DOI: 10.35595/2414-9179-2024-2-30-171-180

Sabine A. Akzhigit[1], Marzhan M. Toguzova[2], Almagul K. Abdygalieva[3], Zhanat Kanatuly[4], Dauren Zh. Kulenov[5]

MONITORING OF AGRICULTURAL LAND IN THE ARAL SEA REGION USING REMOTE SENSING DATA OF THE EARTH

ABSTRACT

The article researches the use of satellite monitoring to analyze changes in vegetation and soil cover of agricultural land in the Aral Sea Region, located in Kyzylorda Region, on the border of Kazakhstan and Uzbekistan, using geographic information systems (GIS). These technologies are widely used to monitor natural disasters, agriculture, forest and water resources and analyze environmental pollution and predict its effects. The purpose of the study is to assess and analyze the impact of environmental degradation on agricultural land using Earth remote sensing data. The methodology includes analyzing time series of space images to calculate vegetation indices, which makes it possible to identify the dynamics of changes and assess the level of land degradation. Landsat-8 space images data for different time intervals from 2014 to 2023 were used. The object of the study was agricultural plots in Kazaly district, located on the territory of the Aral Sea. Analysis and assessment of changes in the study area were carried out using Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Salinity Index (NDSI) on Landsat satellite images. Data processing was performed in the EOSDA Land Viewer and QGIS software environment. As a result of satellite data processing, maps of the dynamics of agricultural crop development using NDVI, maps of water availability in the study area using NDWI, and maps assessing the degree of salinization of the soil cover were obtained. The obtained results allow us to understand more deeply the scale of the Aral Sea ecological problem and contribute to the development of actual effective strategies of adaptation and restoration of the affected agroecosystems.

KEYWORDS: satellite monitoring, space images, environmental problems, remote sensing of the earth, Aral Sea

INTRODUCTION

The use of satellite monitoring technologies of vegetation cover is one of the most successfully developed areas of scientific and applied research of the Earth from space. It is important to note the diversity and different scales of objects studied in this process — from microscale, defined by the size of individual plants, to regional and global, defined by the size of climatic zones and continents. Earth remote sensing data have a wide range of uses. They are used

[1] D. Serikbayev East Kazakhstan Technical University, School of Earth Sciences, 19, Serikbayeva str., Ust-Kamenogorsk, Republic of Kazakhstan, 070004, *e-mail:* **esimkanova8@gmail.com**

[2] D. Serikbayev East Kazakhstan Technical University, School of Earth Sciences, 19, Serikbayeva str., Ust-Kamenogorsk, Republic of Kazakhstan, 070004, *e-mail:* **marzhan123@mail.ru**

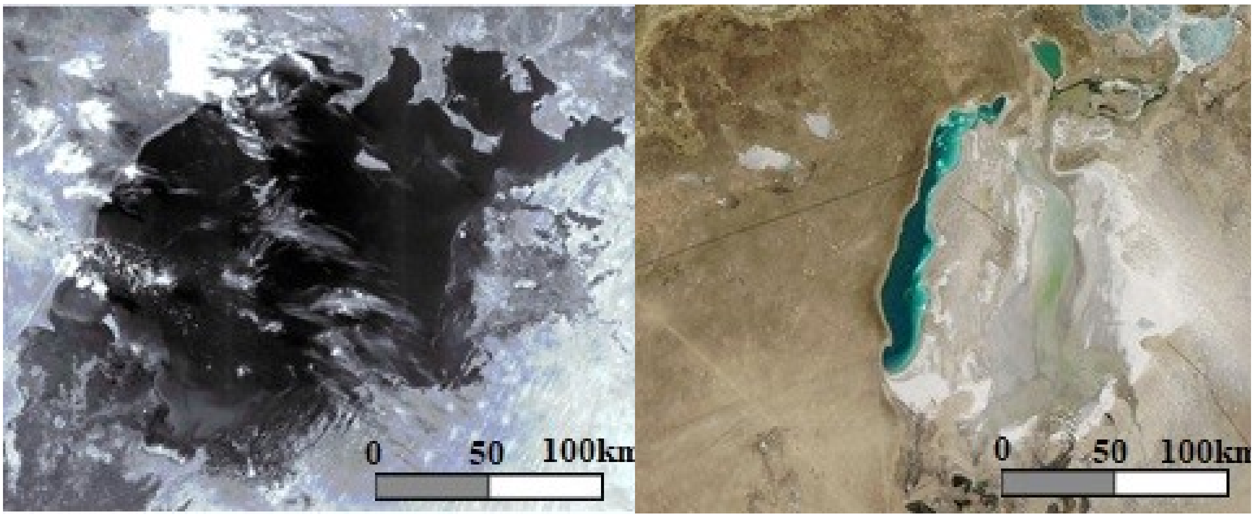
[3] D. Serikbayev East Kazakhstan Technical University, School of Earth Sciences, 19, Serikbayeva str., Ust-Kamenogorsk, Republic of Kazakhstan, 070004, *e-mail:* **alma-abdygalieva@mail.ru**

[4] D. Serikbayev East Kazakhstan Technical University, School of Earth Sciences, 19, Serikbayeva str., Ust-Kamenogorsk, Republic of Kazakhstan, 070004, *e-mail:* **zhanat-12345@mail.ru**

[5] D. Serikbayev East Kazakhstan Technical University, School of Earth Sciences, 19, Serikbayeva str., Ust-Kamenogorsk, Republic of Kazakhstan, 070004, *e-mail:* **dauren.kulenov@yandex.ru**

in monitoring studies and threat analyses in emergency situations [*Rakhymberdina* et al., 2022; *Apshikur* et al., 2023], in agriculture — for operational control of crop condition as well as modeling and forecasting of crop yields both on regional and local scales [*Rakhymberdina* et al., 2022; *Toguzova* et al., 2022], space images are widely used in the study of forest communities [*Polyakova* et al., 2023], landscape structure [*Franklin* et al., 2023], as well as for analyzing the degree of pollution of land and water resources, assessment of anthropogenic and technogenic impact on the environment [*Shevyrev* et al., 2013; *Semeniaka* et al., 2022], built three-dimensional models using remote sensing data allow to analyze and predict environmental impacts [*Toguzova* et al., 2016; *Jurado* et al., 2022; *Toguzova* et al., 2022]. Remote sensing is the most suitable method to conduct monitoring of land degradation, salinization processes, desertification, dust storms, especially in arid areas because it easily covers large areas with high spatial and temporal resolution [*Albarakat* et al., 2018; *Asfaw* et al., 2018; *Kim*, 2020]. Thus, satellite images provide detailed multispectral information about land surface features, which proves to be invaluable for a wide range of applications.

One of the most important environmental problems of Central Asia is the problem of the Aral Sea [*Ginzburg* et al., 2010; *Petrov*, 2021; *Teslenok*, 2023]. Over the last fifty years, the area of the Aral Sea has shrunk six times, the territory has been covered with desert, which has contributed to sand and dust storms, salinization of adjacent territories, which destroy the local ecosystem and make the Aral Sea Region uninhabitable (Fig. 1).



a b

Fig. 1. Changes in the territory of the Aral Sea in satellite images; a — in 1960, b — in 2023

The use of remote sensing tools and methods, as well as GIS technologies allow to assess the dynamics of vegetation cover changes in adjacent territories, to determine the degree of degradation and desertification. The results obtained can be used to develop science-based strategic decisions aimed at supporting measures to preserve and restore the Aral Sea ecosystem.

The aim of the study is to analyze and monitor the Aral Sea territory using multi-temporal satellite images based on the calculation of vegetation indices NDVI (normalized relative vegetation index), NDSI (normalized salinity index) and NDWI (normalized water difference index) with the involvement of methods of their processing, modeling, analysis and display in EOSDA LandViewer and QGIS software environment.

RESEARCH MATERIALS AND METHODS

Various methods and tools of remote sensing are used to study the Aral Sea problems and analyze the dynamics of degradation processes. In studies [*Reddy* et al., 2018] used high-resolution remote sensing data from Cartosat-1 and Cartosat-2 satellites and their integration with digital elevation models, as well as applied light detection and ranging systems with ground data, which allows monitoring of degraded lands at the local level. Scientist's research [*Kumsa* et al., 2022] on land degradation in the Aral Sea was based on the processing of Landsat-7 and Landsat OLI 8 satellite images for the years 2000 and 2022. The maximum likelihood method of supervised classification was used to analyze satellite images. To analyze water level changes in the Aral Sea, scientists [*Khorshiddoust* et al., 2022] used Moderate Resolution Imaging Spectroradiometer (MODIS) images and Landsat-7 and 8 satellite images, and applied object classification of images into six classes. Shortwave infrared (SWIR) atmospheric correction algorithm was applied to obtain normalized brightness spectra of the images. To analyze vegetation cover, soil, and water scientists actively use vegetation indices [*Kravtsova* et al., 2021; *Kurganovich* et al., 2022], which allow tracking changes in vegetation cover, water level, soil condition and other parameters. Information on the extent and spatial distribution of different types of degraded land is necessary for strategic planning and assessment of degraded land development. The use of remote sensing techniques makes it possible to assess land degradation and its spatial distribution at reasonable cost and with greater accuracy over large areas. Remote sensing data provide timely, accurate and reliable information on degraded land at regular intervals in a cost-effective manner. The use of space-based multispectral data has shown its potential in providing information on the nature, extent, spatial distribution and magnitude of different types of degraded land. Land degradation assessment and monitoring using remote sensing offers several advantages such as data consistency, near real-time reporting and a source for spatial data. The use of remotely sensed data is an effective tool for analyzing and monitoring degraded lands in the Aral Sea.

The study used multi-temporal archived remote sensing data from Landsat-8 satellite. Landsat-8 channels provide data in different spectral bands for calculating indices. Landsat images can be found in the public domain on the NASA website. Multispectral space images for July in 2014, 2017, 2020, 2023 were selected for the study. The resolution of the images is 30 meters. All images were pre-enhanced with filters and freed from atmospheric influence. High resolution Google Earth remote sensing images served as auxiliary verification data. Analysis and assessment of changes in the study area was carried out using normalized difference vegetation index, normalized difference water index and normalized salinity index on Landsat satellite images. Data processing was performed in the EOSDA Land Viewer and QGIS software environment.

RESEARCH RESULTS AND DISCUSSION

To analyze and monitor the state of the adjacent lands of the Aral Sea, remote sensing data were used as a basis for data extrapolation to trace the change in vegetation cover over time. Fig. 2 presents the study area, a plot of 10,634.4 ha in the Aral Sea basin in the Kazaly District. This area is used for agriculture. The space images were interpreted using an automated method to calculate vegetation indices, which consists of extracting green vegetation using a simple arithmetic transformation. The assessment of the presence and condition of vegetation in the study area was determined through a standardized NDVI index, which is also used for monitoring drought, water surface, monitoring and forecasting agricultural production. The formula (1) for determining NDVI is as follows:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1),$$

where NIR and RED are the red and near-infrared channels of Landsat-8, respectively.

As a result, the following results were obtained (Fig. 3).

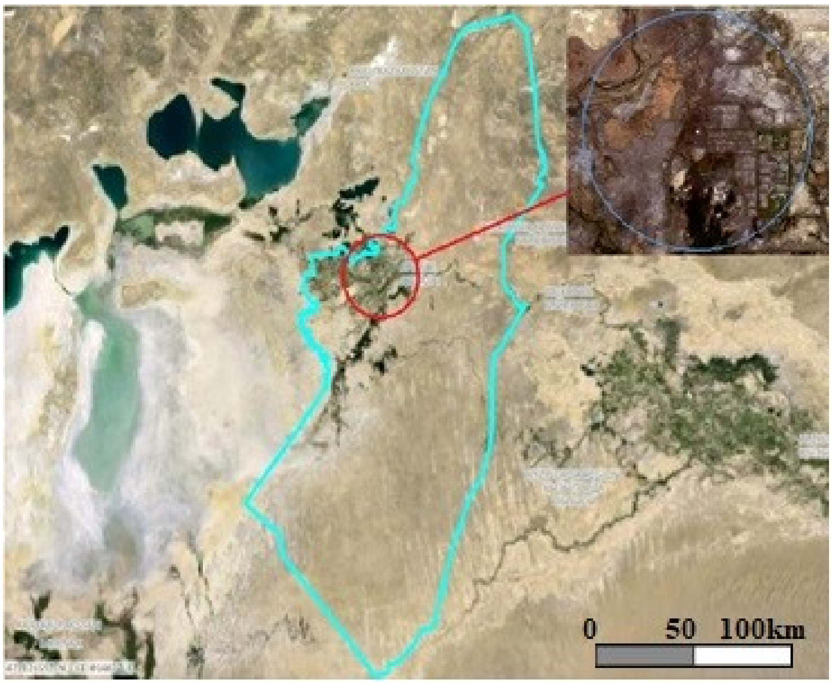


Fig. 2. The studied area in the Kazaly District

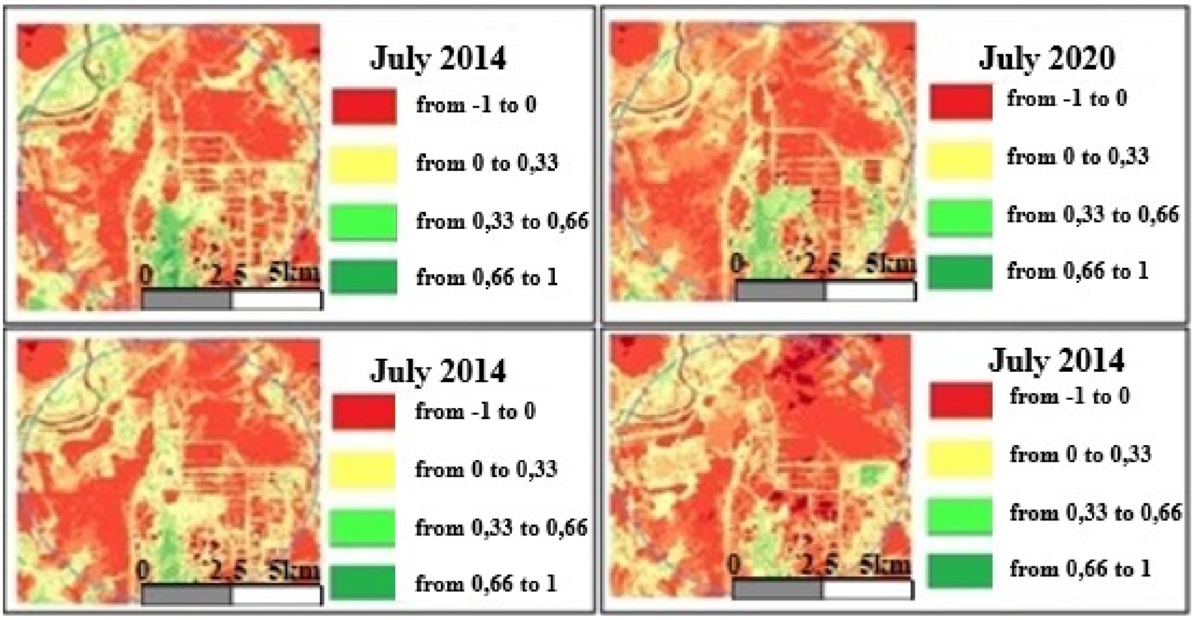


Fig. 3. Results of NDVI vegetation index calculation in the study area

NDVI analysis showed that the largest area of the study site (more than 50 %) has low index values (from −1 to 0.33). This indicates absence or weak vegetation, which may be caused by soil salinity, drought or degradation of vegetation cover. About 30 % of the area has NDVI values between 0.33 and 0.66, indicating moderate vegetation density. Such areas may be water or nutrient deficient. Only about 20 % of the territory is characterized by high NDVI values (from 0.66 to 1), which corresponds to dense vegetation cover with high productivity. However, this indicator has been steadily decreasing since 2014. Based on the obtained data, a graph (Fig. 4) was drawn up showing the distribution of the area of the study land plot by NDVI value ranges. This graph not only illustrates the current state of vegetation, but can also serve as a basis for the development of sustainable farmland management strategies to minimize the negative impact of abiotic stressors and improve the agro-ecological situation in the region.

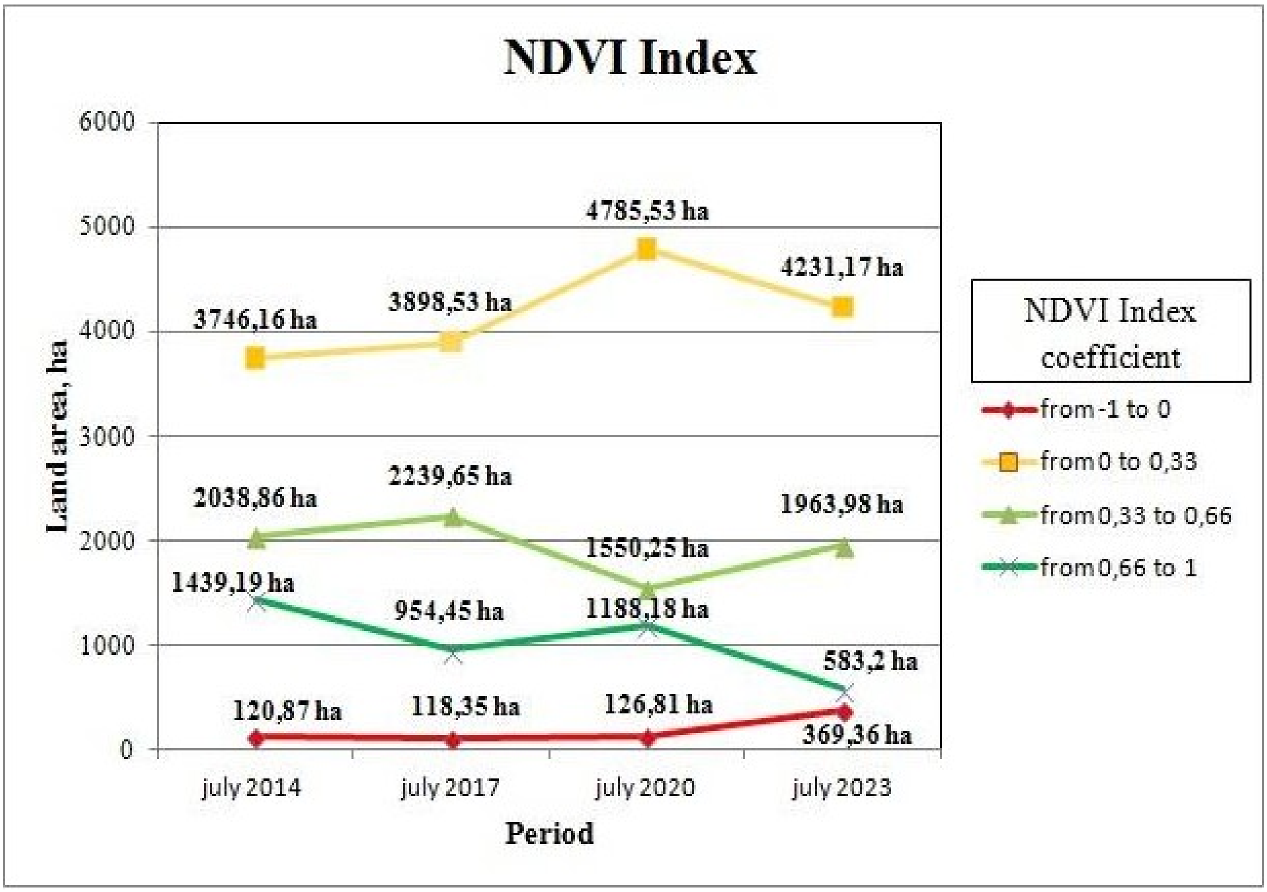


Fig. 4. Distribution of areas of the studied land plot by ranges of NDVI values

NDWI and NDSI indices were investigated to assess the state of vegetation and soil salinity in the study area. Determination of these indices provides additional information on factors limiting crop productivity. Normalized Difference Water Index is an index used to estimate the moisture content of vegetation or land surface based on the analysis of remote sensing satellite image data. The formula (2) for determining NDWI is as follows:

$$NDWI = (Green - NIR) / (Green + NIR) \quad (2),$$

where NIR and Green are the green and near-infrared channels of Landsat-8, respectively.

NDWI index values (Fig. 5) correspond to the following ranges: −1 to −0.3 correspond to arid, non-wet soils; −0.3 to 0 moderate drought, non-wet soils; 0 to 1 flooded, wet soils, water surfaces.

A visual representation of the distribution of land parcels across these ranges is presented in Fig. 6, which shows the area of land plots falling into each of the NDWI categories.

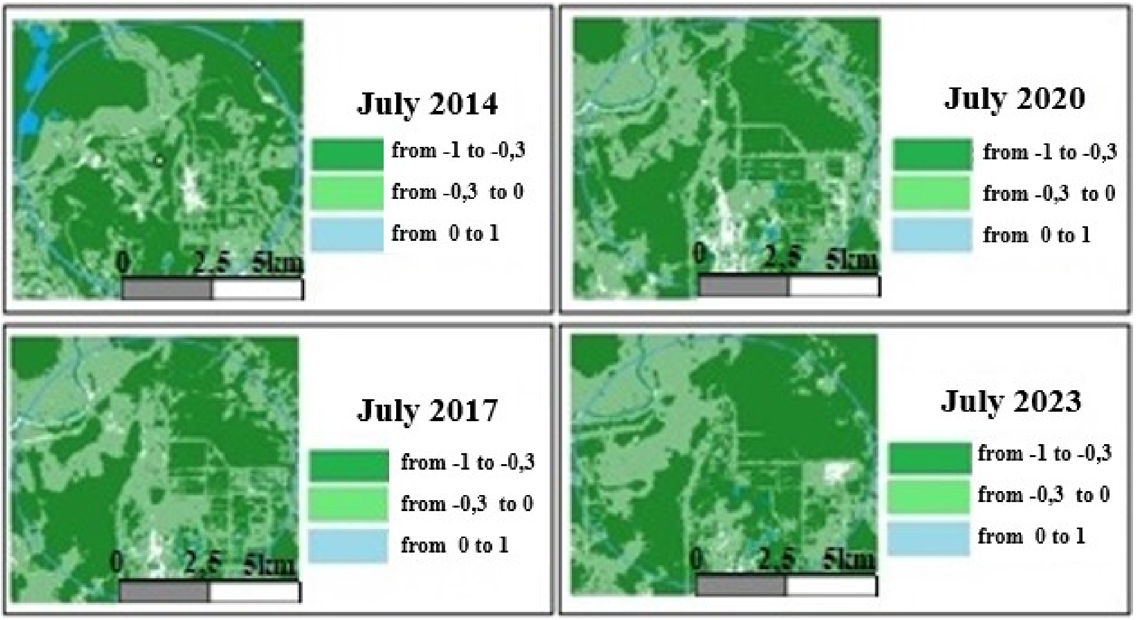


Fig. 5. Results of NDWI vegetation index calculation in the study area

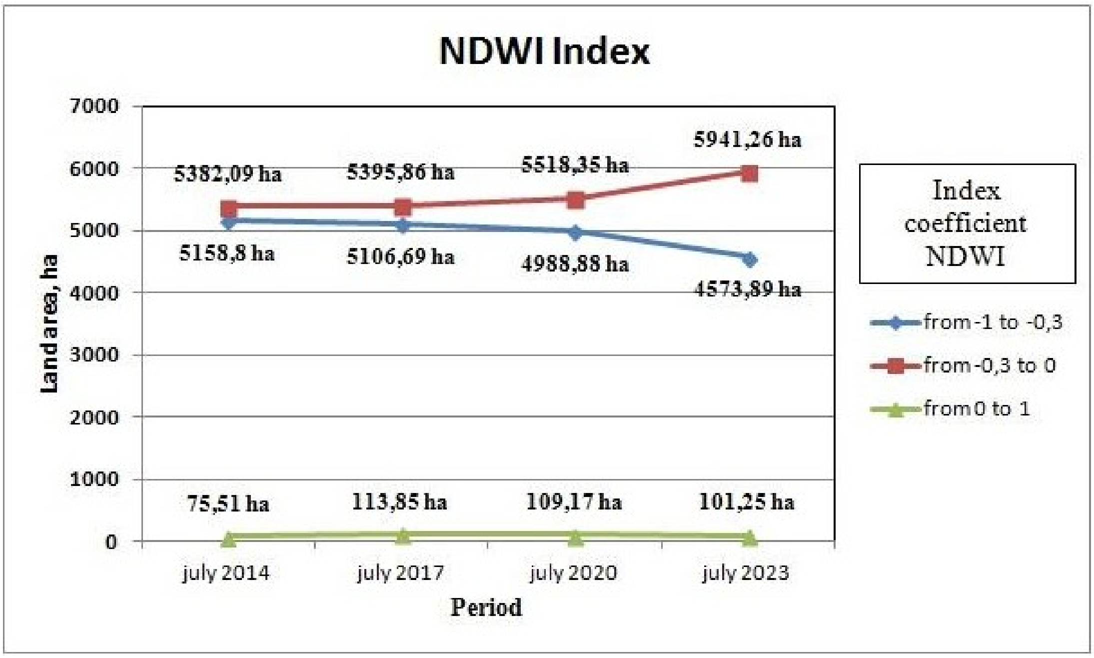


Fig. 6. Distribution of areas of the studied land plot by ranges of NDWI values

These studies show that over the last 10 years (2014–2023), the Aral Sea coastal zone has experienced steady degradation of vegetation cover and deterioration of hydrological condition. Reduction of vegetation density is caused by soil salinization, drought and increased temperatures. These factors significantly reduce agro-productivity and biodiversity of the region. In addition, the results obtained using the water availability index (NDWI) confirm that most of the territory is characterized by aridity and the presence of non-water soils, i. e. dried up and moisture-depleted soils.

The Normalized Difference Salinity Index was used to quantify the degree of soil salinity in the study area. The formula (3) for determining the NDSI index is as follows:

$$NDSI = (RED - SWIR) / (RED + SWIR) \quad (3),$$

where RED is the pixel value in the red channel of the spectrum,
SWIR — pixel value in the short-wave infrared channel of the spectrum.

The NDSI index takes values in the range from −1 to 1, with values from −0.11 to 0 indicating a high degree of soil salinity. Analysis of the obtained data confirms the stable presence of saline areas in the study area (Fig. 7). The calculated values of normalized difference salinity index, ranging from −0.19 to 0.18, indicate a high degree of salinity in the study area. The combination of such natural factors as dry and hot weather, reduced humidity, soil dynamics, dust hygroscopicity, and granulometric composition of soils led to the formation of sand and salt deserts. The presence of these factors led to degradation and disappearance of vegetation on the territory adjacent to the Aral Sea, which is confirmed by the obtained values of vegetation index NDVI.

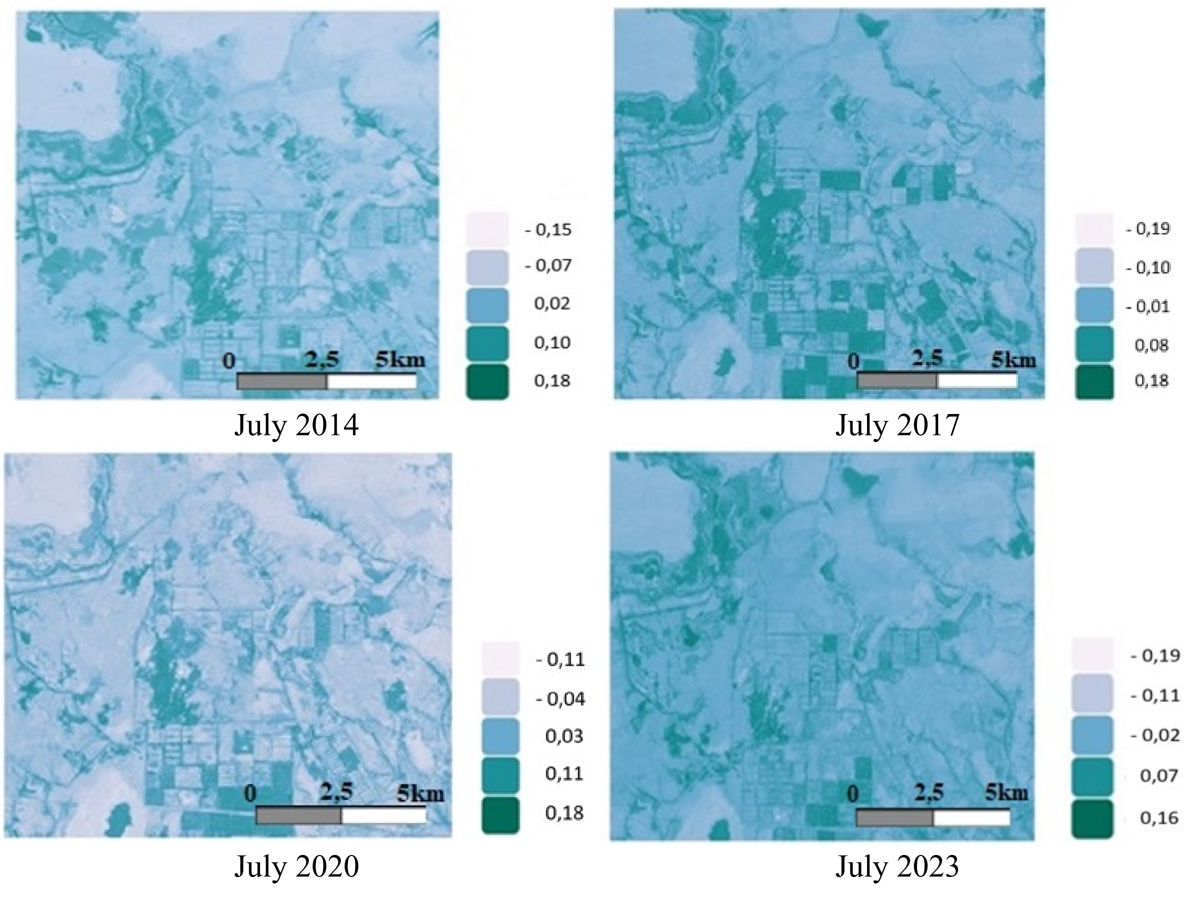


Fig. 7. Results of calculation of vegetation index NDSI in the study area

Based on the presented results of this study, the authors recommend integrating this method of calculating NDVI, NDWI and NDSI indices as monitoring tools for agricultural land plots, as well as in ecological disaster zones to prevent ecosystem destruction. At the moment, most of the tools for analyzing remote sensing data are in open access with open source code, which enables all landowners to monitor the condition of their fields, crops. All this together is a valuable tool on the way to more detailed and short-term monitoring of land plots online.

CONCLUSIONS

Remote sensing of the Earth is a key tool for continuous monitoring of the condition of the studied land. Regular analyses of space images using salinity (NDSI), vegetation cover (NDVI) and water availability (NDWI) indices will allow to:

- monitor the dynamics of salinization and land degradation;
- evaluate the efficiency of implemented land reclamation and restoration measure;
- identify new problems and take timely remedial action.

The research results showed that more than 50 % of the studied area has low NDVI values, indicating the absence or weak presence of vegetation. NDWI values showed that most of the territory is characterized by aridity and lack of water resources, while NDSI values indicated the stable presence of saline areas in the studied region. These results confirm that over the last 10 years (2014–2023) the coastal zone of the Aral Sea has undergone significant vegetation cover degradation and a deterioration of hydrological conditions. The decrease in vegetation density is caused by soil salinization, drought, and rising temperatures, which significantly reduce the agro-productivity and biodiversity of the region. The obtained data also confirm that most of the territory is characterized by aridity and dried soils, necessitating urgent measures to restore the ecosystem and adapt agricultural lands.

Thus, modern remote sensing technologies allow obtaining up-to-date and reliable information on the state of land with high spatial and temporal resolution. The use of satellite images in different spectral ranges expands opportunities for detailed analysis of various environmental components, such as soil, vegetation, and water resources. Introduction of automated systems for space images processing will optimize the monitoring process and increase its efficiency. Continuous monitoring of land condition using remote sensing methods is a prerequisite for the development and implementation of effective strategies to improve its condition and ensure sustainable use in the future.

REFERENCES

Albarakat R., Lakshmi V. Monitoring Dust Storms in Iraq Using Satellite. Sensors, 2019. No. 19. P. 3687. DOI: 10.3390/s19173687.

Apshikur B., Kurmangaliyev T. B., Goltsev A. G., Alimkulov M. M., Kapasov A. K. The method of multi-criteria analysis for determining the flood-hazardous area and the development of protective structures. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2023. P. 9–17. DOI: 10.5194/isprs-archives-xlviii-5-w2-2023-9-2023.

Asfaw E., Suryabhagavan K. V., Argaw M. Soil salinity modeling and Mapping Using Remote sensing and GIS: The case of Wonji sugar cane irrigation farm, Ethiopia. Journal of the Saudi Society of Agricultural Sciences, 2018. V. 17. Iss. 3. P. 250–258. DOI: 10.1016/j.jssas.2016.05.003.

Dubovyk O. The role of Remote Sensing in land degradation assessments: opportunities and challenges. European Journal of Remote Sensing, 2017. No. 50(1). P. 601–613. DOI: 10.1080/22797254.2017.1378926.

Franklin S., Lavigne M., Wulder M., Stenhouse G. Change detection and landscape structure mapping using remote sensing. The Forestry Chronicle, 2023. No. 78. P. 618–625. DOI: 10.5558/tfc78618-5.

Ginzburg A., Kostyanoy A., Sheremet N., Kravtsova V. Satellite monitoring of the Aral Sea Region. Problems of Ecological Monitoring and Ecosystem Modeling, 2010. V. 23. P. 150–193.

Jurado J., López A., Pádua L, Sousa J. Remote sensing image fusion on 3D scenarios: A review of applications for agriculture and forestry. International Journal of Applied Earth Observation and Geoinformation, 2022. V. 112. DOI: 10.1016/j.jag.2022.102856.

Khorshiddoust A. M., Patel N., Khalilzadeh E. A comparative study of the surface level changes of Urmia Lake and Aral Lake during the period of 1988 to 2018 using satellite images. Frontiers of Earth Science, 2022. DOI: 10.1007/s11707-022-1010-5.

Kim J., Lee S., Song C., Jo H.-W. Identifying potential vegetation establishment areas in the Aral Sea using satellite images. Land Degradation and Development, 2020. No. 31(1). DOI: 10.1002/ldr.3642.

Kravtsova V. I. The possibilities of comparing for multitemporal imagery of various resolution under the northern river deltas dynamics investigation. InterCarto. InterGIS. GI support of sustainable development of territories: Proceedings of the International conference. Moscow: MSU, Faculty of Geography, 2021. V. 27. Part 1. P. 277–291 (in Russian). DOI: 10.35595/2414-9179-2021-1-27-277-291.

Kulenova N., Toguzova M., Assylkhanova Z., Mamysheva A., Sadenova M., Rakhymberdina M. Development of three-dimensional models of the spread of pollution on agricultural land in industrial cities. AIP Conference proceedings, 2022. V. 2570. P. 040014. DOI: 10.1063/5.0100029.

Kumsa A., Assen M. GIS and remote sensing based land degradation assessment and mapping: Case study Adea Woreda. Research Square, 2022. DOI: 10.21203/rs.3.rs-1876897/v1.

Kurganovich K. A., Kochev D. V., Bosov M. A. The hybrid method of water levels and volumes reconstructing in the Arakhley lake (Trans-Baikal territory) according to Landsat remote sensing data with unmanned aerial vehicles images fusion. InterCarto. InterGIS. GI support of sustainable development of territories: Proceedings of the International Conference. Moscow: MSU, Faculty of Geography, 2022. V. 28. Part 1. P. 368–382 (in Russian). DOI: 10.35595/2414-9179-2022-1-28-368-382.

Petrov G. Modern problems of integrated use of water and energy resources of the Aral Sea basin. Water Resources, Energetics and Ecology, 2021. V. 1. No. 1. P. 20–34.

Polyakova A., Mukharamova S., Yermolaev O., Shaykhutdinova G. Automated recognition of tree species composition of forest communities using Sentinel-2 Satellite Data. Remote Sensing, 2023. No. 15. P. 329–349. DOI: 10.3390/rs15020329.

Radočaj D., Obhođaš J., Jurišić M., Gašparović M. Global open data remote sensing satellite missions for land monitoring and conservation: A Review. Land, 2020. No. 9. Iss. 11. P. 402. DOI: 10.3390/land9110402.

Rakhymberdina M., *Grokhotov E., Assylkhanova Z.*, *Toguzova M.* Using space survey materials for modeling hydrodynamic accidents at mining enterprises in Kazakhstan. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2022. DOI: 10.5194/isprs-archives-XLVI-5-W1-2022-193-2022.

Rakhymberdina M., Kulenova N., Shaimardanov Zh., Assylkhanova Z., Toguzova M., Kassymov D. Using remote sensing data to support intelligent agricultural GIS to monitor the condition of arable land and crops. Chemical Engineering Transactions, 2022. V. 94. P. 838–888. DOI: 10.3303/cet2294147.

Reddy G. P. Kumar N., Singh S. K. Remote Sensing and GIS in mapping and monitoring of land degradation. Geotechnologies and the Environment, 2018. V. 21. P. 401–424.

Semeniaka V., Zatserkovnyi V., Shovkoplias T., Polyakova N., Martyniuk L. Remote Sensing of the Earth and GIS technology in monitoring surface water pollution using the example of the Kremenchug Reservoir. International Conference of Young Professionals “GeoTerrace-2022”, 2022. DOI: 10.3997/2214-4609.2022590069.

Shevyrev S. L., Antsiferova G. A., Rusova N. I., Khamzikeeva M. J. Analysis of satellite images as a method of controlling natural and anthropogenic processes using the example of the middle Crow current (Tambov Region). Bulletin of the VSU, 2013. No. 1. P. 35–39 (in Russian).

Shoshany M., Goldshleger N., Chudnovsky A. Monitoring of agricultural soil degradation by remote-sensing methods: a review. International Journal of Remote Sensing, 2013. No. 34. Iss. 17. P. 6152–6181. DOI: 10.1080/01431161.2013.793872.

Teslenok S., Kalashnikova L., Mushtaikin A. Preparation of materials for geographic information and cartographic monitoring of the Aral Sea shoreline based on remote sensing data. DSPU Journal, 2023. V. 17. No. 3. P. 88–105 (in Russian). DOI: 10.31161/1995-0675-2023-17-3-88-105.

Toguzova M., Rakhymberdina M., Kulenova N., Shaimardanov Zh., Assylkhanova Z., Apshikur B., Beisekenov N. Analysis of process modeling in modern software program to support “Smart” agriculture. Chemical Engineering Transactions, 2022. V. 97. P. 19–24. DOI: 10.3303/CET2294145.

Toguzova M., Rakhymberdina M., Nurshaiykova G., Gusarenko Y. Development of third-dimensional model of Ust-Kamenogorsk city for environmental monitoring purposes. AIP Conference Proceedings. SGEM, 2016. V. 2570. P. 239–246. DOI: 10.1063/5.0100029.

Wang J., Zhen J., Hu W., Chen S., Lizaga I., Zeraatpisheh M., Yang X. Remote sensing of soil degradation: progress and perspective. International Soil and Water Conservation Research, 2023. V. 11. P. 429–454. DOI: 10.1016/j.iswcr.2023.03.002.