International Journal of Advances in Applied Sciences (IJAAS)
Vol. 14, No. 3, September 2025, pp. 662~670
ISSN: 2252-8814, DOI: 10.11591/ijaas.v14.i3.pp662-670

Determination of soil salinization by hyperspectral remote sensing in the Shirvan Plain

Sahib Shukurov Khudaverdi[1], Aygun Ismayilova Azer[2], Ramil Sadigov Ali[3], Maya Karimova Javanshir[3], Turkan Hasanova Allahverdi[4], Gunel Asgarova Farhad[5]
[1]The State Cadastre and Registry of Real Estate Public Legal Entity, State Service on Property Issues, Ministry of Economy of Azerbaijan Republic, Baku, Azerbaijan
[2]Department of Physical Geography, Faculty of Geography, Baku State University, Baku, Azerbaijan
[3]Department of Engineering and Applied Sciences, Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan
[4]Faculty of Ecology and Soil Science, Baku State University, Baku, Azerbaijan
[5]Department of Soil Genesis, Geography and Cartography, Institute of Soil Science and Agrochemistry, Ministry of Science and Education of Azerbaijan Republic, Baku, Azerbaijan

Article Info

Article history:

Received Feb 11, 2024
Revised May 16, 2025
Accepted Jun 8, 2025

Keywords:

Bonitet scale
Flatness index
Soil salinization
Spectral analysis
Vegetation cover index

ABSTRACT

The determination of soil salinization in the Shirvan Plain, considered the main agricultural zone of Azerbaijan, negatively affects the productivity of agricultural crops. Based on 10 m Sentinel-2 images on Google Earth Engine platforms and by examining SI1, green-red band normalized difference vegetation index (GRNDVI), green normalized difference vegetation index (GNDVI), normalized difference vegetation index (NDVI), and difference vegetation index of the environment (DVI), four remote sensing salinity monitoring index models, S1DI1, S1DI2, S1DI3, and S1DI4, were constructed to extract soil salinity information in the Shirvan Plain in combination with the measured electrical conductivity. The results show that the overall classification accuracy of S1DI1 (SI1-GRNDVI), S1DI2 (SI1-GNDVI), S1DI3 (SI1-NDVI), and S1DI4 (SI1-DVI) models for salinity monitoring are 82.35%, 83.10%, 81.96%, and 79.25%, respectively.

Corresponding Author:

Sahib Shukurov Khudaverdi
The State Cadastre and Registry of Real Estate Public Legal Entity, State Service on Property Issues
Ministry of Economy
Baku, Azerbaijan
Email: sukurov.sahib@inbox.ru

1. INTRODUCTION

As a result of the influence of economic activity, the number of listed anions causes the formation of soil types with different salt compositions in most territories. Of the easily soluble salts in water, the most toxic for plants are NaCl, Na_2SO_4, $MgCl_2$, CaCl, $MgSO_4$, and Na_2CO_3. Ions Cl, SO_4^2, HCO_3, Na, K, Ca_2, and Mg^2 have a specific effect on plants [1], [2]. When 0.5% Cl or 0.2% Na accumulate in a plant, its leaves burn and necrosis develops. In the case of a high concentration of NaCl ions in the solution, the transpiration process worsens. At the same time, the structure of the soil, water, and air regime is disrupted [3]. That is why it is necessary to flush the soil of salts in the studied areas. On saline soils with poor water permeability, it is advisable to grow salinity-resistant plants. One of the factors that has a significant impact on the productivity of the Shirvan Plain agrolandscapes is the amount of humus in the soil. There are sharp differences in its distribution across the territory [4], [5]. The salinization of soils in the Shirvan Plain is related to the geological history of land emergence. Before the fourth period (Oligocene), Azerbaijan's Kura-Araz lowland, including the Shirvan Plain, was part of the western basin of the present Caspian Sea.

According to geological data, the area has been submerged and emerged multiple times. Therefore, soil salinization in this arid and semi-desert zone not only hinders the development of agriculture but also poses a threat to the ecological environment and biosphere.

Since soil salinization is characterized by strong spatial heterogeneity, the application of remote sensing technologies is of great importance. It is necessary to collect and analyze more to predict soil salinization, which requires significant financial resources, but does not provide the necessary speed and accuracy in the era of modern development. Soil salinization poses a serious threat to the biosphere and ecological environment as a form of soil degradation. As a result of salinization, valuable soil resources are lost, creating significant ecological problems. If the amount of salinity in the soil, which is easily soluble in water, affects the normal development of plants, these soils are considered salinized. In most cases, the amount of salinity in the top meter of these soils exceeds 0.3% [6]–[8]. Remote sensing tools for collecting information about the condition of the land, along with the application of geographic information systems (GIS), numerical simulations, and the use of mathematical models for assessment, analysis, damage calculation, and prevention processes, are modern methods employed. A variety of data makes a valuable contribution to dynamic environmental monitoring. This type of survey allows the collection of continuous spectral data at a finer scale, more fully revealing the characteristics of the Earth's surface. Results show that models established with measured reflectance values are more accurate for pH prediction [9]–[11]. The spatial-temporal mapping of soil salinization ensures prompt decision-making for measures to mitigate the negative effects of soil degradation. For this purpose, satellite technologies ensure the collection of economically beneficial, rapid, high-quality, and accurate spatial data on salinized soils. Using vegetation indices from vegetation cover is effective in predicting soil texture and moisture content, accurately forecasting the soil's moisture content. Due to its continuous coverage capability, the hyperspectral remote sensing technology is an important method for monitoring the physical and chemical properties of soil, thanks to its strong dynamics and high discrimination ability. This method stands out for soil salinization inversion studies in various regions due to its superior modeling, spectral emulation method, and variable selection approach. However, considering only the spectral information of bare soils without considering the indirect effects of vegetation information on the spectrum of salinized soils could hinder a comprehensive study of soil salinization [12], [13].

High salinity and alkalinity cause evaporation and drying of vegetation cover. Therefore, the condition of vegetation and the salinity of the vegetation can be used as an indirect indicator of vegetation cover salinization problems in salt-affected areas [14]. Conducting soil research based on spectral analysis in Azerbaijan has become very relevant and is considered important for the development of agriculture. Spectroscopy can be used to analyze the various degrees of soil salinity based on the spectral characteristics of vegetation, particularly red edge and green peak characteristics, in saline areas [15]. To achieve this, spectral characteristics of vegetation cover at various salinity levels were studied spectroscopically, and based on correlation coefficients, characteristic indicators of soil salinity were determined in relation to the salinity of the soil, and a multi-variant non-linear regression model for soil salinity assessment was established [16]. The model is validated with measured data, demonstrating that it is a more effective method for obtaining highly accurate salinity information. The application of remote hyperspectral sensing technology facilitates the operational monitoring of the dynamics of salinization over time [17], [18].

2. RESEARCH METHOD

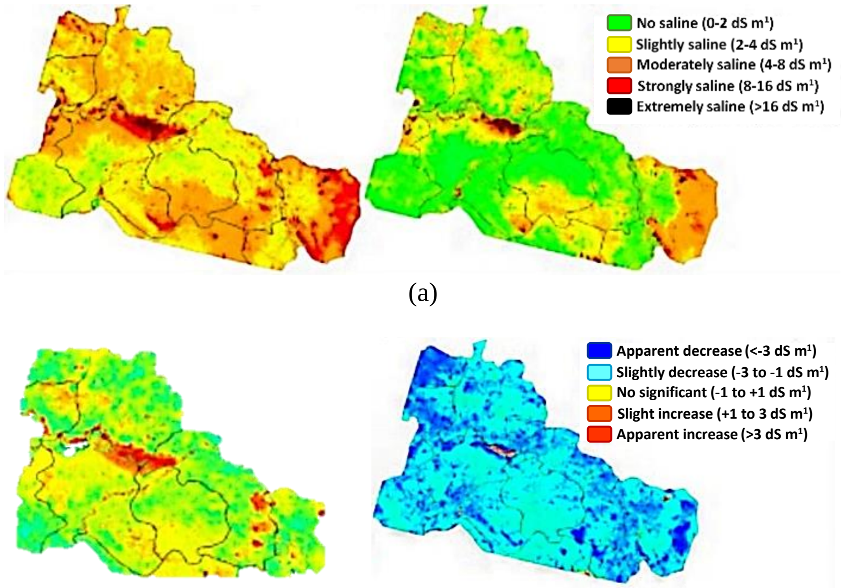
The images were captured in open-air, windy, and cloudless conditions between 10:00-14:00. As a result of the experiment, 80 data collection units (40 plant samples and 40 soil samples) were obtained. Soil samples were collected up to a depth of 20 cm. The permeability of soil samples, as well as the pH and electrical conductivity (EC) of the soil, were measured, and a linear relationship was established between permeability and the total salt content of the soil to calculate soil salinity [16], [17], [19]. The soil physicochemical parameters include the contents of eight major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, CO_3^{2-}, and Cl^-), pH, EC, and particle size distribution. It is important to calculate the brightness coefficient of hyperspectral satellite images and confirm the results with laboratory analysis. The coefficient of determination, or R^2, is a measure that provides information about the goodness of fit of a model. In the context of regression, it is a statistical measure of how well the regression line approximates the actual data. Important when a statistical model is used either to predict future outcomes or in the testing of hypotheses.

$$R^2 = 1 - \frac{sum\ squared\ reqression\ (SSR)}{Total\ sum\ squared\ (SST)} + \cdots;\ R^2 = 1 - \frac{\sum(Yi - Yi)^2}{\sum(Yi - Yi)^2}$$

The sum squared regression is the sum of the residuals squared, and the total sum of squares is the sum of the distance the data is away from the mean, all squared. As it is a percentage, it will take values between 0 and 1. To calculate R^2 needs to find the sum of the residuals squared and the total sum of squares. The predicted value is calculated by plugging the x value into the regression line equation.

3. RESULTS AND DISCUSSION

Mountain ranges surrounding the Shirvan Plain from the north and northwest have influenced its climate, resulting in the implementation of climatic zones in this plain. This has also affected the spread of vegetation cover across the zones. The prevailing climate and vegetation cover have also influenced the distribution of soil cover across zones. Plain is covered by saline soils, while the foothill areas are covered by alluvial soils. The area, as shown in Figure 1, experiences a semi-arid to arid climate, characterized by dry and warm winters, typical of semi-arid warm steppe and arid desert climates. This climate type is observed in the western and foothill areas, characterized by low humidity, mild, low-precipitation winters, and relatively hot summers. The annual duration of sunshine hours in the area varies between 2,100 to 2,400 hours. With increasing altitude and cloudiness, the annual duration of sunshine hours and total solar radiation decreases. The annual radiation balance gradually decreases to 40 kcal/cm^2. The average annual air temperature in the area ranges from 14 to 15 °C. Research area's soil salinity degrees in 2020 and 2024 are shown in Figures 1(a) and 1(b).



(a)

(b)

Figure 1. Research area in 2020 and 2024 of (a) saline soil degree and (b) apparent decrease and slight increase

After collecting spectral data, undisturbed soil samples from 0 to 20 cm depth were excavated at the same points. Gravel and plant residues were removed from the collected soil samples. The moisture content (%) of the soil was determined using the oven-drying and weighing method [20], [21]. After air-drying and sieving, a soil-water mixture of 1:5 soil to water was prepared for measuring EC using the PNT 3000 COMBI+ device. The problem of preserving plant biodiversity requires a deep study of the physiological characteristics of species. The integral indicator of plant vital activity is the EC of tissues [15]. The EC of these soils varies between 0 and 25 dS m^{-1} in both laboratory and field conditions. Table 1 shows the EC and pH values measured from the soil samples.

The original reflectivity of the soil and vegetation cover is subjected to differential transformation of the square root using the spectral reflectivity to perform logarithmic differential transformation is used as a spectral index (SI) [22], [23]. The coefficients of the soil and vegetation cover are calculated. Measured by the soil salinity according to the rule (1) for assessing spectral indicators.

$$rj = \frac{\sum_{i=1}^{n}(Rij-Rj)(SCi-SC)}{\sqrt{\sum_{i=1}^{n}(Rij-Rj)^2\sum_{i=1}^{n}(SCi-SC)^2}} \quad (1)$$

Table 1. Measured EC and pH values of soil samples

Depth (cm)	EC (dS m^{-1})	Temperature indicator (°C)	pH
0-20	25	24	8.15
0-20	23	25	8.22
0-20	22	24	8.22
0-20	0.6	25	8.20
0-20	0.5	24	8.20
0-20	5.0	25	8.20
0-20	0.6	22	8.18
0-20	0.4	24	8.18
0-20	20	25	8.95
0-20	21	25	8.66
0-20	17	24	8.60
0-20	13	25	8.62
0-20	13	24	8.46
0-20	20	24	9.0
0-20	19	22	8.60
0-20	12	24	7.75
0-20	16	24	8.55
0-20	24	22	8.43
0-20	12	23	8.37
0-20	15	22	8.47

Through field research and the use of the above formulas, specific vegetation parameters were identified. To study vegetation cover in different periods, it is necessary to have information on hyperspectral ability [24], [25]. Satellite images were used to analyze the spectral brightness coefficient of the areas under consideration. The model being developed also depends on the statistical information extracted from the indices [26]. This includes linear regression, factor analysis, and principal component analysis were calculated. Data should be in units of reflectance before creating spectral indices. The soil SI can reflect the distribution of soil salinity, and using characteristic wavelengths with the highest correlation with soil salinity to establish a high spectral soil SI offers significant advantages in detecting salinization. This index is similar to the normalized difference vegetation index (NDVI), but it suppresses the effects of soil pixels. It uses a canopy background adjustment factor, L, which is a function of vegetation density and often requires prior knowledge of vegetation amounts optimal value of L=0.5 is used to account for first-order soil background variations.

$$SAVI = \frac{1.5\times(NIR-Red)}{(NIR+Red+0.5)} \tag{2}$$

In this experiment, general vegetation indices with simple ratios are selected. These include the radar vegetation index (RVI), NDVI, and difference vegetation index (DVI).

$$DVI = NIR - Red \tag{3}$$

$$OSAVI = \frac{NIR-Red}{NIR+Red+0.16} \tag{4}$$

$$MSAVI2 = \frac{2\times NIR+1-\sqrt{(2\times NIR+1)^2-8(NIR-Red)}}{2} \tag{5}$$

The correlation coefficient between soil salinity measured with the salinity index and the SI is R^2=-0.588, which passes the significance test at the 0.01 level and indicates that it can be used to invert soil salinity.

$$SI = 2\times\sqrt{R^2 1050 + R^2 850} \tag{6}$$

Creating a remote sensing model. Statistics are used to analyze the statistical relationship between variables [27]. It can help us accurately understand the degree of influence of variables on each other, conducting a multivariate linear regression (analysis of trend surface) by considering soil salinity as the dependent variable and the salt index and vegetation index as independent variables. Figure 2 shows the scatter plot of the different indices. The results show that there is a good non-linear relationship between soil salinity and the two indices (Figures 2(a) to 2(d)), with an R-squared value of 0.755 for the determined model and an F-value of 6.3.

$$Y = 15330000.35\times 12 - 270.215\times 22 - 33546.02\ \times 1\times 2 + 300.10 \tag{7}$$

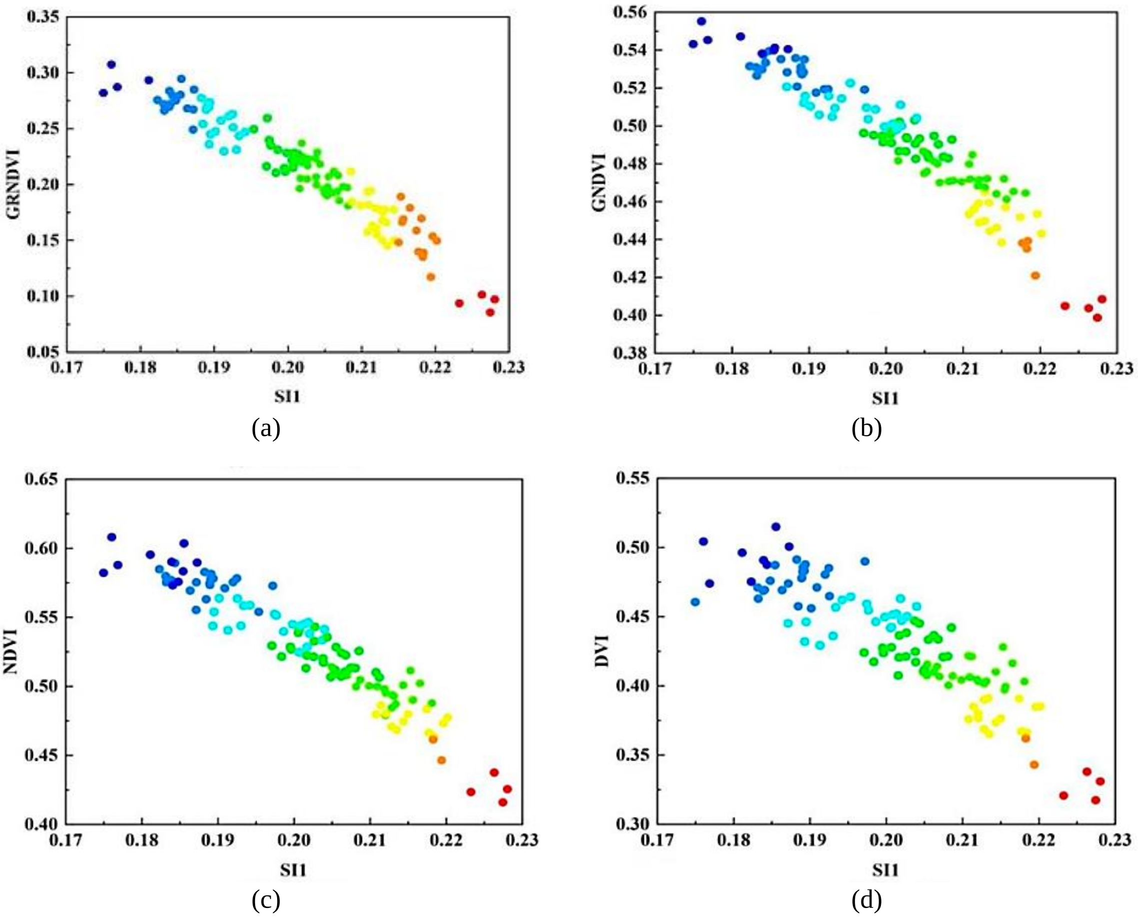


Figure 2. Scatter plot of different indices (a) SI1-green-red band normalized difference vegetation index (GRNDVI), (b) SI1-green normalized difference vegetation index (GNDVI), (c) SI1-NDVI, and (d) SI1-DVI

In tests of significance at the 0.01 level, where x1 is the salinity index and x2 is the vegetation index. An inversion model has been tested based on twelve soil sample units that did not participate in modeling. The model samples are clustered around the diagonal, as shown mainly, with a proximity of 0.755. Figure 3 shows the spatial distribution of soil salinity levels in cotton fields in the Shirvan region. There is good agreement between simulated and measured values, indicating that the model established here is effective and validated (Figures 3(a) to 3(d)). Therefore, it can be used to predict the overall salt content of the soil. Using the remote sensing salinity monitoring index model to invert the soil salinity of cotton fields in the Shirvan Plain, S1DI1 has the highest number of correctly classified sample points, while S1D3 and S1DI4 have relatively few correctly classified sample points. The overall accuracy of S1DI1, S1DI2, S1DI3, and S1DI4 is 94.59%, 95.49%, 95.79%, and 95.763%, respectively. Figure 4 shows the agreement with the measured conductivity. Among the sample classification errors, the classification errors of sample points of model S1DI1, model S1DI2, model S1DI3, and model S1DI4 were mainly caused by non-saline soil (Figures 4(a) to 4(d)). Long-term anthropogenic impact (deep melioration plowing, afforestation, cultivation of agricultural, and horticultural crops using irrigation) has caused significant changes in the properties of solonetz soils of the Shirvan Plain, which persist even after a long (more than 32 years) post-irrigation period.

The chemistry of saline soils in the area with smoothed microrelief is predominantly chloride-sulfate-sodium, only in the upper part (16 to 35 cm) is NaCl. Vertical distribution of the activity of Na^+, $Cl^–$, and Ca^{2+} ions measured in pastes with 35% humidity in sample wells. The distribution of gypsum in the vertical profile of soils in the areas forms three distinct maxima: the first is in the middle part of the upper meter layer, the second is at a depth of about 2 m, and the third is at the depth of the lower part of the fourth and upper fifth meter layers. The formation of these gypsum maxima indicates that the process of salt accumulation proceeded with three distinct interruptions, which exactly correspond to the three cycles of river water retreat noted above, whereas in the area, the connection between gypsum accumulation and these later cycles was already weaker or lost.

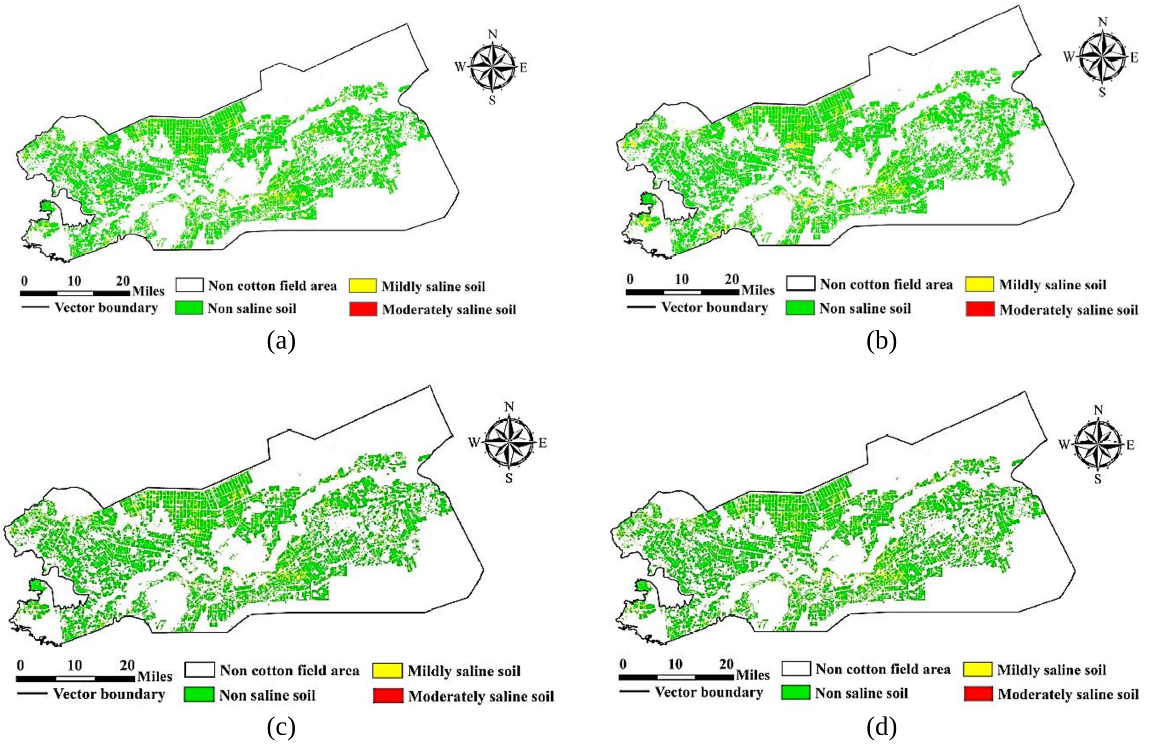


Figure 3. Spatial distribution of soil salinity levels in cotton fields of the Shirvan region: (a) SIDI1, (b) SIDI2, (c) SIDI3, and (d) SIDI4

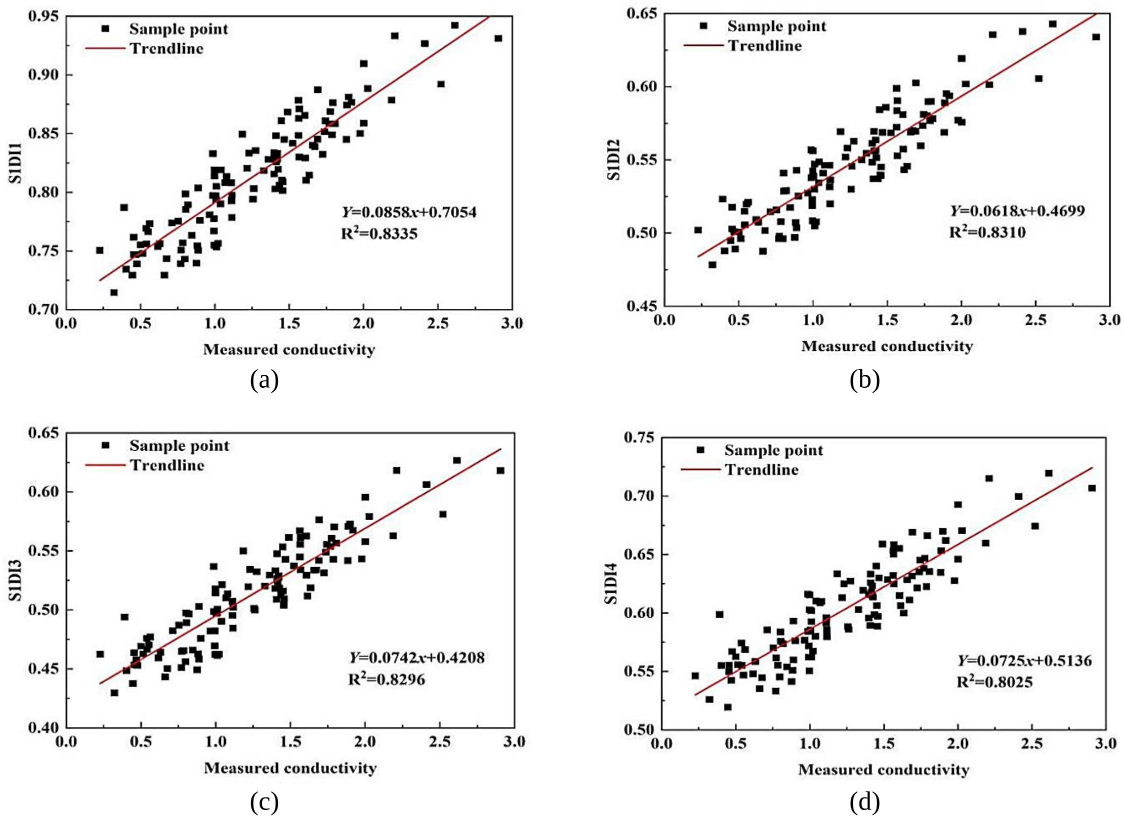


Figure 4. Conformity with measured conductivity of (a) S1DI1, (b) S1DI2, (c) S1DI3, and (d) S1DI4

4. CONCLUSION

The purpose is to highlight the potential regressions between the synthetic image of the indices used here as an explanatory variable and each of the vegetation and soil indices used as variables to explain. As studies have shown, in the soils of the studied area, under the influence of plowing and long-term irrigation, the original solonetz soils were transformed into soils that are not found in virgin conditions. Long-term sustainable changes in vegetation as a result of phytomelioration can be judged by the fact that the planted forest stands have partially survived, but their species composition has changed: *Ribes aureum*, *Cotinus coggygria, Ulmus pumila, Ulmus laevis, and Lonicera tatrica* grow among the tree species, *Pyrus communis,* and individual specimens of *Quercus robur* exist in a sparse and depressed state. The resulting tree species are covered by grass species of the local flora, characteristic of the solonetz complex vegetation: *Galatella villosa, Limonium caspium, L. gmelinii, Festuca valesiaca, Elaeagnus angustifolia, Poa bulbosa, Artemisia lerchiana, A. pauciflora, Stipa capillata, S. lessingiana, Chorispora tenella, Descurainia sophia, Tanacetum achilleifolium, Artemisia santonica, Kochia prostrata, Galium verum, Limonium caspium, Limonium gmelinii, Lamium amplexicaule, Tanacetum vulgare, Tulipa gesneriana, Polygonum aviculare*. Over most of the area, dead trees remain (GNDVI). Plant communities on the fallow land are characterized by a higher density and species richness than on virgin solonetz, and annual ephemeral species predominate (DVI). On former forest plantations, wormwood overgrowth is more successful than on former arable land. The species composition and structure of the modern vegetation cover on reclaimed lands indicate that restorative succession is developing in the grass cover.

ACKNOWLEDGEMENTS

This work was supported by the equipment provided by the Institute of Soil Science and Agrochemistry, Baku State University (Faculty of Geography, Ecology and Soil Science), and Azerbaijan State University of Economics. Our gratitude to the colleagues of the Registry of Real Estate Public Legal Entity.

FUNDING INFORMATION

The authors state no funding is involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sahib Shukurov Khudaverdi	✓	✓	✓			✓		✓	✓	✓			✓	
Aygun Ismayilova Azer		✓			✓	✓		✓		✓	✓	✓		✓
Ramil Sadigov Ali	✓		✓	✓			✓		✓	✓	✓	✓	✓	✓
Maya Karimova Javanshir	✓		✓	✓	✓	✓	✓			✓	✓		✓	
Turkan Hasanova Allahverdi	✓		✓	✓	✓		✓		✓	✓		✓	✓	✓
Gunel Asgarova Farhad		✓			✓	✓		✓	✓		✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

This study received permission from the Azerbaijan Republic Government. All informed consents are based on the recommendations of the Ministry of Science and Education of Azerbaijan on soil research.

ETHICAL APPROVAL

This study complies with the research ethics code, ensures that all procedures are carried out by established ethical standards, and has received approval from the relevant ethics committee.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SSK], upon reasonable request.

REFERENCES

[1] S. K. Shukurov and Z. H. Aliyev, "Test measurements of salinity in irrigation water and soil and classification of salinity," *Int. Clinc Med Case Rep. Journal.*, vol. 2, no. 12, pp. 1–8, 2008, [Online]. Available: https://shorturl.at/cLtrT
[2] G. I. Metternicht and J. A. Zinck, *Remote sensing of soil salinization*. CRC Press, 2008. doi: 10.1201/9781420065039.
[3] W. Ding, Y. Cai, Z. Cai, K. Yagi, and X. Zheng, "Soil respiration under maize crops: effects of water, temperature, and nitrogen fertilization," *Soil Science Society of America Journal*, vol. 71, no. 3, pp. 944–951, May 2007, doi: 10.2136/sssaj2006.0160.
[4] K. Macnunlu, R. H. Baba-Zade, and T. Hasanova, "Ecological sustainability of agroecosystem and productivity assessment in the barda area using ndvi and savi," *Advances in Biology and Earth Sciences*, vol. 10, no. 1, pp. 148–157, 2025, doi: 10.62476/ABES.101148.
[5] A. Ismayilova, S. Shukurov, L. Hasanaliyeva, S. Osmanova, G. Asgarova, and T. Hasanova, "Modern soil cover of natural cenoses and agrosenoses landscapes of the kur-araz plain," *Advances in Biology & Earth Sciences*, vol. 10, no. 2, pp. 314–325, 2025, doi: 10.62476/abes.102314.
[6] L. Wang *et al.*, "Integrative modeling of heterogeneous soil salinity using sparse ground samples and remote sensing images," *Geoderma*, vol. 430, 2023, doi: 10.1016/j.geoderma.2022.116321.
[7] M. M. E. S. Gad, M. H. A. Mohamed, and M. R. Mohamed, "Soil salinity mapping using remote sensing and gis," *Geomatica*, vol. 75, no. 4, pp. 295–309, 2022, doi: 10.1139/geomat-2021-0015.
[8] D. L. Rowell, *Soil science*. Routledge, 2014. doi: 10.4324/9781315844855.
[9] G. I. Metternicht and J. A. Zinck, "Remote sensing of soil salinity: potentials and constraints," *Remote Sensing of Environment*, vol. 85, no. 1, pp. 1–20, 2003, doi: 10.1016/S0034-4257(02)00188-8.
[10] J. P. Mehta and B. Shreshthamani, "Analysis of the physic-chemical properties of the soil and climatic attribute on vegetation in central himalaya," *Nature and Science*, vol. 12, no. 11, pp. 46–54, 2014.
[11] R. A. Sadigov, M. G. Mustafayev, and A. M. Azimov, "Analysis of the erosion processin undeveloped mountain gray-cinnamon (chestnut) soils in the shamkirchay water reservoir basin," *Sabrao Journal of Breeding and Genetics*, vol. 56, no. 5, pp. 2067–2078, 2024, doi: 10.54910/sabrao2024.56.5.29.
[12] G. Mammadova, A. Gahramanova, L. Bunyatova, T. Babayeva, and L. Huseynova, "Determination of main properties and fertility capacity of soils under hazelnut cultivation in azerbaijan," *Proceedings of the Bulgarian Academy of Sciences*, vol. 77, no. 4, Apr. 2024, doi: 10.7546/CRABS.2024.04.18.
[13] H. Chen, J. Wu, and C. Xu, "Monitoring soil salinity classes through remote sensing-based ensemble learning concept: considering scale effects," *Remote Sensing*, vol. 16, no. 4, 2024, doi: 10.3390/rs16040642.
[14] G. S. Mammadov and A. J. Hashimov, "An assessment of reclamation conditions in the irrigated lands of the azerbaijan republic," *Journal of Water and Land Development*, vol. 14, no. 1, pp. 97–100, 2010, doi: 10.2478/v10025-011-0008-2.
[15] S. S. Khudaverdi, "Mapping of soil salinity in absheron soil based on sentinel-2 using lightgbm," *Comptes Rendus de L'Academie Bulgare des Sciences*, vol. 77, no. 12, pp. 1879–1887, 2024, doi: 10.7546/CRABS.2024.12.17.
[16] A. Ismayil, R. Alakbar, V. Gudrat, R. Islam, and T. Allahverdi, "Soil salinization in ujar region of azerbaijan with index application and various methods comparison," *Proceedings of the Bulgarian Academy of Sciences*, vol. 78, no. 6, pp. 506–512, Jun. 2025, doi: 10.7546/CRABS.2025.06.18.
[17] H. Chen, J. Wu, and C. Xu, "Optimization of multi-source remote sensing soil salinity estimation based on different salinization degrees," *Remote Sensing*, vol. 17, no. 7, 2025, doi: 10.3390/rs17071315.
[18] X. Ge *et al.*, "Updated soil salinity with fine spatial resolution and high accuracy: the synergy of sentinel-2 msi, environmental covariates and hybrid machine learning approaches," *Catena*, vol. 212, 2022, doi: 10.1016/j.catena.2022.106054.
[19] C. Kobayashi *et al.*, "Estimating soil salinity using hyperspectral data in the western australian wheat belt," in *2013 IEEE International Geoscience and Remote Sensing Symposium - IGARSS*, IEEE, Jul. 2013, pp. 4325–4328. doi: 10.1109/IGARSS.2013.6723791.
[20] L. B. Novruz, G. M. Israphil, T. H. Allahverdi, A. G. Yarish, S. A. Maharram, and G. A. Yashar, "Main eco-properties of hazelnut (corylus avellana l.) on the sheki-zagatala economic region," *International Journal of Advances in Applied Sciences*, vol. 14, no. 1, pp. 77–85, 2025, doi: 10.11591/ijaas.v14.i1.pp77-85.
[21] J. W. Doran and M. R. Zeiss, "Soil health and sustainability: managing the biotic component of soil quality," *Applied Soil Ecology*, vol. 15, no. 1, pp. 3–11, Aug. 2000, doi: 10.1016/S0929-1393(00)00067-6.
[22] H. Wulf, T. Mulder, M. E. Schaepman, A. Keller, and P. C. Jörg, "Remote sensing of soils," 2015. doi: 10.13140/2.1.1098.0649.
[23] N. A. I., M. R. N., A. M. M., and H. T. A., "Bioecological edificators of gray-brown soils in ganja-gazakh massif (azerbaijan)," *Environment and Ecology Research*, vol. 10, no. 3, pp. 392–397, Jun. 2022, doi: 10.13189/eer.2022.100307.
[24] S. M. Talibi and T. A. Hasanova, "Environmentally significant indicators of mountain meadow soils in azerbaijan," *Bulletin of Nizhnevartovsk State University*, vol. 57, no. 1, pp. 102–107, Jan. 2022, doi: 10.36906/2311-4444/22-1/11.
[25] R. Taghizadeh-Mehrjardi, B. Minasny, N. Toomanian, M. Zeraatpisheh, A. Amirian-Chakan, and J. Triantafilis, "Digital mapping of soil classes using ensemble of models in isfahan region, iran," *Soil Systems*, vol. 3, no. 2, p. 37, May 2019, doi: 10.3390/soilsystems3020037.
[26] R. A. Sadigov and M. G. Mustafayev, "Analysis of mountain-forest cinnamon soil types in the basin of the new shamkirchay reservoir," *Sabrao Journal of Breeding and Genetics*, vol. 56, no. 1, pp. 266–279, 2024, doi: 10.54910/sabrao2024.56.1.24.
[27] S. Akhundova *et al.*, "Study of the modern bio-ecological state absheron coastlines," *Advances in Biology and Earth Sciences*, vol. 10, no. 1, pp. 168–176, 2025, doi: 10.62476/ABES.101168.

BIOGRAPHIES OF AUTHORS

Sahib Shukurov Khudaverdi Ph.D. specializes in Agricultural Sciences. He works at the State Property Service under the Ministry of Economy of the Republic of Azerbaijan, specifically within the State Cadastre and Real Estate Register Public Legal Entity. Also serves as a lecturer at Baku State University, Faculty of Ecology and Soil Science. He is the author of 75 scientific papers and 2 books. He can be contacted at email: sukurov.sahib@inbox.ru.

Aygun Ismayilova Azer Ph.D. specializes in Geography. She is currently a lecturer at Department of Physical Geography, Faculty of Geography, Baku State University. She is the author of 55 scientific papers and 7 university-level educational programs. She has supervised more than 30 undergraduate and graduate students. She can be contacted at email: aygunmammadovaazer@gmail.com.

Ramil Sadigov Ali Ph.D. works as an Associate Professor at the Department of Engineering and Applied Sciences, Faculty of Engineering, Azerbaijan State University of Economics (UNEC). He is also the Director of the Laboratory Work Organization Center. He is the author of more than 200 scientific articles and 4 books. He has served as the scientific supervisor for over 100 undergraduate and graduate students. He can be contacted at email: ramil_sadigov@unec.edu.az.

Maya Karimova Javanshir Ph.D. specializes in Economics. She is an Associate Professor at the Department of Engineering and Applied Sciences, Azerbaijan State University of Economics (UNEC). She is the author of more than 55 peer-reviewed scientific papers. She has supervised 32 undergraduate and graduate students. She can be contacted at email: karimova-maya@internet.ru.

Turkan Hasanova Allahverdi Ph.D. specializes in Agricultural Sciences. She is an Associate Professor and lecturer at Baku State University. She is the author of 100 scientific research articles, including 7 indexed in Scopus and WoS, 1 monograph, 1 collective monograph, and 2 educational programs. She serves as a reviewer for 17 WoS and Scopus journals and is a member of the editorial board for two Scopus-indexed journals. She is engaged in innovative laboratory research in ecology and soil biology. She can be contacted at email: turkanhesenova@mail.ru.

Gunel Asgarova Farhad works as a researcher at the Institute of Soil Science and Agrochemistry, Ministry of Science and Education of the Azerbaijan Republic. Azerbaijan, Baku. She is the author of 35 research articles (4 Scopus and WoS), 1 book. She serves as a reviewer in 5 scientific journals and conducts soil research in an agricultural laboratory. She can be contacted at email: asgarova.g@mail.ru.