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SPATIAL ASSESSMENT OF SOIL FERTILITY USING GIS AND REMOTE SENSING: A CASE STUDY OF SOUTHERN KAZAKHSTAN

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SUMMARY

This study aimed to determine the spatial variability of soil properties using arable lands at the Kokzhon deposit in the Zhambyl Region, Kazakhstan. The research used Sentinel-2 and Landsat-8 images from 2016 to 2022, covering the spring-to-autumn periods. The indices NDVI (Normalized Difference Vegetation Index), SAVI (Soil Adjusted Vegetation Index), NDMI (Normalized Difference Moisture Index), and NDRE (Normalized Difference Red Edge Index) reached their calculations using the raster calculator in the ArcGIS software environment. Spatial data processing took place in QGIS. Likewise, the conduct of channel resolution normalization and index calculation used the 'nearest neighbor' method. The highest vegetation index (0.7–0.8) resulted in favorable years, 2018 and 2020, indicating the optimum soil fertility in specific areas. However, the minimum vegetation index (0.1–0.3) pointed to the need for reclamation measures. The resulting maps allow for effective identification and zoning of fertile areas. The GIS technologies and satellite data application demonstrated the maximum efficiency in assessing soil fertility. The methodology considered spatial heterogeneity and monitored the dynamic variations to make decisions for the management of sustainable agriculture. The obtained results can be beneficial to develop strategies for restoring low-fertility lands and increasing crop yields.

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Keywords: Soil fertility, GIS, remote sensing, vegetation indices, precision agriculture

Key findings: The study highlighted the use of GIS and remote sensing (Sentinel-2 and Landsat-8) to assess soil fertility in Southern Kazakhstan. Vegetation indices identified zones of high and low soil fertility, enabling targeted land management. The approach provides a scalable tool for improving agricultural planning in semi-arid regions.

INTRODUCTION

Globally, agriculture depends upon the soil's health, and according to the Food and Agriculture Organization (FAO), over 33% of the world's soil has already degraded (UNDRR, 2023). Such a situation could result in a threatening crisis in agriculture, especially in arid and semi-arid regions such as Central Asian countries, where land overuse, erosion, and climate change worsen the degradation (Shaimerdenova, 2022). According to recent studies, about 90 million hectares of land are under the eroded category, and some are at risk of erosion, with 29.3 million hectares now experiencing erosion in Kazakhstan (Bureau of National Statistics, 2019), requiring immediate action in restoring soil fertility (Bauyrzhan *et al.*, 2022). Fertile soil provides the foundation for sustainable farming and plays a vital role in the global food security and sustainable development goals (SDGs), especially in countries where agriculture serves as the backbone of the economy (Lal *et al.*, 2021; Silver *et al.*, 2021).

However, studies over the years have established various structures to reclaim post-industrial and abandoned lands for agricultural purposes and sustainable development (Toktar, 2022; Laiskhanov *et al.*, 2023). In this context, the restoration of degraded lands, especially those affected by past mining activities, has strategic importance. In Sarysu district, Kazakhstan, the Kokzhon site is an example of such a reclaimed area, where it is necessary to assess the effectiveness of reclamation measures and determine the land's potential for agricultural purposes.

In soil fertility assessment, one of the most promising GIS applications is the use of satellite imagery to formulate various indicators of soil health. Satellite images Sentinel-2 and Landsat-8 are widely functional

to calculate the vegetation indices closely related to the quantity and quality of vegetation cover. This study selected remote sensing data from satellite images of Landsat-8 and Sentinel-2. By analyzing these indices, it is possible to assess the nutrients absorbed by the crops and the overall condition of soil health (Nikonorova *et al.*, 2021).

In contrast, remote sensing provides enhanced spatial and temporal resolution as compared with conventional methods that necessitate physical sampling and laboratory analysis. Remote sensing indices facilitate the precise calibration of various parameters (Khanal *et al.*, 2020). For instance, NDVI evaluates overall vegetation health, NDMI signifies moisture stress, and NDRE represents the plant's physiological processes and conditions (Izbastina *et al.*, 2020). Employing multiple indices within a single study enables the development of a comprehensive overview of soil fertility and its dynamic fluctuations. Thus, the planned strategies in this research consider the regional variations in soil fertility and promote evidence-based decision-making in effective management of agriculture and the ecosystem. The presented study aimed to examine the spatial variability of soil properties on agricultural lands of the Kokzhon deposit in the Zhambyl Region.

MATERIALS AND METHODS

Study site

The study site was an agricultural plot of the Kokzhon deposit (43°34'04" N, 69°31'30" E), located 12 km from the city of Zhanatas, Sarysu District, Zhambyl Region, Kazakhstan. On this site, the reclamation works proceeded in two stages, i.e., technical and biological. The plot area was 110 m × 115 m.

Kokzhon deposit characteristics

The geographical area of the Kokzhon site has a diverse landscape characteristic. Figure 1a shows the Kokzhon deposit area, where the mountain ranges, hilly terrain, gorges, and river valleys can be visible. The area is also rich in natural resources, including forests, rivers, and lakes. The Kokzhon phosphorite deposit sits at an elevation of 500–700 meters above sea level and comprises multi-tiered industrial dumps and several large quarries. The quarries range from 1.6 to 2.98 km in length, 360–430 m in width, and 90–95 m in depth. Three industrial dumps also exist with heights of 50–70 m, and their total area was between 16 and 27 ha. Overall, the Kokzhon phosphorite deposit covers an area of over 1000 ha. During the warm season, the average air temperature was 15 °C–17 °C in the mountainous and northern peripheral areas and 18 °C–19 °C in the central areas. In particular years, daily temperatures can reach 45 °C–47 °C in desert regions and 40 °C–42 °C in mountainous areas.

Research methods

The study relied on an integrated approach combining traditional methods of soil analysis

(physical, chemical, and biological properties) with modern GIS and remote-sensing technologies (ArcGIS and QGIS).

Software tools

ArcGIS, designed as a comprehensive solution for managing spatial data, offers a range of tools for data collection, management, and analysis. In ArcGIS, the 'soil fertility index' tool calculates the soil fertility based on a set of soil parameters, including soil texture, organic matter content, pH level, and nutrient availability. The tool used a weighted sum method to integrate these soil parameters and generate a soil fertility index. The resulting index provides an overall picture of soil fertility, helping land managers identify areas that may require additional management practices, such as fertilization and soil amendments.

In ArcGIS, the Spatial Analyst tool can help analyze and visualize the soil data in a spatial context. This tool enables users to develop maps displaying soil fertility levels across the landscape. These maps can also be effective in identifying areas with high and low fertility, supporting land managers in making decisions regarding land use practices, such as crop rotation, irrigation, and fertilization.

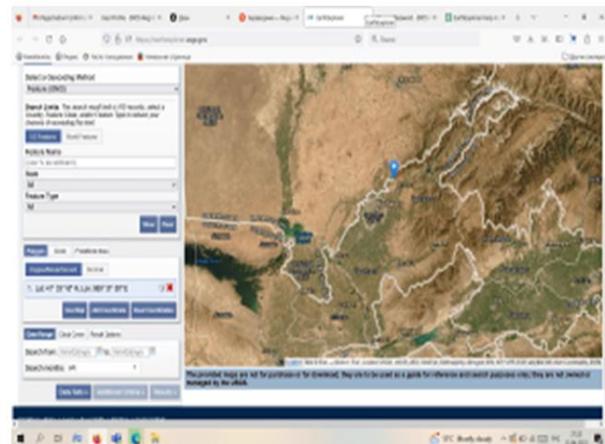


Figure 1. Geographic and satellite overview of the study area, a) Location of the Kokzhon deposit site in Southern Kazakhstan and b) Example of Landsat-8 satellite image metadata used in the study (Google Earth Engine Explorer).

Table 1. Characteristics of Sentinel-2 spectral bands (Tabunshchik *et al.*, 2018).

Sentinel-2 Bands	Resolution (m)
Band 1- Coastal aerosol	60
Band 2- Blue	10
Band 3- Green	10
Band 4- Red	10
Band 5- Vegetation Red Edge	20
Band 6- Vegetation Red Edge	20
Band 7- Vegetation Red Edge	20
Band 8- NIR	10
Band 8A- Narrow NIR	20
Band 9- Water vapor	60
Band 10- SWIR- Cirrus	60
Band 11- SWIR	20
Band 12- SWIR	20

Satellite systems: Sentinel-2 and Landsat-8

The Sentinel-2 satellite system is one of the key components of the European Space Agency's (ESA) Earth Observation program (Phiri *et al.*, 2020). Its main objective is to provide access to high-resolution optical imagery of the Earth for a wide range of users. Sentinel-2 features a multispectral imaging system, capturing radiation in 13 optical bands. The characteristics of the Sentinel-2 spectral bands are available in Table 1. The bands cover important parts of the electromagnetic spectrum, from visible light (red, green, and blue bands) to the near-infrared (NIR) and shortwave infrared (SWIR) regions. This further allows for the acquisition of information about vegetation cover, soil properties, water bodies, and other environmental elements. The satellite system Landsat 8 is part of the United States Geological Survey (USGS) Earth Observation program. It provides a valuable set of optical images for monitoring and studying the Earth's surface (Kataev and Butin, 2019).

Vegetation and soil indices

The research method was according to the calculation of vegetation and soil indices. Vegetation indices served to monitor the condition of various crops, assess their yields, track the variations in land use and vegetation

cover, and evaluate the effects of natural disasters on plant health (Pavlova, 2021). The study used the indices, viz., NDVI, SAVI, NDMI, and NDRE.

The NDVI (Normalized Difference Vegetation Index) indicates the presence and condition of vegetation (relative biomass) by using the contrast between two spectral bands from multispectral raster data: the absorption of chlorophyll in the red band and the high reflectance of plant material in the near-infrared (NIR) band.

$$NDVI = (NIR - RED) / (NIR + RED)$$

The NDVI values range from -1.0 to +1.0, where negative values indicate the presence of clouds, water, and snow; values near to zero indicate bare and rocky soils. Lowest values (0.1 or less) correspond to barren areas of rock, sand, and snow. Moderate values (0.2 to 0.3) reflect shrublands and grasslands, while higher values (0.6 to 0.8) indicate temperate and tropical forests.

The development of SAVI (Soil-Adjusted Vegetation Index) sought to account for the soil brightness and reduce the influence of soil reflectance on vegetation indices. SAVI is similar to NDVI; however, it includes a soil brightness correction factor to minimize the soil's effect on index values.

$$SAVI = ([NIR - RED] / [NIR + RED + L]) \times (1 + L)$$

The soil adjustment factor L is a variable representing the proportion of vegetation cover in a given area. SAVI values range from -1 to 1, and the higher values indicate greater vegetation cover and higher soil fertility.

Normalized Difference Moisture Index (NDMI) determines the moisture content in vegetation using a combination of NIR and shortwave infrared (SWIR) spectral bands. It is a reliable indicator of water stress in crops.

$$\text{NDMI} = (\text{NIR} - \text{SWIR}) / (\text{NIR} + \text{SWIR})$$

The NDMI values range from -1.0 to 1.0. The values closer to -1 indicate little or no vegetation; around zero suggests low vegetation density, high water stress, and sparse cover, and the values near 1 imply dense and healthy vegetation.

The OSAVI (Optimized Soil-Adjusted Vegetation Index) is a modified version of SAVI and also uses reflectance in the infrared spectrum. OSAVI uses a standard soil adjustment factor of 0.16, with values ranging between -1.0 and 1.0. Values from -1 to 0.2 indicate bare soil, 0.2–0.4 represents the germination stage, and 0.4–0.6 corresponds to the leaf development stage.

$$\text{OSAVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED} + 0.16)$$

The NDRE (Normalized Difference Red Edge Index) is applicable in remote sensing to measure chlorophyll content in plants. Its calculation depends on the combination of NIR and Red Edge spectral bands (which lie between visible red and NIR).

$$\text{NDRE} = (\text{NIR} - \text{Red Edge}) / (\text{NIR} + \text{Red Edge})$$

The NDRE values span from -1.0 to 1.0. The values from -1 to 0.2 indicate bare soil or early-stage crops, 0.2–0.6 suggests unhealthy or immature vegetation, and 0.6–1.0 signifies healthy and mature crops.

The use of GDVI (Green Difference Vegetation Index) helps assess vegetation health based on satellite imagery. Its

calculation consists of subtracting the red spectral band value from the green band value.

$$\text{GDVI} = \text{Green} - \text{Red}$$

Where Green is the pixel value in the green spectral band, and Red is the pixel value in the red spectral band. GDVI helps distinguish between green and red reflectance and serves as an indicator of vegetation health and density.

Methodology for assessing agricultural land using GIS technologies

In this study, the methodology for assessing the agricultural land conditions using GIS (geographic information systems) technologies included the following stages:

Data collection included relevant data such as digital maps, satellite images, soil information, and climatic data.

The creation of a geospatial database where the collected data underwent organization and storage in a geospatial database, enabling their integration and analysis through GIS tools.

Data processing and analysis applied various GIS technologies to process the information. The technologies included soil cover classification, identification of vegetation characteristics, time-series analysis of satellite imagery, and estimation of potential crop yield.

Modeling and forecasting based on processed data developed models to assess the current state of arable lands and forecast their variations. The results provided a foundation for decision-making and planning future activities aimed at improving land-use efficiency.

Delineation of agricultural objects

A completed user registration as an initial step acquired satellite Sentinel-2 and Landsat-8 images. Then, configuring parameters took place, selecting the target area near the city of Zhanatas. The choice imagery was for both spring and autumn periods.

Three Sentinel missions occurred, but this study utilized Sentinel-2 data. The suitable image selected was free from cloud cover and other distortions. After selecting the image, the retrieval of its detailed information succeeded.

Using Landsat-8, under search criteria, the specified geographic area was either selecting the territory using a polygon or manually entering coordinates within which the data search continued. The search also set the desired acquisition dates for the imagery. In the 'cloud cover' tab, the allowable cloud cover percentage was set to 20%.

Data Sets: After setting the search criteria, the appropriate satellite and cartographic datasets selected were as follows:

- 2014 Landsat Collection 2 Level 1: Landsat 8-9 OLI/TIRS C2 L1
- 2016 Landsat Collection 2 Level 1: Landsat 8-9 OLI/TIRS C2 L1
- 2018 Landsat Collection 2 Level 1: Landsat 8-9 OLI/TIRS C2 L1
- 2020 Landsat Collection 2 Level 1: Landsat 8-9 OLI/TIRS C2 L1
- 2022 Landsat Collection 2 Level 1: Landsat 8-9 OLI/TIRS C2 L1

Calculation of vegetation indices using software

For Sentinel-2, an Earth observation satellite system, various spectral bands entailed the calculation of the different vegetation indices, such as NDVI, NDMI, NDRE, and SAVI. The bands used by Sentinel-2 for these indices were as follows:

NDVI (Normalized Difference Vegetation Index)

Red Band (B4): Wavelength range was around 665 nm.

Near-Infrared Band (B8): Wavelength range was around 842 nm.

Figure 2a, showing the NDVI index values, indicates areas of dense, moderate, and sparse vegetation.

NDMI (Normalized Difference Moisture Index)

Near-Infrared Band (B8): Wavelength range was around 842 nm.

Shortwave Infrared Band (B11): Wavelength range was around 1610 nm.

Figure 2b shows the NDMI index values, which provide information about moisture sufficiency and deficiency in crop plants.

NDRE (Normalized Difference Red Edge Index)

Red Band (B4): Wavelength range was around 665 nm.

Red Edge Band (B5): Wavelength range was around 705 nm.

Figure 2c, displaying the NDRE index values, indicates areas of dense, moderate, and sparse vegetation.

SAVI (Soil Adjusted Vegetation Index)

Red Band (B4): Wavelength range was around 665 nm.

Near-Infrared Band (B8): Wavelength range was around 842 nm.

Figure 3 shows the SAVI index values indicating areas of dense, moderate, and sparse vegetation, as well as the presence of low vegetation. Each of these vegetation indices utilizes different combinations of satellite Sentinel-2 bands to assess the various aspects of vegetation, such as green biomass, soil moisture, and the physiological conditions of crop plants.

Satellite Landsat-8, an Earth observation system, also utilizes various spectral bands to calculate the vegetation indices, such as NDVI, NDMI, NDRE, and SAVI. These indices used different combinations of satellite Landsat-8 bands to assess the vegetation parameters, such as green biomass, soil moisture, and plant health. After selecting the vegetation indices, the practical part of the

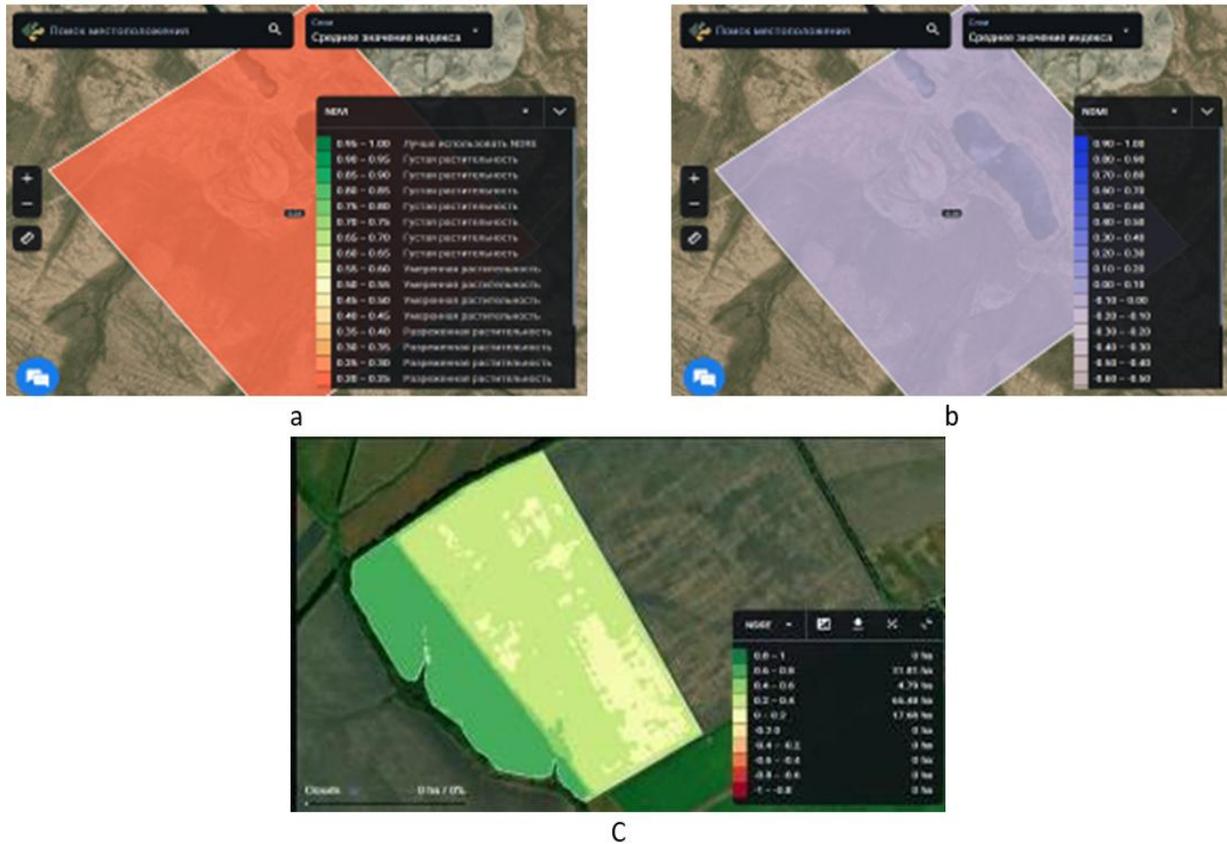


Figure 2. Spatial distribution of vegetation indices derived from Sentinel-2 imagery: a) Normalized Difference Vegetation Index (NDVI) (EOSDA Crop Monitoring, n.d.), b) Normalized Difference Moisture Index (EOSDA Crop Monitoring, n.d.), and c) Normalized Difference Red Edge Index (NDRE) (EOSDA Crop Monitoring, n.d.).

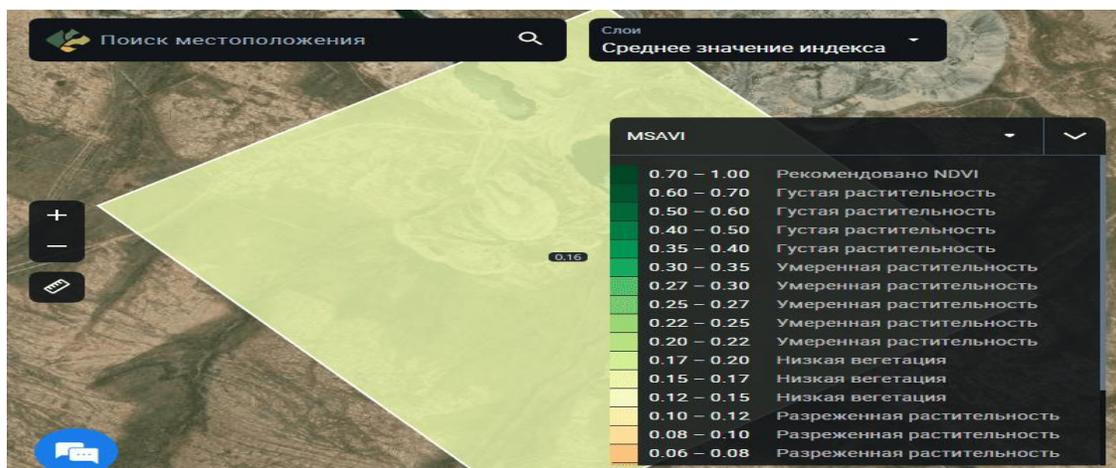


Figure 3. Soil Adjusted Vegetation Index (SAVI) for the Kokzhon Area (EOSDA Crop Monitoring, n.d.).

analysis begins. In the 'Layers' tab, inputting multispectral bands (4, 3, and 2) ensued. For each index, the adding of required bands also took place via the same tab, before calculating the selected index.

Parameter configuration

Next, parameter settings for the satellite images underwent configuration. Locating the target area near the city of Zhanatas occurred. In the 'Search Criteria' tab, setting the acceptable cloud cover was at 0%–10%, with the desired time frame also selected.

Resolution adjustment

Before calculating the indices, it was necessary to check the resolution of each spectral band. If discrepancies appeared, resolution and projection resampling must take place. This study applied the 'nearest neighbor' resampling method. The essence of this method was that

the output pixel value assignment relied on the value of the nearest input pixel. In the 'Input Raster' window, the raster product to be resampled entailed indication, while selecting the band to be used for resampling attained inputting in the 'Output Cell Size' window. The resampling technique used was bilinear.

Calculation of NDVI, NDMI, SAVI, and NDRE Indices

- Using the 'Raster Calculator' tool calculated the NDVI following the earlier given formula.
- The NDMI calculation used the formula as previously given above.
- The NDRE computation utilized the formula given above. Figure 4a showed the raster calculator where computing the NDRE index occurred.
- The SAVI calculation followed the formula given earlier. Figure 4b showed the raster calculator that computed the SAVI index.

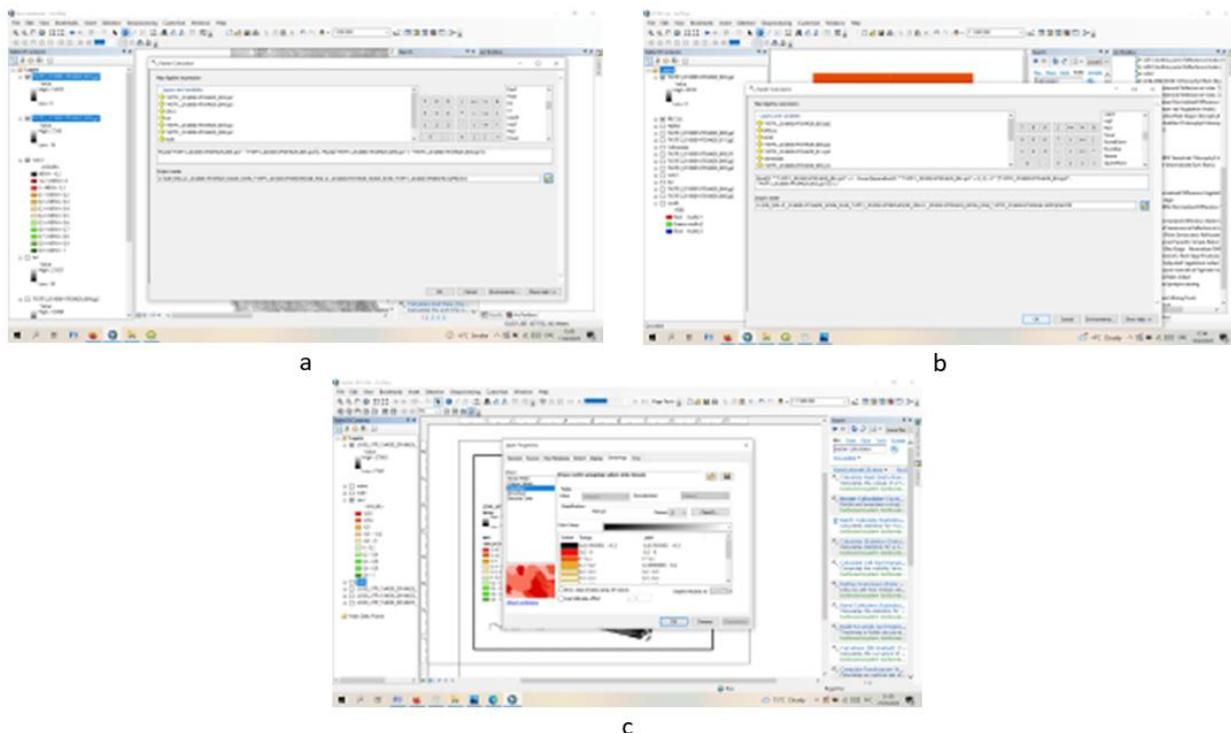


Figure 4. Index calculation and visualization interfaces in ArcGIS: a) NDRE computation using the Raster Calculator, b) SAVI computation using the Raster Calculator, and c) Symbology settings in Layer Properties for visualizing index values.

To configure the vegetation index layer, open the layer properties and set the desired number of classes, color scheme, and value range. Figure 4c showed the 'properties' window containing information about the symbology settings.

RESULTS AND DISCUSSION

The analysis of remote sensing and GIS technology data made it possible to determine the maximum vegetation index values for the studied agricultural area. The observations revealed maximum vegetation index values ranged from 0.7 to 0.8, indicating better soil fertility in those arable areas. However, the minimum values ranged from 0.1 to 0.3, which may suggest areas with lower fertility. The NDVI reflects the activity and health of the vegetation cover. Higher NDVI values also showed associations with more fertile soils and better growing conditions for crop plants (Mukhametov *et al.*, 2024). However, to achieve a more accurate assessment, the soil reflectance influence on NDVI also needs consideration.

The SAVI reflects the soil characteristics, such as mineral composition and moisture content, allowing a more precise evaluation of soil fertility. Higher SAVI values revealed better soil fertility. Higher NDMI values also emerged as associated with more fertile soils with better water retention capacity. The said index appeared to be a useful indicator for determining soil fertility and its agricultural potential. The NDRE index, which focused on the near-infrared spectrum, allows for the assessment of the physiological state of vegetation. Higher NDRE values reflected fertile soils and a healthier plant cover (Chebyshev *et al.*, 2024). One of the most common methods of obtaining the NDRE data was the satellite imagery, including sensors capable of capturing the red-edge and near-infrared wavelengths. These data can achieve processing and analysis using specialized software and GIS to produce NDRE maps and evaluate the vegetation condition.

The results demonstrated the significant potential of using remote sensing

and GIS technologies to assess the spatial and temporal variations in soil fertility, particularly in agricultural lands affected by human activities, such as the Kokzhon site in Southern Kazakhstan. By analyzing the data obtained from satellites Sentinel-2 and Landsat-8 using key vegetation indices (NDVI, SAVI, NDMI, and NDRE), the study provided a detailed understanding of how different areas within the site vary in their capacity to support vegetation and, eventually, agricultural productivity. These results align with recent studies that focus on utilizing remote sensing in assessing and managing soil fertility (AbdelRahman *et al.*, 2021; Asgarova, 2023).

The high NDVI and NDRE index values (0.7–0.8) noted in some years of study, especially in 2018 and 2020, reflect the years with better soil fertility and vegetation health. Such higher values imply an integration of better climatic conditions, effective biological reclamation, and improved land management practices in those years. However, the low index values (0.1–0.3), specifically observed during 2016 and 2022, highlighted the areas with degraded soil quality and poor plant coverage, possibly caused by water deficit conditions, nutrient deficiency, and inefficient reclamation approaches. Such evidence also gained support from Li *et al.* (2021), whose study reported NDVI values proved positively correlated with climatic conditions.

This tendency of fluctuation emphasizes the need to consider seasonal and interannual variations in soil fertility. One chief advantage of remote-sensing technology is being able to identify variations across different time periods. Particularly between spring and autumn, seasonal variations may highlight the deviations in soil moisture, crop phenology, and land use intensity. Combining several vegetation indices also helped to clarify the agroecosystem in more subtle ways. This practice corresponds with the research of Haseeb *et al.* (2025), who integrated five remote sensing indices to predict yield and underlined the need for integrating various indices for correct predictions and monitoring.

Methodologically, the study effectively showed how useful it is to combine the datasets of both satellites Sentinel-2 and

Landsat-8 to raise the observation frequency and resolutions. Using raster-based calculations in ArcGIS and visualizations in QGIS by other researchers also provided a replicable workflow. Moreover, a technically wise choice to improve index computation dependability is the use of the 'nearest neighbor' resampling technique to normalize various spatial resolutions between satellite bands. These findings were consistent with past studies of Belal *et al.* (2021), Zhang *et al.* (2024), and Abbaszad *et al.* (2023). They also underlined the values of using datasets from the satellites Sentinel-2 and Landsat-8 in evaluating soil fertility and precision agriculture through raster-based calculations.

However, the relatively small size of the analyzed area (110 m × 115 m) is a limitation to this study and raises questions about the scalability of the results. Although the results are valid for this specific site, further studies across a broader region are essential to confirm the general applicability of the methods and findings. Additionally, while remote sensing provides powerful indirect indicators, the absence of validation data, such as physical soil samples and crop yield records, limits the ability to precisely calibrate and interpret the satellite-derived indices. Including such data in future research would enhance accuracy and support more robust decision-making (Hagn *et al.*, 2024). Notwithstanding these limitations, the results have clear ramifications for environmental and agricultural players. These approaches help to map soil fertility, thus enabling focused interventions, supporting sustainable land use planning, and post-mining recovery.

Furthermore, several directions of future research with predictive modeling of soil fertility under various land-use and climate scenarios could possibly take place by merging machine learning with remotely sensed time series data (Pokhariyal *et al.*, 2023). Higher-resolution images would also make fine-scale study possible. Likewise, broadening the research to investigate the effects of particular land management activities, such as crop rotation techniques, irrigation schedules, and organic amendments on the vegetation indices,

could help better link the observed satellite signals with on-the-ground operations.

In conclusion, the presented study reinforces the values of geospatial technologies in modern agricultural management and land restoration. By combining the remote sensing with GIS analysis and appropriate vegetation indices, this provides a powerful and scalable toolset for monitoring and improving soil fertility in vulnerable and variable landscapes such as those found in Southern Kazakhstan (Vaslavskaya *et al.*, 2025).

CONCLUSIONS

The foregoing investigation used remote sensing and GIS technologies to assess the soil fertility in the Sarysu District, Kazakhstan, revealing seasonal patterns in vegetation index values, with peaks in 2016, 2018, 2020, and 2022. The higher NDVI values (0.7–0.8) indicated favorable conditions for crop growth, while lower values (0.1–0.3) highlighted areas necessitating reclamation and improvement. Satellite data confirmed the region's general suitability for agriculture. The application of GIS allows for targeted soil management and supports sustainable farming practices. Continued investment in GIS infrastructure and stakeholder involvement is essential for long-term land use optimization.

REFERENCES

- Abbaszad P, Asadzadeh F, Rezapour S, Aqdam KK, Shabani F (2023). Evaluation of Landsat 8 and Sentinel-2 vegetation indices to predict soil organic carbon using machine learning models. *Model Earth Syst. Environ.* 10(2): 2581–2592. <https://doi.org/10.1007/s40808-023-01916-x>.
- AbdelRahman MAE, Hegab RH, Yossif TMH (2021). Soil fertility assessment for optimal agricultural use using remote sensing and GIS technologies. *Appl. Geomat.* 13(4): 605–618. <https://doi.org/10.1007/s12518-021-00376-1>.
- Asgarova M (2023). The assessment and management of soil fertility using GIS and remote sensing. *Adv. Land Manag.* 3(2): 97–106.

- Bauyrzhan, T., Natalya, K., Zarina, I., Andrey, K., Meruert, K., Karime, A., & Aliya, B. (2022). Phytochemical Study of *Crambe Tatarica* Sebeok, A Promising Source Of Medicinal Plant Extracts. *Pakistan Journal of Botany*, 54(2), 653–666. [https://doi.org/10.30848/PJB2022-2\(38\)](https://doi.org/10.30848/PJB2022-2(38))
- Belal AA, El-Ramady H, Jalhoum M, Gad A, Mohamed ES (2021). Precision farming technologies to increase soil and crop productivity. In: M. Abu-hashim, F. Khebour Allouche, and A. Negm (Eds.). *Agro-environmental sustainability in MENA regions*. Springer, Cham, pp. 117–154. https://doi.org/10.1007/978-3-030-78574-1_6.
- Bureau of National Statistics. Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2019). Environmental statistics in Kazakhstan. <https://stat.gov.kz>.
- Chebyshev N, Ansabayeva A, Mironova E, Kazak A (2024). The distribution of *Fusarium* in barley crops: PCR. *Polish J. Env. Stud.* 33(2): 1559–1568.
- EOSDA Crop Monitoring (n.d.). Available: <https://crop-monitoring.eos.com/main-map/fields/9196845?viewedField=9196845>.
- Google Earth Engine Explorer (n.d.). Available: <https://explorer.earthengine.google.com>.
- Haseeb M, Tahi Z, Mahmood SA, Tariq A (2025). Winter wheat yield prediction using linear and nonlinear machine learning algorithms based on climatological and remote sensing data. *Inf. Process. Agric.* <https://doi.org/10.1016/j.inpa.2025.02.004>.
- Izbastina, K., Kurmanbayeva, M., Bazargaliyeva, A., Ablaihanova, N., Inelova, Z., Moldakaryzova, A., Mukhtubaeva, S., Turuspekov, Y. (2020). Morphological, anatomical structure and molecular phylogenetics of *anthemis troztkiana* claus. *Pakistan Journal of Botany*, 52(3), 935–947. [https://doi.org/10.30848/PJB2020-3\(39\)](https://doi.org/10.30848/PJB2020-3(39))
- Kataev MYu, Butin SM (2019). Sravnitel'nyy analiz metodov povysheniya prostranstvennogo razresheniya sputnikovykh dannykh LANDSAT-8 (Comparative analysis of the methods of increasing the spatial resolution of satellite data LANDSAT-8). *Proc. Tomsk State Univ. Control Syst. Radioelectr.* 22(2):67–71. <http://dx.doi.org/10.21293/1818-0442-2019-22-2-67-71>.
- Khanal S, Kc K, Fulton JP, Shearer S, Ozkan E (2020). Remote sensing in agriculture — accomplishments, limitations, and opportunities. *Remote Sens.* 12(22): 3783. <https://doi.org/10.3390/rs12223783>.
- Laiskhanov S, Smanov Z, Kaimuldinova K, Aliaskarov D, Myrzaly N (2023). Study of the ecological and reclamation condition of abandoned lands and their development for sustainable development goals. *Preprints* <https://doi.org/10.20944/preprints202307.2008.v1>.
- Lal R, Bouma J, Brevik E, Dawson L, Field DJ, Glaser B, Hatano R, Hartemink AE, Kosaki T, Lascelles B, Monger C, Muggler C, Ndzana GM, Norra S, Pan X, Paradelo R, Reyes-Sánchez LB, Sandén T, Singh BR, Spiegel H, Zhang J (2021). Soils and sustainable development goals of the United Nations: An International Union of Soil Sciences perspective. *Geoderma Reg.* 25: e00398. <https://doi.org/10.1016/j.geodrs.2021.e00398>.
- Li P, Wang J, Liu M, Xue Z, Bagherzadeh A, Liu M (2021). Spatio-temporal variation characteristics of NDVI and its response to climate on the Loess Plateau from 1985 to 2015. *CATENA* 203: 105331. <https://doi.org/10.1016/j.catena.2021.105331>.
- Mukhametov A, Ansabayeva A, Efimov O, Kamerova A (2024). Influence of crop rotation, the treatment of crop residues, and the application of nitrogen fertilizers on soil properties and maize yield. *Soil Sci. Soc. Am. J.* 88(6): 2227–2237.
- Nikonorova IV, Gumenyuk AE, Pivovarov IA (2021). Otsenka sostoyaniya plodorodiyi pochv sel'skokhozyaystvennykh ugodiy s ispol'zovaniyem GIS-tekhnologiy (Assessment of soil fertility conditions of agricultural lands using GIS technologies). *Adv. Curr. Nat. Sci.* 12: 173–178. <https://doi.org/10.17513/use.37755>.
- Pavlova AI (2021). Primeneniye vegetatsionnykh indeksov dlya tsifrovogo pochvennogo kartografirovaniya na osnove kosmicheskikh snimkov Sentinel-2 (Application of vegetation indices for digital soil mapping based on Sentinel-2 satellite images). *Siberian J. Life Sci. Agric.* 3(6): 119–131. <http://dx.doi.org/10.12731/2658-6649-2021-13-6-119-131>.
- Phiri D, Simwanda M, Salekin S, Nyirenda VR, Murayama Y, Ranagalage M (2020). Sentinel-2 data for land cover/use mapping: A review. *Remote Sens.* 12(14): 2291. <http://dx.doi.org/10.3390/rs12142291>.
- Pokhariyal S, Patel NR, Govind A (2023). Machine learning-driven remote sensing applications for agriculture in India—a systematic review. *Agronomy* 13(9): 2302. <https://doi.org/10.3390/agronomy13092302>.

- Shaimerdenova AA (2022). Monitoring sostoyaniya zemel'nykh resursov i ikh otsenka v usloviyakh tekhnogenogo vozdeystviya na primere Zhambylskoy oblasti (Monitoring and assessment of land resources under technogenic impact: A case study of Zhambyl Region). Dissertation for the degree of Doctor of Philosophy, Kazakh National Agrarian Research University, Almaty, pp. 83–85, 95.
- Silver WL, Perez T, Mayer A, Jones AR (2021). The role of soil in the contribution of food and feed. *Phil. Trans. R. Soc. B* 376: 20200181. <https://doi.org/10.1098/rstb.2020.0181>.
- Tabunshchik VA, Petlyukova EA, Khitrin MO (2018). Primeneniye sputnikovykh snimkov Sentinel-2 dlya analiza zemel' ispol'zuyemykh v sel'skom khozyaystve (na primere Razdol'nenskogo rayona Respubliki Krym) (The use of satellite imagery Sentinel-2 for analysis of land used in agriculture [for example Razdolnensky District of the Republic of Crimea]). *Trudy Karadagskoy nauchnoy stantsii im. T.I. Vyazemskogo - prirodnoy zapovednika RAN* 1(5): 45–57. <http://dx.doi.org/10.21072/eco.2021.05.05>.
- Toktar M (2022). Results of reclamation of man-made dumps of phosphorite deposits in the semi-desert zone of Kazakhstan. Almaty, pp. 4, 8.
- UNDRR (2023). Soil degradation. Available: <https://www.undrr.org/quick/78502>.
- Vaslavskaya I, Vaslavskiy Y, Stepanova D, Kochetkov E, Trukhanov S, Shakhov D. (2025). Implementation of ESG principles in business as a tool for managing environmental and social risks. *Int. J. Ecosyst. Eco. Sci.* 15(2): 63–70.
- Zhang M, Aqdam MK, Fadel HA, Wang L, Waheeb K, Kadhim A, Hekmati J (2024). Evaluation of soil fertility using combination of Landsat 8 and Sentinel-2 data in agricultural lands. *Environ. Monit. Assess.* 196(2): 131. <https://doi.org/10.1007/s10661-024-12301-1>.