ASSESSMENT OF SOIL SALINITY USING THE NDVI VEGETATION INDEX BASED ON REMOTE SENSING DATA

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Abstract. This article examines the assessment of soil salinity in the irrigated meadow-sierozem soils of the E. Qahhorov agricultural area in Khovos District, Syrdarya Region, based on remote sensing data. Sentinel-2 satellite data covering the period from 2016 to 2025 were used in the study, and the Normalized Difference Vegetation Index (NDVI) was calculated using geospatial technologies. The long-term and seasonal dynamics of vegetation cover in the study area were analyzed, and the relationship between NDVI values and salinity levels was assessed. Based on an NDVI classification adapted to the natural conditions of the study area, criteria for the indirect assessment of soil salinity levels were proposed. The results demonstrated that the NDVI can be effectively used as an indicator for determining the impact of soil salinity on vegetation cover, assessing salinity spatially, and conducting long-term monitoring of salinity in irrigated agricultural lands.

Keywords: soil salinity, remote sensing, NDVI, Sentinel-2, vegetation index, irrigated meadow-sierozem soils, geographic information systems.

High levels of soil salinity adversely affect crop growth and productivity, ultimately leading to land degradation. Soil salinity is considered one of the most important factors contributing to the degradation of land resources. This process often occurs in combination with intensified soil erosion, inappropriate agricultural practices, the consequences of mining activities, overgrazing, and deforestation [4,5].

Soil salinity is a particularly serious environmental problem in arid and semi-arid regions. The occurrence of salinity is associated not only with natural factors but also with direct human economic activities, and it develops in two forms: natural and secondary salinization [3,6].

Remote sensing has fundamentally transformed the ability to monitor dynamic processes occurring in soils and, more broadly, across the Earth system. These processes encompass a wide range of phenomena, from natural environmental changes to anthropogenic impacts. Spectral indices play an important role in remote sensing and have been used since the era of Landsat-1, the first Earth observation satellite launched for civilian purposes in 1972. Spectral indices use the spectral characteristics of objects to describe and even quantitatively assess specific properties of different targets.

By analyzing the spectral reflectance of salts on the soil surface and vegetation that has undergone adverse changes as a result of salinity, various salinity and vegetation indices have been developed to quantitatively assess the effects of salinity on soils and vegetation under different environmental conditions [1].

The salinization process not only alters the physicochemical properties of soil but also significantly affects the condition of vegetation cover. Therefore, in assessing salinity, considerable attention has been given not only to the specific spectral characteristics of soils but also to indices that characterize vegetation conditions. The Normalized Difference Vegetation Index (NDVI) is one of the most widely used vegetation indices and is employed to assess green biomass and photosynthetic activity of vegetation.

As a result of soil salinization, the osmotic pressure of the soil solution increases, which significantly restricts water uptake by plant root systems. Consequently, physiological stress develops in plants, leading to reduced vegetative growth and decreased biomass accumulation. Under saline conditions, a reduction in the amount of chlorophyll pigments in plants is observed, resulting in decreased photosynthetic activity. These physiological changes are also clearly reflected in the spectral reflectance characteristics of vegetation.

The chlorophyll content of vegetation strongly influences data acquired in the visible and near-infrared portions of the spectrum. Spectral data from the visible and near-infrared regions (400–2500 nm) are also associated with the water content of plant tissues. Analysis of spectral data within the 400–2500 nm wavelength range, together with indices calculated from these data, enabled the identification, assessment, and mapping of soil salinity levels in the study area.

Materials and Methods

The study utilized remote sensing data covering the Khovos District of Syrdarya Region for the period from 2016 to 2025. The satellite data required for the study were obtained from the open-access Copernicus Data Space Ecosystem platform and ArcGIS 10.8.1

Several preprocessing procedures were performed to prepare the acquired satellite imagery for subsequent analysis. To ensure a unified spatial coordinate system for all raster and vector layers, the data were reprojected to the UTM Zone 42N projection based on the WGS 1984 geodetic datum. The satellite images were clipped to the predefined boundaries of the study area, and only the portions corresponding to the agricultural area under investigation were retained.

The study area comprised the irrigated meadow-sierozem soils of the E. Qahhorov agricultural area in Khovos District, Syrdarya Region.

Results and Discussion

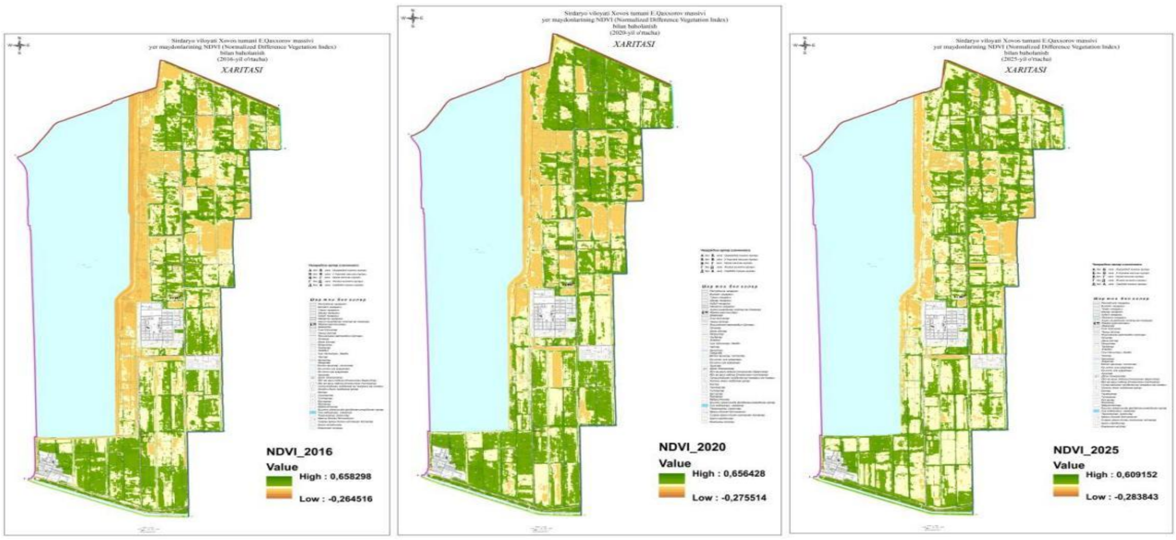
Within the framework of the study, the Normalized Difference Vegetation Index (NDVI) was calculated using satellite imagery acquired during the period from 2016 to 2025, and its long-term and seasonal dynamics were analyzed.

NDVI values range from −1 to +1. In general, negative values correspond to water surfaces, artificial structures, bare rocks, clouds, and snow cover. The index was calculated using the following formula:

NDVI = (NIR − Red) / (NIR + Red)

where ***NIR*** represents the near-infrared band and ***Red*** represents the red band.

In addition to the spatial characteristics of the study area, the application of indices is also directly influenced by the temporal factor. Not only soil parameters corresponding to a specific time period but also the overall temporal range of the data should be carefully considered, as different soil properties vary considerably in their degree of temporal dependence [2]. Accordingly, multi-year (2016, 2020, and 2025) satellite imagery was analyzed during the study, and changes in vegetation cover dynamics and their temporal development trends were assessed (Figure 1).



2016 year 2020 year 2025 year

Figure 1. Multi-year NDVI monitoring of the study area

According to the analysis results, the proportion of vegetation cover in the study area accounted for 67.28% of the total area in 2016, increasing to 71.94% in 2020. By 2025, however, the proportion of vegetation-covered area had decreased to 46.36%. These results indicate that vegetation cover dynamics in the study area varied considerably over the years. This variation can be attributed to the natural and climatic conditions of the area, limited precipitation, high rates of evapotranspiration, and increasing anthropogenic pressure resulting from human economic activities.

The highest vegetation index values were observed during the spring and summer seasons, ranging from 0.4 to 0.61, and covered a relatively small area, amounting to 44.91 ha in 2025. Toward the end of the growing season, the adverse effect of salinity on vegetation cover intensifies due to high evapotranspiration and the accumulation of salts on the soil surface. Consequently, a decrease in NDVI values was observed during the autumn season, allowing saline areas to be distinguished more clearly. For the study area, the NDVI coefficient values recorded across different years and seasons ranged from −0.24 to 0.61.

Based on the obtained results, NDVI values were classified according to the corresponding levels of soil salinity (Table 1).

Table 1.

NDVI Classification Adapted for the Assessment of Soil Salinity Levels in the E. Qahhorov Agricultural Massif

Existing Classification		**Proposed Classification for Assessing Soil Salinity Levels**	
Index value	**Classes**	**Index value**	**Classes**
-1-0	Water surfaces, artificial structures, rocks, clouds, and snow cover	-1-0	Water surfaces or other land cover
0-0,1	Bare land	0-0,1	Very strongly saline
0,1-0,2	Sparsely developed vegetation	0,1-0,2	Strongly saline
0,2-0,4	Moderately developed vegetation	0,2-0,3	Moderately saline
0,4-0,6	Well-developed vegetation	0,3-0,4	Slightly saline
0,6-1,0	Very well-developed vegetation	0,4-1,0	Non-saline

The NDVI classification developed and adapted to the natural conditions of the study area for the purpose of assessing soil salinity provides an opportunity for the rapid identification, spatial assessment, and monitoring of soil salinity within the study area.

Conclusion

In conclusion, the NDVI index proved to be an important indirect indicator for identifying and assessing soil salinity. With increasing salinity, physiological stress in plants intensifies, while reductions in chlorophyll content, photosynthetic activity, and biomass are reflected in decreased NDVI values. The results of the study showed that NDVI values characterize the vegetation condition of the study area and confirmed a significant reduction in vegetation cover in saline areas.

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