interpretation is difficult because the reflectance characteristics of soils are constantly changing under the influence of external factors [3]. Soil texture is an important parameter of soil health and its assessment at different spatial scales is important for ecological modelling. Soil survey databases remain the primary source of soil data for such models, as these data are often not available at higher resolutions for large-scale studies [4]. Although digital soil mapping (DSM) provides spatial data on soil parameters at various scales, DSM products often have large uncertainties. The availability of S2 data at 5-day intervals and 10–60 m resolution allows soil properties to be assessed in near real time and at a spatial resolution suitable for many agricultural applications [5].

Saline soils, including saline-solonetz soils, occupy about 20% of the agricultural land area of Azerbaijan. Salinization, the most important determinant of agricultural productivity, poses serious challenges to sustainable land management in arid and semi-arid regions. Regions of Azerbaijan, characterized by diverse ecological landscapes, are particularly prone to soil salinization, which affects crop yields and ecosystem and ecosystem health. The territory of Azerbaijan is an ancient agricultural region, because of the thousand-year influence of anthropogenic factors; salinization of soils of irrigated lands has become widespread.

Remote sensing technologies, such as Sentinel-2 satellite imagery, offer promising opportunities for monitoring and mapping soil salinity at large spatial scales with high temporal resolution. The peculiarities of each region are manifested in the characteristic optical properties of the landscape, which form its external appearance. The process of remote sensing in agriculture is based on information collected by various aerospace devices over a certain period. The collected data

could be used to analyze various aspects of the agricultural target: crop yield and productivity. The development of new technologies for collecting spatial data – drones, digital cameras, satellite data, indicative sensors, and more – and their analysis using GIS provide expanded capabilities and significant impetus to address and solve contemporary problems facing agriculture, as well as environmental sustainability, and ultimately food security [6, 7]. By identifying homogeneous areas by their optical characteristics, we can solve the problems of physical and geographical zoning. Thus, when photographing the earth from space, we record its instantaneous state. This work aims to use remote sensing techniques to map soil salinity levels in the southern territories of Azerbaijan, focusing on the synergy between spectral reflectance data and ground truth measurements. Using multispectral capabilities of Sentinel-2 satellites, the spatial distribution of soil salinization is analyzed, clarifying the main environmental factors determining salinization processes. Methodologically, a combination of spectral indices, machine learning algorithms and geographic information systems are used to produce accurate and spatially detailed soil salinity maps. The aim of this study is improving agricultural sustainability and land management in the context of saline soils in the southern regions of Azerbaijan. The soils of Absheron suffer from oil pollution caused by intensive oil and gas extraction. This leads to deterioration of their quality and fertility. As a result of pollution there are decrease in nutrients (nitrogen, phosphorus, potassium) and degradation of soil cover, which hinder agricultural use of land.

Materials and methods. The Absheron Peninsula, located in Azerbaijan, has a diverse soil cover, which is largely determined by climatic conditions and anthropogenic activities. The research focused on Guzdek down station (40°28'57.00"N, 49°39'46.00"E), Yashma (40°42'36.00"N, 49°28'48.00"E) and Sumgayit districts (40°35'23"N, 49°40'07"E in Absheron region). Indices calculated from data in spectral channels of Sentinel-2 satellite were used to classify soils by salinity degree.

Remote sensing has become a valuable tool for mapping soil salinity on a regional scale. The research paper explores the application of remote sensing technology, specifically the combination of Sentinel-1 synthetic aperture radar [7].

Sentinel-1 synthetic aperture radar (SAR) and Sentinel-2 multispectral satellite imagery are used to map soil salinity. The study combines data from several sources, including SAR and multispectral imagery, as well as digital elevation models (DEMs), to develop a robust soil salinity prediction model [8]. The results demonstrate that the inclusion of SAR indices along with traditional terrain and vegetation indices significantly improves the prediction accuracy of the models. Although the study utilizes ground-sampling sites for model validation, the number of sampling sites (60) is considered relatively small to accurately validate predictive models over the entire study area. The paper investigates the application of remote sensing methods using Sentinel-2 satellite images for predicting

soil salinization in super-arid conditions. The most important problem of soil salinization is considered, especially in arid and semi-arid regions, where it contributes to land degradation and desertification. Using high-resolution Sentinel-2 and Landsat-8 satellite images and remote sensing techniques, the study aims to assess soil salinization by producing soil electrical conductivity (EC) maps. Two different regression approaches, MLP and SVR, were used. In addition, two feature selection algorithms, GA and SFS, were implemented on the data to improve model performance.

Through a combination of field studies and different modelling approaches including regression and feature selection algorithms, the study demonstrates the effectiveness of the proposed soil salinity monitoring method [8]. Using Sentinel-2 satellite imagery and ground data, researchers are developing a method to detect salinity-prone soils using two complementary approaches: assessing salinity in bare soils using the salinity index (SI) and monitoring the indirect effects of salinity on rice growth using time-series vegetation index (NDVI). The results indicate difficulties in using SI due to infrequent periods of soil exposure, but emphasize the effectiveness of using NDVI to describe rice-growing conditions over time. NDVI is an indicator of the greenness of the biomes.

Correlations between NDVI, soil electrical conductivity, and crop yields provide valuable information on soil salinity dynamics. The classification approach of the study based on NDVI models shows promise in identifying areas with different levels of salinization, while further research is needed to confirm its effectiveness in identifying moderate soil salinity limitations over large areas [9,10]. The study addresses the critical need for accurate prediction of agricultural soil salinization, especially in arid and semi-arid regions, using Sentinel-2A (S2) satellite data. Using multiple linear regression analysis, the study found significant correlations between soil salinity (EC) values and various S2 data parameters, including individual bands, band ratios, and spectral indices [11]. The combination of SWIR-1 band and simplified brightness index is the most effective predictor of soil salinity, showing a robust correlation. By combining Sentinel-1 radar data and Sentinel-2 optical data, the study develops an innovative approach to predict soil salinity using integrated radar and optical sensor variables [12]. The study focuses on feature selection strategies and regression learning methods using various machine-learning models such as random forest, linear regression, back propagation neural network, and support vector regression. By combining Sentinel-1 synthetic aperture radar (SAR) images and Sentinel-2 multispectral images, the study aims to improve the accuracy of soil salinity inversion detection, overcoming the limitations of each individual sensor. The data are for the lower Absheron region for the period 2020–2024. The results showed that salinity indices could be used for soil salinity mapping and represent a valuable tool to assess soil salinity in rice growing areas affected by salinity problems. The use of satellite imagery in agriculture helps to cover a large area of land and can help in checking the condition of crops.

Results and discussion. The Absheron Peninsula, located on the eastern coast of the Caspian Sea in Azerbaijan, has unique geological features that have been formed over millions of years. The technology of food production revolves in an annual cycle from manual work to high-tech modern machine cultivation of the land. The study addresses the problem of accurate soil salinity monitoring in bare soil areas using satellite remote sensing data [12,13]. By fusion of Sentinel-1 synthetic aperture radar (SAR) images and Sentinel-2 multispectral images, the study aims to improve the accuracy of soil salinity inversion, overcoming the limitations of each individual sensor [14–16]. Experiments conducted in an irrigation district demonstrate that fusion of VV (Sentinel-1) and Sentinel-2 images yields higher accuracy compared to other fusion methods and individual images. Using machine learning models such as back propagation (BP), support vector machine (SVM), and random forest (RF), the study constructed a soil salinity inversion model, with RF achieving the most satisfactory results. Three main areas located in Sumgayit, Guzdek down station, and Yashma provinces where sampling studies were conducted were identified: near the town of Sumgayit, near the Caspian Sea (Fig. 1). The neighbourhoods around Absheron have less vegetation and sandy soil. The Yashma area is more agricultural, but the soil becomes alkaline in summer. Guzdek down station is close to Jeyranbatan reservoir and the alkaline soil here is different.

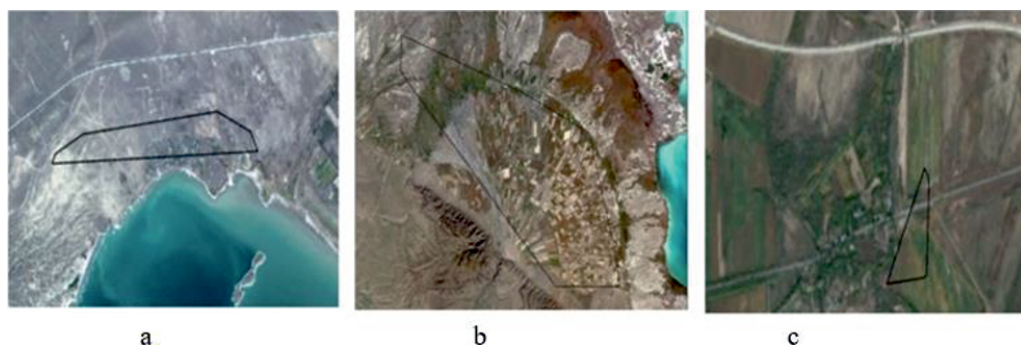


Fig. 1. Extraction of the study area from the satellite image:
a – Sumgayit, b – Guzdek down station, c – Yashma

The salinity map of Yashma region ($40^{\circ}42'36.00''\text{N}$, $49^{\circ}28'48.00''\text{E}$) based on SI spectral index obtained from remote sensing data is shown in Fig. 2. The coloured dots show the result of machine learning where soil samples were obtained for salinity estimation.

Figure 3 shows the salinity map of the Sumgayit ($40^{\circ}35'23''\text{N}$, $49^{\circ}40'07''\text{E}$) region based on the SI spectral index derived from remotely sensed data. Such information helps in preparing decisions on issues related to production and increasing soil productivity, preventing and combating degradation.

Figure 4 presents a map of salinity in the Guzdek down station region

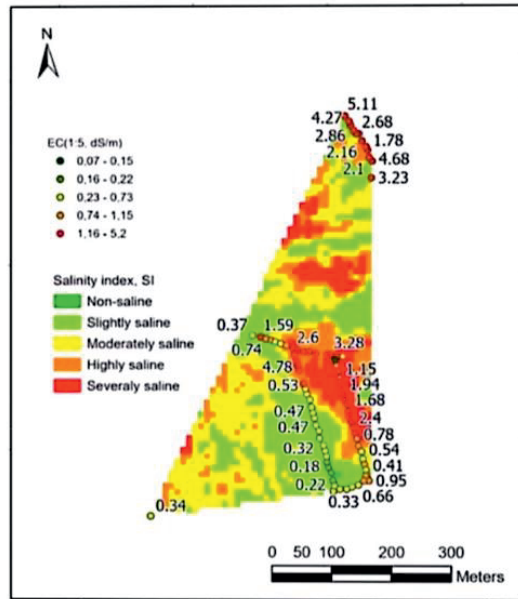


Fig. 2. Soil salinity map of the Yashma region

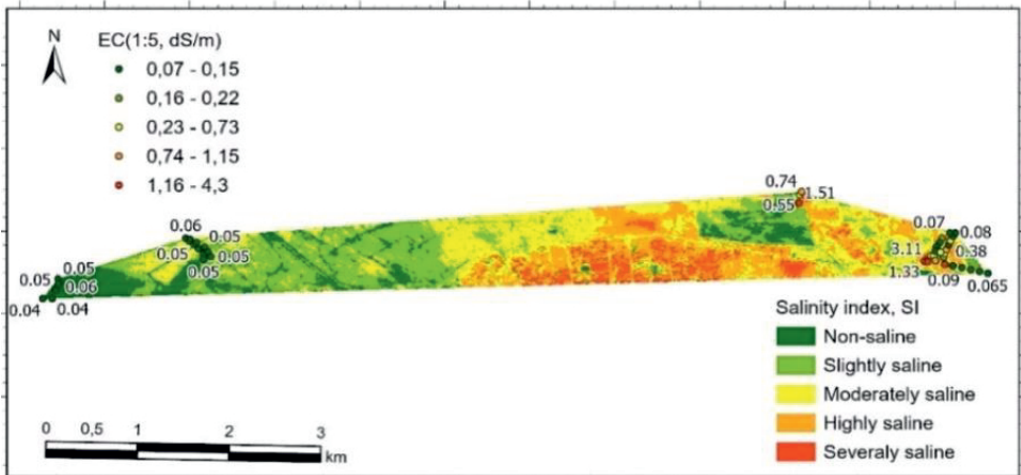


Fig. 3. Soil salinity map of the Sumgayit region

(40°28'57.00"N, 49°39'46.00"E) based on the SI spectral index derived from remote sensing data.

The following conclusion can be drawn from Fig. 2–4: when the area of interest does not cover a large part of the territory (in the example of Yashma), the accuracy of soil salinity estimation based on machine learning and using remote sensing, gives similar results. This is because the algorithm is trained specifically for local conditions and variations within a smaller area, resulting in predictions

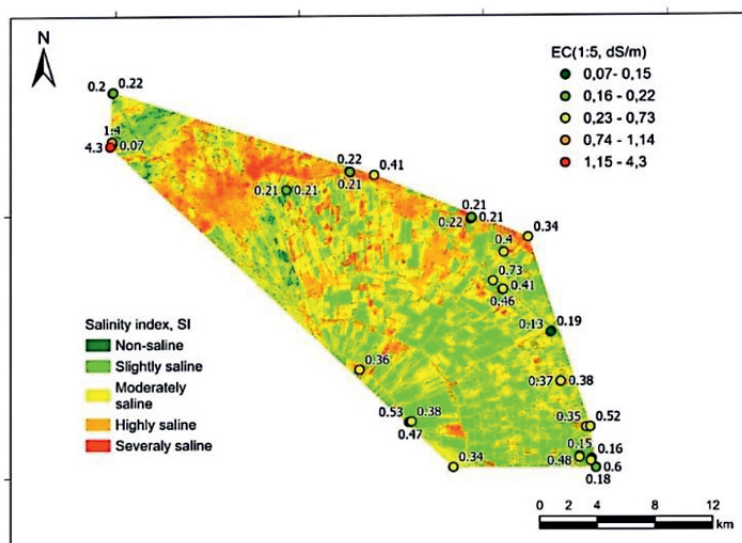


Fig. 4. Soil salinity map of the Guzdek down station region

that are more accurate. In addition, large-scale areas often show significant spatial heterogeneity of soil salinity levels (Guzdek down station is an example). The variability of soil properties, soil use and environmental conditions over a large area can make accurate collection and modelling using remotely sensed data and machine learning algorithms difficult.

Conclusion. This study presented the results of salinity assessment of Absheron soils using Sentinel-2 satellite imagery. The research focused on Guzdek down station, Yashma, and Sumgayit districts located in Absheron region. Indices calculated from data in spectral channels of Sentinel-2 satellite were used to classify soils by salinity degree. The dataset for training the machine-learning model consisted of 198 soil samples, of which 155 were selected for the training sample and 43 for the test sample. Based on the comparative analysis of machine learning and remote sensing methods, it was found that they provide similar results for soil salinity assessment when the study area is limited to a small-scale territory. This work has important implications for understanding soil salinity dynamics and could be used in further research on land and agricultural management at the regional level. The results of this study provide valuable information on the spatial variability of soil salinity, facilitating targeted land management strategies and mitigation measures. In addition, the application of remote sensing technologies to soil salinity mapping offers a cost-effective and scalable approach to monitoring environmental change and supporting decision-making processes. Thus, this study contributes to the broader goal of improving agricultural sustainability and land management in the context of saline soils in the regions of Azerbaijan.

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