https://doi.org/10.55764/2957-9856/2026-3-24-35.32

IRSTI 36.01:01
UDC 631

Zh. M. Zhumatayeva*[1], Zh. K. Mukaliyev[2], K. Zh. Kassymkhanova[3], S. R. Turganaliev[4]

[1] *PhD student (Al-Farabi Kazakh National University, Almaty, Kazakhstan; ***zhazka06@gmail.com***)
[2] Senior lecturers (Al-Farabi Kazakh National University, Almaty, Kazakhstan; *Zh.mukaliyev@kaznu.kz*)
[3] Master's degree student (Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan*; kamila-k@bk.ru*)
[4] Candidate of Economic Sciences, Associate Professor (International Education Corporation, Almaty, Kazakhstan; *S.Turganaliev@mail.ru*)

INTEGRATED GIS ASSESSMENT OF AGRICULTURAL LAND CONDITIONS IN EASTERN KAZAKHSTAN USING SENTINEL-2 NDVI AND SOIL DATA

Abstract. This study evaluates the effectiveness of geoinformation tools for monitoring and managing agricultural lands in Abai and East Kazakhstan regions. A unified geodatabase was developed by integrating topographic base maps, digital soil maps, and Sentinel-2 satellite data, including true-color composites, the Normalized Difference Vegetation Index (NDVI), and thematic agricultural land-use layers. The methodology includes atmospheric and cloud masking, composite generation, regional NDVI statistics by land-use classes and soil types, and the assessment of workflow efficiency in terms of accuracy, timeliness, labor intensity, and interoperability. The results include cartographic and analytical products characterizing the condition of agricultural landscapes, identifying agroecological stress zones, and distinguishing temporarily low vegetation activity associated with agricultural operations from potentially persistent pasture degradation. The scientific novelty lies in the integrated interpretation of Sentinel-2 NDVI data, agricultural land-use classes, and digital soil information within a unified GIS environment. The practical significance of the study is determined by the reproducibility of the workflow, the possibility of regular data updating, and the applicability of the resulting spatial information to agricultural land monitoring and management.

Keywords: GIS, agricultural land monitoring, NDVI; Sentinel-2, remote sensing, soil mapping, land management, agroecological stress, pasture degradation, Kazakhstan.

Introduction. Accelerated climate variability and increasing anthropogenic pressure intensify the spatial heterogeneity of agricultural land productivity, complicating decision-making for sustainable land management. Geographic Information Systems (GIS), which integrate satellite observations, topographic data, and soil information, have become essential tools for agricultural monitoring and planning [7, 13]. However, the operational effectiveness of such integrated approaches under Kazakhstan's continental climate conditions and heterogeneous land-use structure remains insufficiently studied [11]. Recent studies highlight the potential of vegetation indices and supervised classification for agro-landscape mapping [5, 6]; however, many approaches remain limited to a single observation period, insufficiently account for soil variability, and rarely integrate the resulting datasets into unified geodatabases suitable for practical land-management applications [3].

This study is based on the hypothesis that the combined analysis of Sentinel-2 satellite data, including true-color composites and the Normalized Difference Vegetation Index (NDVI), thematic agricultural land-use layers, and digital soil maps can improve the objectivity of agro-landscape condition assessment and enhance the operational applicability of the results for land-management purposes [14].

Research aim: To evaluate the effectiveness of an integrated set of GIS tools for monitoring and managing agricultural lands using Abai and East Kazakhstan regions as case studies.

Objectives: Integrate topographic base maps, soil polygons, and satellite data into a unified geodatabase [3, 15].

Generate and validate comparable maps based on true-color composites and NDVI [8].

Calculate and analyze regional NDVI statistics by agricultural land-use classes and soil types [4, 11].

Develop decision-support outputs and assess the workflow using efficiency criteria, including accuracy, timeliness, labor intensity, and interoperability.

Demonstrate the potential of the integrated results for refining and updating digital soil maps as part of an agricultural land-monitoring system [1].

The scientific novelty of the study lies in the development of a unified GIS-based workflow that integrates Sentinel-2 NDVI data, agricultural land-use classes, and digital soil maps within a single geodatabase for two contrasting regions of Kazakhstan. The integrated interpretation of these datasets makes it possible to distinguish temporarily low vegetation activity associated with agricultural technological phases from potentially persistent agroecological stress in pastures and hayfields. The territorial significance of the study is determined by the comparative assessment of Abai and East Kazakhstan regions, which differ substantially in relief, soil conditions, moisture availability, and agricultural land-use patterns (figures 1).

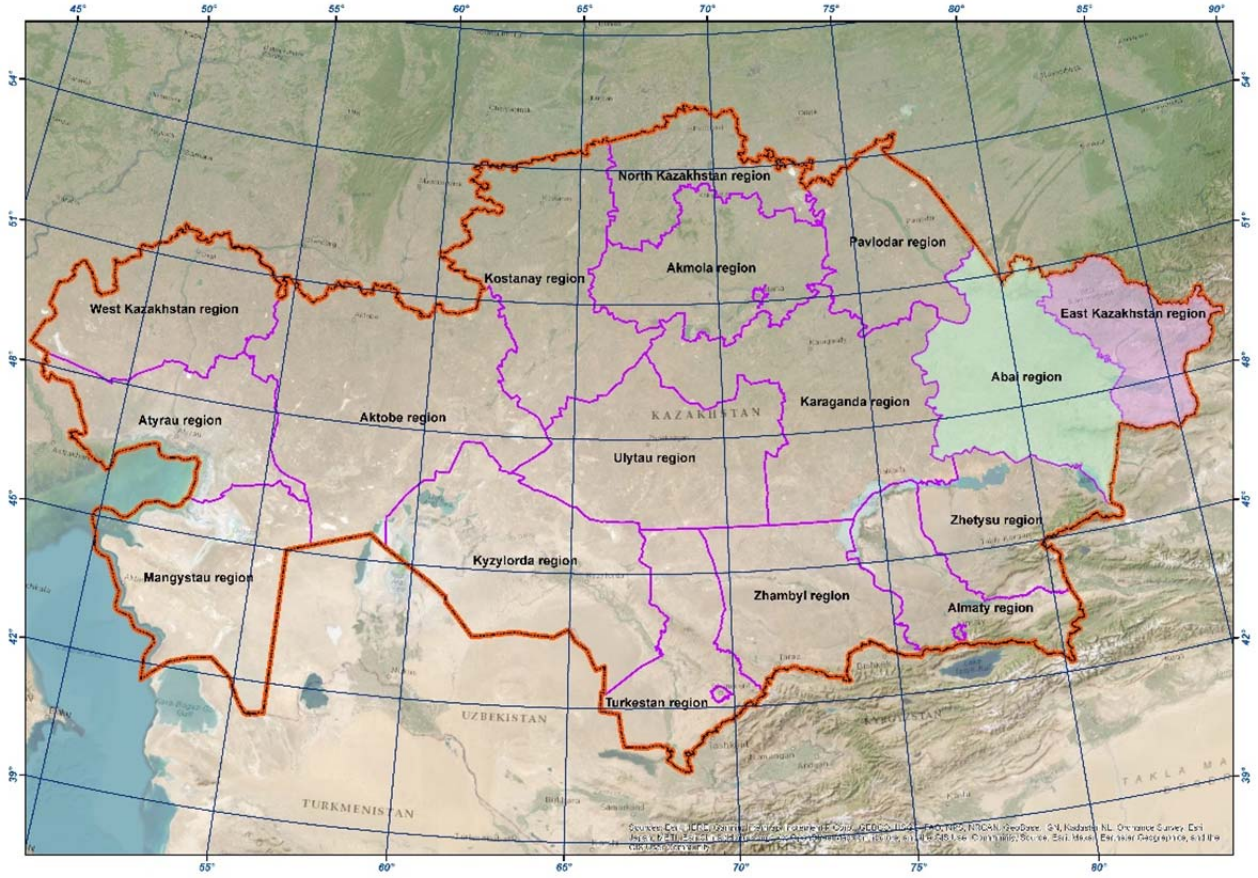


Figure 1 – Location of Abai and East Kazakhstan Regions within Kazakhstan (compiled by the authors)

Research materials and methods. The study areas comprise agricultural lands in Abai Region and East Kazakhstan Region (EKR). Both regions are characterized by a continental climate but differ considerably in their orographic structure and moisture conditions. Abai Region is predominantly characterized by dry plateaus and intermontane basins, whereas EKR includes mountainous areas with pronounced altitudinal zonation [11]. These contrasting natural conditions provide a suitable basis for comparative analysis of the factors influencing agricultural landscape productivity.

All area and geometric calculations were performed in the QazTRF-23 coordinate reference system, whereas EPSG:4326 and EPSG:3857 were used for web-based visualization (figures 2–4).

Satellite data. Sentinel-2 L2A data from the Copernicus programme, with a spatial resolution of 10-20 m, were used for both regions. A common observation period from June 1 to June 30, 2025, was selected to ensure comparability between the study areas. Satellite scenes were selected using the Copernicus Browser with a cloud-cover threshold (CLOUDY_PIXEL_PERCENTAGE) of ≤ 40% (figures 3–5) [5]. The analysis used bands B2, B3, B4, and B8 together with the Scene Classification Layer (SCL).



Figure 2 – Topographic base map of Abai Region (compiled by the authors)

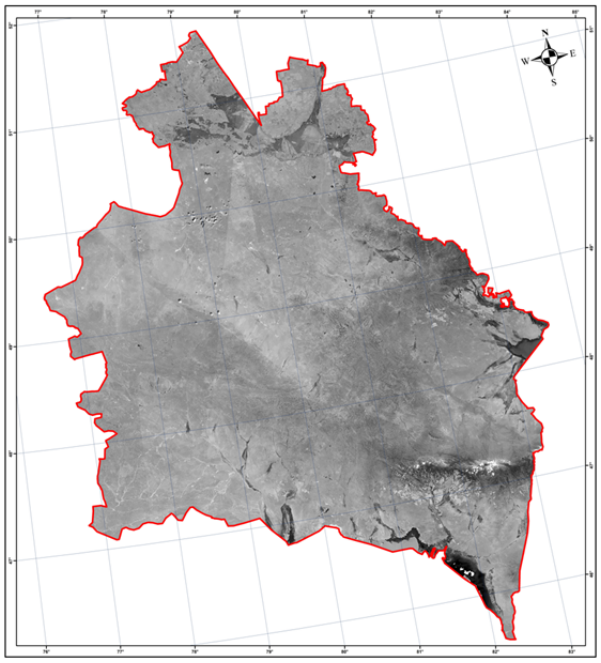


Figure 3 – Sentinel-2 L2A imagery of Abai Region (compiled by the authors)

Digital soil maps for both regions were prepared in vector format and standardized according to a common nomenclature, including the FAOSOIL, DOMSOIL, PHASE, MSC, and AREA_HA attributes [2, 3]. Current district boundaries of Abai Region and EKR were used as administrative spatial units for data integration and subsequent analysis.

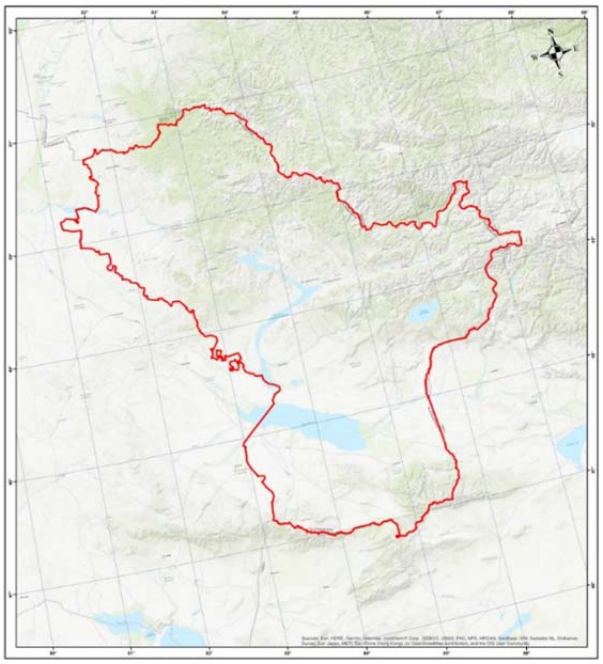


Figure 4 – Topographic base map of East Kazakhstan Region (compiled by the authors)

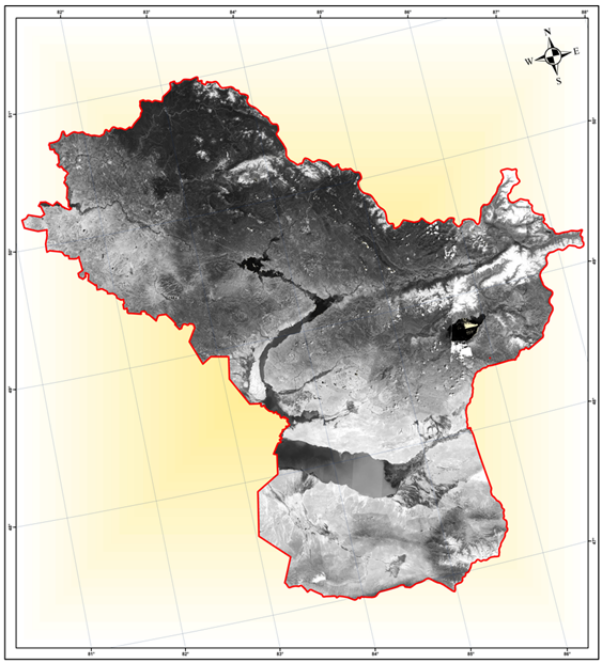


Figure 5 – Sentinel-2 L2A imagery of East Kazakhstan Region (compiled by the authors)

Scene selection and SCL-based masking were performed using identical procedures for both regions. True-color composites and NDVI products were generated using the same processing parameters, including median compositing and histogram stretching. The resulting products were exported in GeoTIFF/COG format at a spatial resolution of 10 m. The use of a standardized processing workflow minimized methodological differences and ensured comparability between the two study regions [6].



Figure 6 – Sentinel-2 true-color composite of East Kazakhstan Region (compiled by the authors)



Figure 7 – Sentinel-2 true-color composite of Abai Region (compiled by the authors)

Soil data preparation and normalization. Georeferencing and vectorization of scanned soil maps were performed according to a unified protocol. The root mean square (RMS) georeferencing error did not exceed 1.5 pixels, and the minimum polygon inclusion threshold was set at 0.5 ha. Polygon geometry validity was checked using the ST_IsValid procedure [5]. Soil attributes for both regions were standardized using common parameters, including FAO soil codes, soil phases, and soil texture, enabling cross-analysis by "soil type × land-use type" [2, 3].

NDVI zonal statistics. Zonal statistics were calculated at two levels: (i) by agricultural land-use classes and (ii) by soil polygons, with subsequent aggregation within the districts of both regions [4, 12]. The calculated indicators included mean and median NDVI, standard deviation (SD), first and third quartiles (Q1–Q3), and the proportions of pixels with NDVI < 0.35 and NDVI > 0.60. Soil and agricultural land-use layers were overlaid, and the resulting indicators were aggregated by administrative units [17].

The soil × agricultural land-use overlay was performed separately for Abai Region and EKR, after which the resulting indicators were compared across identical soil classes and land-use types [11].

A uniform observation period and identical processing parameters were applied to both regions. Compatible agricultural land-use and FAO soil legends, areal normalization, stratification by "soil type × land-use type," and differentiation according to orographic position (plateau, slope, and floodplain) were used to ensure methodological consistency. Non-parametric Mann - Whitney tests were applied where appropriate, with statistical significance set at $p < 0.05$.

Results. A comprehensive assessment of agricultural land conditions and the optimization of land use require an integrated spatial database containing both quantitative and qualitative indicators [1]. An essential feature of such a database is the ability to visualize information in cartographic form and to combine multiple spatial datasets within a unified analytical environment.

A GIS-based model provides an effective framework for integrating and analyzing heterogeneous spatial data [7, 13]. It enables the production of detailed cartographic materials describing the spatial distribution of agricultural lands, water resources, terrain characteristics, soil conditions, and other factors affecting agricultural productivity [16]. In addition to visualization, the model supports spatial analysis, identification of spatial patterns, evaluation of land-use conditions, and decision support for agroecological planning [12].

The geoinformation model used in this study comprises three logically structured information blocks: graphical, attribute, and computational-analytical components (table).

Logically structured Information blocks

Stage	Purpose	Input data/sources	Formats and tools	Main actions	Output/result	Assessment criteria
Graphica	Collection and systematization of Initial spatial Information for cartographic modeling of the region	Satellite Images; aerial photography; geodetic and satellite positioning systems; modern and archival planning cartographic materials	Vector (ship, gab), GRID (raster), TIN (triangulated Irregular network, analog (paper)	Digitization of geo-data, georeferencing, projection; vectorization raster/ vector conversion; preparation of base layers	Base map of the area: boundary, hydrography, roads, land cover, etc.	Geometric accuracy; projection consistency; layer completeness
Attribute	Collection of statistical quantitative and qualitative characteristics necessary for spatial analysis	Administrative/sectoral data; land plot registers; land quality and Indicators; field surveys	Tabular DB (DBMS, CSV/Excel; geodatabase (GDB/PG); metadata	Data Integration (join/relate; cleaning and validation; coding/classification; metadata completion	Attribute database - complete characteristics for each polygon/object	Data relevance, reliability; code correspondence; proportion of null values
Computational analytica	Assessment of land resource use efficiency and decision support	Graphical and attribute layers; Indices (NDVI, NDWI, MSI, etc.); regulatory standards	GIS/RS methods (overlay, buffer, Interpolation, reclassification, modelin); cartographic diagrams	Calculation of Indicators; comparison and Integration; pattern Identification; cartographic visualization	Analysis maps, ratings, reports, recommendations	Model accuracy; sensitivity/robustness; visual clarity; Impact on decision-making

Note. Compiled by the authors.

The integration of quantitative and qualitative spatial information into a unified geodatabase enabled cartographic visualization and spatial analysis of agricultural territories. The database structure also provided a consistent basis for comparing the two study regions and interpreting spatial relationships among vegetation condition, land use, soils, and relief.

NDVI composites for June 1–30, 2025 revealed distinct spatial gradients in vegetation activity. Higher NDVI values were associated primarily with floodplains, areas adjacent to water bodies, irrigated lands, and productive hayfields, whereas lower values occurred in dry areas, erosion-prone slopes, and cropland with temporarily exposed soil during particular stages of agricultural operations. The intra-regional spatial variability of NDVI reflects the combined influence of microrelief, soil-moisture conditions, and current land-use practices.

Comparison of NDVI maps with Sentinel-2 true-color composites confirmed the spatial correspondence between areas of visually dense green vegetation and higher NDVI values. In contrast, bare or sparsely vegetated surfaces generally showed lower index values. The agricultural land-use mask made it possible to interpret low NDVI values in their land-use context and to distinguish temporary reductions associated with cropland preparation or harvesting from potentially persistent agroecological stress in pastures and hayfields caused by moisture deficit or excessive grazing pressure.

NDVI patterns differed among the main agricultural land-use classes (figures 7, 8):

-Cropland showed relatively low and variable NDVI values, reflecting differences in cultivation stages. The proportion of pixels with NDVI < 0.35 was higher in dry areas and plateau landscapes [10, 14].

- Hayfields generally demonstrated more stable NDVI values, while greater within-class variability was observed in wetter areas and following precipitation events [14].

- Pastures showed an increased proportion of NDVI < 0.35 in dry areas and zones potentially affected by high grazing pressure. Local patches of higher NDVI were associated with depressions, watering points, and areas with relatively favorable moisture conditions [15].

Regional differences should be interpreted in relation to agricultural operations, microrelief, soil properties, and moisture availability [6, 7]. The soil maps of Abai Region and East Kazakhstan Region reveal substantially different natural conditions influencing agricultural productivity [2, 11].

Abai Region is dominated by chestnut and light-chestnut soil complexes distributed across plateaus and intermontane basins, including sandy and loamy soil varieties. These combinations are generally associated with lower moisture-retention capacity and contribute to a lower background level of vegetation activity under dry conditions [11].

East Kazakhstan Region is characterized by a more pronounced mountain and slope-related spatial mosaic. Alluvial soil complexes occur within major river floodplains, while heavier-textured soils are more widespread in valleys and mountainous areas. These conditions generally provide more favorable moisture availability and contribute to higher vegetation activity in selected parts of the region [11, 16].

The spatial relationship between soil properties and vegetation activity indicates that alluvial and heavy-textured soils are generally associated with higher NDVI values, whereas light-textured and saline soils tend to show lower and more variable vegetation activity [2, 12].



Figure 8 – Agricultural land use in Abai Region (compiled by the authors)

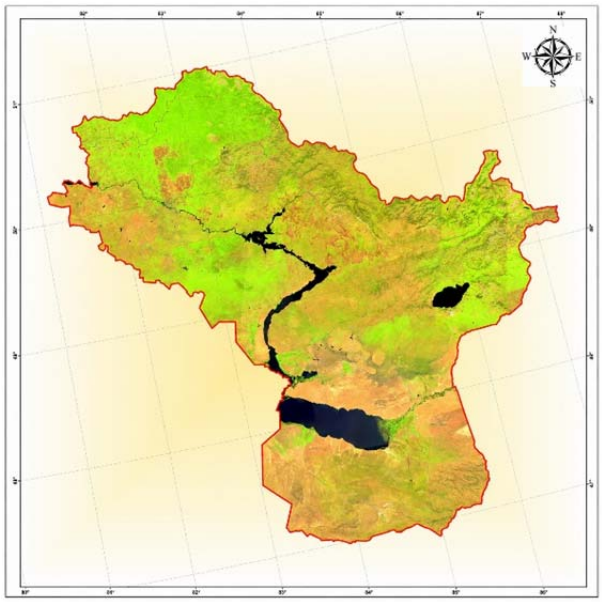


Figure 9 – Agricultural land use in East Kazakhstan Region (compiled by the authors)

The agricultural land-use layer revealed clear differences in the spatial configuration of agricultural territories in the two regions (figures 8, 9).

In Abai Region (figure 8), large areas of cropland are distributed across plateaus and intermontane depressions, while pastures and hayfields form a more heterogeneous spatial pattern [11]. This configuration increases the occurrence of areas with temporary soil exposure during particular agricultural operations and therefore increases the likelihood of relatively low NDVI values during such periods [10].

In East Kazakhstan Region (figure 9), agricultural lands are more closely associated with river valleys, floodplains, foothill areas, and mountain slopes [16]. Areas with more favorable moisture conditions, including valleys and locations adjacent to water bodies, generally support more stable vegetation activity during the early-summer observation period [4, 12].

For cropland, low NDVI values during the selected observation period may reflect agricultural operations such as soil preparation or fallow conditions. In contrast, persistently low NDVI values in pastures and hayfields may indicate agroecological stress related to moisture deficit, excessive grazing pressure, or vegetation degradation [7, 12].

The NDVI composites for June 1–30, 2025 revealed spatial patterns associated with land use, relief, and moisture availability (figures 10, 11). In East Kazakhstan Region, the highest vegetation activity was associated mainly with floodplains of major watercourses, valleys, and hayfields located in areas with favorable moisture conditions. Spatial variability of NDVI was more pronounced because of altitudinal zonation and contrasting terrain conditions.

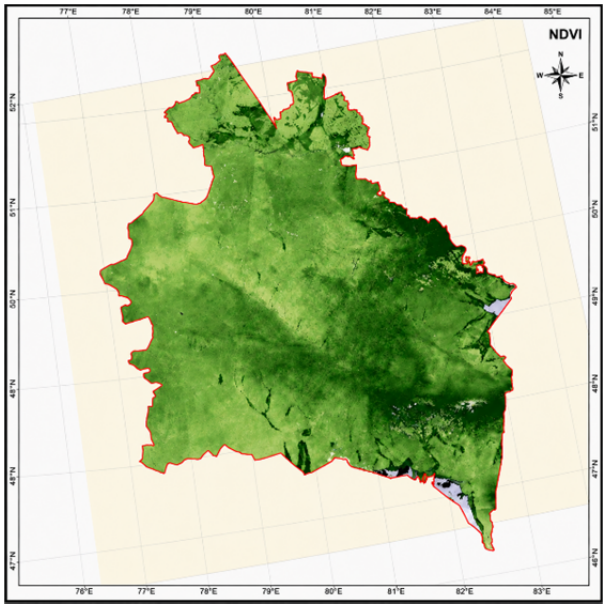


Figure 10 – NDVI distribution in Abai Region
(compiled by the authors)

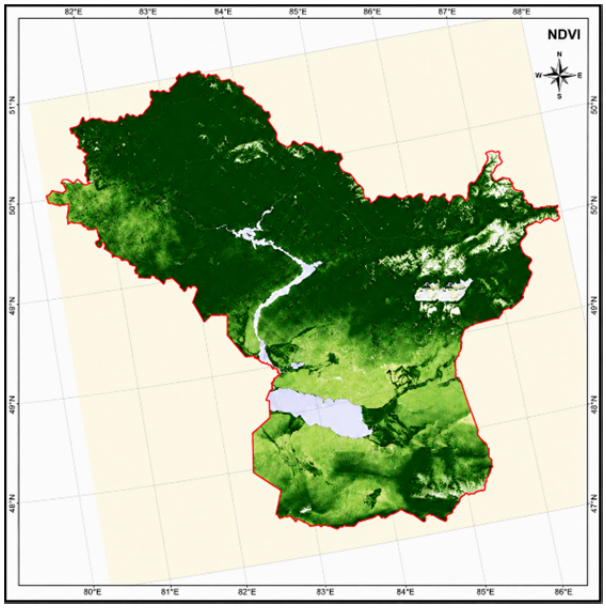


Figure 11 – NDVI distribution in East Kazakhstan Region
(compiled by the authors)

In Abai Region, vegetation activity was generally more homogeneous and shifted toward medium and low NDVI values. Plateaus and intermontane basins contained extensive areas of relatively low vegetation activity, whereas localized areas of higher NDVI occurred mainly near water bodies and irrigated agricultural lands [11].

Areas with persistently low NDVI values in Abai Region were spatially associated mainly with pasture plateaus and light-textured or saline soils. In East Kazakhstan Region, lower values were more frequently observed in slope positions where soil depth and moisture-retention capacity are limited.

The soil maps further clarify these regional differences. In Abai Region (figure 12), chestnut and light-chestnut soil complexes predominate, with inclusions of sandy and saline soils. Their relatively low moisture-retention capacity contributes to the prevalence of medium-to-low vegetation activity under dry conditions.

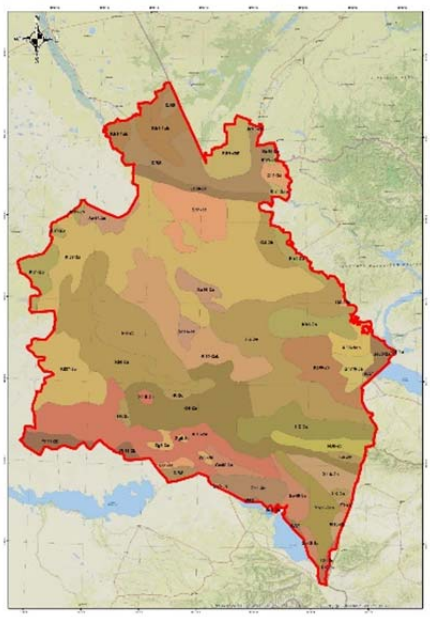


Figure 12 – Soil map of Abai Region
(compiled by the authors)

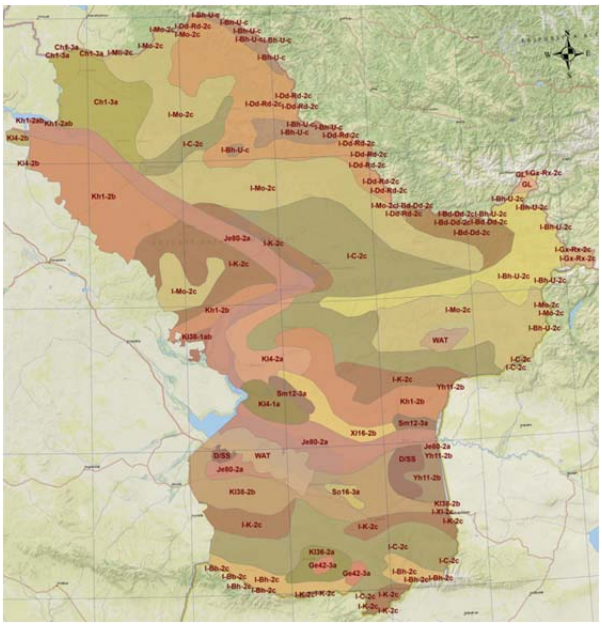


Figure 13 – Soil map of East Kazakhstan Region
(compiled by the authors)

In East Kazakhstan Region (figure 13), alluvial and heavier-textured soils are more widely represented in valleys and other comparatively moist landscape positions. These soil conditions generally support higher vegetation activity and contribute to greater spatial variability of NDVI over relatively short distances [11, 16].

Overall, the spatial analysis indicates that alluvial and heavy-textured soils tend to be associated with higher seasonal NDVI values, whereas light-textured and saline soils are characterized by lower and more variable vegetation activity [2, 12].

Moisture conditions and relief position. East Kazakhstan Region, with its developed network of river valleys, floodplains, and mountainous terrain, showed a greater spatial occurrence of high-NDVI areas and a more pronounced intra-regional mosaic [16, 18]. In Abai Region, the predominance of plateaus and relatively light-textured soils resulted in more extensive areas characterized by medium-to-low NDVI values [11].

Low NDVI values in cropland are primarily associated with particular agricultural phases and temporary soil exposure, whereas persistently low NDVI values in pastures may indicate vegetation stress or degradation [7, 12]. Floodplain hayfields with consistently high vegetation activity may serve as local reference areas for interpreting and calibrating regional NDVI ranges [4].

Abai Region. Areas characterized by persistently low NDVI values require particular attention to grazing pressure, water availability, and soil-protection measures. Potential management actions include regulating livestock pressure on plateau pastures, improving access to water through strategically located watering points and small water-storage facilities, and introducing local erosion-control practices in vulnerable areas [13, 17].

East Kazakhstan Region. Management priorities include sustainable use of slope pastures, contour-based land-management practices, regulation of grazing pressure, and conservation of productive floodplain hayfields [14, 17]. For cropland in both regions, multi-year satellite time series are required to reduce the influence of short-term agricultural operations and to distinguish temporary vegetation changes from persistent land-condition trends [6, 10].

The interpretation presented in this study is limited to the June 2025 observation window and is therefore sensitive to several factors, including the quality of the valid-pixel mask, weather conditions during the selected period, the relevance and accuracy of the agricultural land-use layer, and the thresholds used for NDVI interpretation. Consequently, long-term management conclusions should be supported by multi-year comparative observations and regular updating of agricultural land-use datasets [5, 6].

Discussion. The results demonstrate the practical potential of GIS-based agricultural land monitoring through the integration of multiple spatial data sources [7, 13]. The main contribution of the study is the application of a unified methodological framework combining Sentinel-2 imagery, digital soil maps, and agricultural land-use information. This integrated approach supports the differentiation of natural environmental constraints from land-use-related factors affecting vegetation activity [5, 6].

Methodological advantages and limitations. Sentinel-2 L2A data with a spatial resolution of 10–20 m provided sufficient spatial detail for regional-scale agricultural land assessment, consistent with previous studies demonstrating the applicability of medium-resolution satellite imagery to agricultural monitoring [1, 5]. However, the observation period was limited to June 1–30, 2025, which constrains the interpretation of temporal variability. Although this period represents an important stage of vegetation development in both regions, it cannot fully characterize interannual variability or all phenological stages of agricultural crops [6]. Multi-year NDVI time series would therefore provide a more robust basis for distinguishing persistent land degradation from short-term seasonal variability [11].

The integration of the agricultural land-use mask with NDVI composites improved interpretation of low vegetation-index values by providing land-use context. In cropland, low NDVI values may be associated with soil preparation, fallow conditions, or other agricultural operations, whereas persistently low values in pastures and hayfields may indicate moisture stress, excessive grazing pressure, or vegetation degradation [9, 10]. This distinction addresses an important limitation of vegetation-index interpretation, since low NDVI values alone do not necessarily indicate deterioration of land condition [4, 8]. The results therefore confirm the value of contextual spatial layers in remote-sensing-based agricultural assessment [2, 3].

Regional contrasts and their implications. The differences observed between Abai Region and East Kazakhstan Region reflect contrasting landscape structure, soil properties, and moisture conditions [11, 16]. In Abai Region, the predominance of plateau landscapes and relatively light-textured soils contributes to extensive areas with moderate-to-low NDVI values. This pattern is consistent with previously documented regional conditions associated with land degradation and moisture limitation [11]. The concentration of higher NDVI values near water bodies and irrigated areas further emphasizes the importance of water availability in this comparatively dry environment [12, 16].

In East Kazakhstan Region, greater topographic diversity produces a more pronounced spatial mosaic of vegetation activity [18]. Higher NDVI values are primarily associated with floodplains, valleys, and other landscape positions characterized by more favorable moisture conditions. This pattern is consistent with the redistribution of moisture by relief in mountainous and foothill environments [4, 16]. The resulting spatial heterogeneity may contribute to greater local variability in agricultural land productivity and should therefore be considered in regional monitoring and land-management strategies [17].

Soil-vegetation relationships. The overlay analysis of digital soil maps and NDVI data revealed clear spatial relationships between soil characteristics and vegetation activity [2, 12]. Alluvial and heavier-textured soils were generally associated with higher NDVI values, whereas light-textured and saline soil complexes showed lower and more variable vegetation activity. These results demonstrate the value of digital soil information as an important contextual layer for interpreting vegetation condition [2, 3].

At the same time, soil properties should not be interpreted as the sole determinant of vegetation activity. Local management practices, including irrigation, fertilization, grazing intensity, and land-use history, can substantially modify the vegetation response observed under otherwise similar soil conditions [15]. Therefore, the combined interpretation of soil, land-use, and satellite data provides a more informative basis for agricultural land assessment than the analysis of any single dataset.

Practical applications and management implications. The identification of areas with persistently low NDVI values on pasture plateaus in Abai Region may indicate moisture stress or excessive grazing pressure [7, 12, 13]. Potential management measures include regulation of grazing intensity, strategic placement of watering points, and implementation of local erosion-control measures in vulnerable areas [17]. However, practical implementation also requires consideration of socio-economic factors, including land tenure, livestock management systems, and local land-use practices [13].

For East Kazakhstan Region, the results emphasize the importance of sustainable management of slope pastures and conservation of productive floodplain hayfields [14, 17]. Areas with consistently high vegetation activity in floodplains may also serve as local reference sites for interpreting regional NDVI ranges and supporting long-term vegetation monitoring [4].

The compatibility of the proposed workflow with openly available Sentinel-2 data and standard GIS operations reduces dependence on costly proprietary datasets and specialized infrastructure [5, 6]. The reproducibility of the workflow also creates opportunities for its application by regional agricultural departments and land-management organizations [13, 15].

The proposed three-component assessment framework - NDVI, agricultural land-use information, and digital soil maps - provides a balance between methodological consistency and operational applicability [4, 12, 17]. The framework can be adapted to other administrative regions or agroecological zones while maintaining a common analytical structure [7].

Several limitations should be acknowledged. First, the study is based on a single observation period, which limits conclusions regarding long-term trends [5, 6]. Second, field-based validation data were not available for the present analysis; therefore, the interpretation relies primarily on the spatial consistency between Sentinel-2 true-color composites, NDVI patterns, land-use information, and soil data [8]. Third, socio-economic drivers of agricultural land-use decisions were beyond the scope of this study, although they may significantly influence management outcomes [13].

Future research should therefore include: (1) multi-temporal and multi-year NDVI analysis to establish regional reference ranges and identify long-term trajectories [11]; (2) integration of meteorological data to distinguish climate-driven changes from management-related effects [4, 12]; (3) comparison with agricultural productivity indicators, including crop yield and biomass data, to further evaluate NDVI - soil relationships [10, 14]; and (4) incorporation of field observations and local stakeholder information to strengthen the practical interpretation of monitoring results [13, 17].

The methodology applied in this study addresses specific challenges associated with agricultural monitoring under Kazakhstan's continental climate and heterogeneous landscape conditions [11]. The results show that medium-resolution satellite imagery, when integrated with soil maps, administrative boundaries, and agricultural land-use information, can provide a practical basis for regional land monitoring without requiring highly specialized infrastructure [5, 6, 7].

The comparison between Abai and East Kazakhstan regions further demonstrates the importance of adapting monitoring approaches to regional environmental conditions rather than applying uniform interpretation criteria across contrasting landscapes [11, 16]. At the same time, maintaining a standardized processing workflow ensures methodological comparability between regions [13].

Overall, the integration of topographic, soil, satellite, and agricultural land-use data into a unified geodatabase illustrates the role of GIS as an integrated decision-support environment rather than solely a cartographic visualization tool [3, 7, 15]. This approach is consistent with broader developments in precision agriculture, spatial monitoring, and evidence-based land management [9, 10].

Conclusion. The study demonstrated the effectiveness of an integrated GIS-based approach for monitoring and managing agricultural lands in Abai and East Kazakhstan regions. The proposed workflow combines Sentinel-2 L2A imagery, NDVI analysis, agricultural land-use data, and digital soil maps within a unified geospatial environment, providing a consistent basis for regional comparison and interpretation.

The comparative assessment revealed distinct spatial patterns associated with differences in land use, soil properties, relief, and moisture conditions. In Abai Region, lower vegetation activity was mainly associated with dry plateau areas and light-textured soils, whereas East Kazakhstan Region showed greater spatial heterogeneity, with higher vegetation activity concentrated in floodplains, valleys, and areas with more favorable moisture conditions.

The combined interpretation of NDVI, agricultural land-use classes, and soil information improves the distinction between temporarily low vegetation activity related to agricultural operations and potentially persistent agroecological stress in pastures and hayfields. This approach therefore provides a more context-sensitive assessment than the interpretation of vegetation indices alone.

The developed GIS workflow is reproducible and scalable and can support the regular updating of thematic maps and geospatial databases. The resulting maps and analytical layers can be used to identify areas requiring management attention, regulate grazing pressure, support irrigation and reclamation planning, improve the management of slope lands, and update digital soil and agricultural land-use information.

The use of open Sentinel-2 data and standard GIS procedures makes the proposed approach suitable for operational agricultural land monitoring at the regional level. Further development of the methodology should include multi-year satellite observations, meteorological data, field validation, and agricultural productivity indicators to improve the reliability of long-term land-condition assessment.

Gratitude. The authors express their gratitude to the libraries of Al-Farabi Kazakh National University for providing access to specialized collections and electronic databases, which offered significant methodological and informational support for this research. Special thanks are extended to the anonymous reviewers for their careful reading of the manuscript and constructive comments, which greatly contributed to its substantial improvement. The authors also acknowledge the support of the Institute of Geography and Water Security for promoting scientific dialogue through the journal *Geography and Water Resources*.

REFERENCES

[1] Weiss M., Jacob F., Duveiller G. (2020). Remote sensing for agricultural applications: A meta-review // Remote Sensing of Environment, 236, 111402. DOI: 10.1016/j.rse.2019.111402

[2] Hively W. D., McCarty G. W., Reeves J. B., Lang M. W., Oesterling R. A., Delwiche S. R. (2011). Use of airborne hyperspectral imagery to map soil properties in tilled agricultural fields // Applied and Environmental Soil Science, 2011, 358193. DOI: 10.1155/2011/358193

[3] Ivlieva N. G., Manukhov V. F., Alferina A. V. (2020). Cartographic and geoinformation support of soil and agrochemical research (on the example of a separate agricultural enterprise) // InterCarto. InterGIS, 26(2), 41-53. DOI: 10.35595/2414-9179-2020-2-26-41-53

[4] Joiner J., Yoshida Y., Anderson M. C., Holmes T., Hain C., Reichle R. H., Koster R. D., Middleton E. M., Zeng F. (2018). Global relationships among traditional reflectance vegetation indices (NDVI and NDII), evapotranspiration (ET), and soil moisture variability on weekly timescales // Remote Sensing of Environment, 219, 339-352. DOI: 10.1016/j.rse.2018.10.020

[5] Karmakar P., Teng S. W., Murshed M., Pang P., Li Y., Hao L. (2024). Crop monitoring by multimodal remote sensing: A review // Remote Sensing Applications: Society and Environment, 33, 101093. DOI: 10.1016/j.rsase.2023.101093

[6] Khanal S., Kushal K. C., Fulton J. P., Shearer S., Ozkan E. (2020). Remote sensing in agriculture- accomplishments, limitations, and opportunities // Remote Sensing, 12(22), 3783. DOI: 10.3390/rs12223783

[7] Kingra P. K., Majumder D., Singh S. P. (2016). Application of remote sensing and GIS in agriculture and natural resource management under changing climatic conditions // Agricultural Research Journal, 53(3), 295-302. DOI: 10.5958/2395-146X.2016.00058.2

[8] Sharma S., Beslity J. O., Rustad L., Shelby L. J., Manos P. T., Khanal P., Reinmann A. B., Khanal C. (2024). Remote sensing and GIS in natural resource management: Comparing tools and emphasizing the importance of in-situ data // Remote Sensing, 16(22), 4161. DOI: 10.3390/rs16224161

[9] Zhumatayeva Z., Onalbayeva D., Mukaliyev Z., Bekturganova A., Bekkuliyev A., Turganaliev S. (2025). Analysis of the method of updating agricultural maps by processing satellite images and geoinformation technology data in the land management system // Izdenister Natigeler, 4(108), 342-354. DOI: 10.37884/4-2025/36

[10] Sangeetha C., Moond V., Rajesh G. M., Damor J. S., Pandey S. K., Kumar P., et al. (2024). Remote sensing and geographic information systems for precision agriculture: A review // International Journal of Environment and Climate Change, 14(2), 287-309. DOI: 10.9734/ijecc/2024/v14i23945

[11] Rafikov T., Zhumatayeva Z., Mukaliyev Z., Zhildikbayeva A. (2024). Evaluating land degradation in East Kazakhstan using NDVI and Landsat data // International Journal of Design & Nature and Ecodynamics, 19(5), 1677-1686. DOI: 10.18280/ijdne.190521

[12] Saha A., Patil M., Goyal V. C., Rathore D. S. (2019). Assessment and impact of soil moisture index in agricultural drought estimation using remote sensing and GIS techniques // Proceedings, 7(1), 2. DOI: 10.3390/ecws-3-05802

[13] Sarmah K., Deka C. R., Sharma U., Sarma R. (2018). Role of GIS-based technologies in sustainable agriculture resource planning & management using spatial decision support approach // International Journal of Innovative Research in Engineering & Management, 5(1), 30-34. DOI: 10.21276/ijirem.2018.5.1.7

[14] Shekhar S., Gusain R., Vidhyarthi A., Prakash R. (2022). Role of remote sensing and GIS strategies to increase crop yield // In 2022 International Conference on Advances in Computing, Communication and Materials (ICACCM), 1-6. IEEE. DOI: 10.1109/ICACCM56405.2022.10009217

[15] Ashimkhan N., Rafikov T., Zhildikbayeva A., Mukaliev Zh., Doktyrbek A. Y., Pentaev T. (2025). Application of geographical databases for the development of geo-portals in Kazakhstan // Izdenister Natigeler, 4(108), 470-480. DOI: 10.37884/4-2025/48

[16] Sun T., Cheng W., Abdelkareem M., Al-Arifi N. (2022). Mapping prospective areas of water resources and monitoring land use/land cover changes in an arid region using remote sensing and GIS techniques // Water, 14(15), 2435. DOI: 10.3390/w14152435

[17] Avtar R., Komolafe A. A., Kouser A., et al. (2020). Assessing sustainable development prospects through remote sensing: A review // Remote Sensing Applications: Society and Environment, 20, 100402. DOI: 10.1016/j.rsase.2020.100402

[18] Ye X., Kuang H. (2022). Evaluation of ecological quality in southeast Chongqing based on modified remote sensing ecological index // Scientific Reports, 12, 15694. DOI: 10.1038/s41598-022-19851-9

Ж. М. Жұматаева*[1], Ж. К. Мукалиев[2], К. Ж. Касымханова[3], С. Р. Турганалиев[4]

[1] *PhD докторант (әл-Фараби атындағы Қазақ ұлттық университеті,
Алматы, Қазақстан; ***zhazka06@gmail.com***)
[2] Аға оқытушы (әл-Фараби атындағы Қазақ ұлттық университеті,
Алматы, Қазақстан; *Zh.mukaliyev@kaznu.kz*)
[3] Магистрант (Қ. И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті,
Алматы, Қазақстан; *kamila-k@bk.ru*)
[4] Экономика ғылымдарының кандидаты, доцент
(Халықаралық білім беру корпорациясы, Алматы, Қазақстан; *S.Turganaliev@mail.ru*)

SENTINEL-2 NDVI ЖӘНЕ ТОПЫРАҚ ДЕРЕКТЕРІ НЕГІЗІНДЕ ШЫҒЫС ҚАЗАҚСТАННЫҢ АУЫЛ ШАРУАШЫЛЫҒЫ ЖЕРЛЕРІНІҢ ЖАЙ-КҮЙІН КЕШЕНДІ ГЕОАҚПАРАТТЫҚ БАҒАЛАУ

Аннотация. Мақалада Абай және Шығыс Қазақстан облыстары мысалында ауыл шаруашылығы жерлерін мониторингілеу және басқару үшін геоақпараттық құралдардың тиімділігі бағаланды. Зерттеу барысында топографиялық негіз, цифрлық топырақ карталары және Sentinel-2 спутниктік деректері бірыңғай геодеректер базасына біріктірілді. Спутниктік деректер негізінде табиғи түсті композиттер, нормаланған айырмалық вегетациялық индекс (NDVI) және ауыл шаруашылығы жерлерін пайдаланудың тақырыптық қабаттары қалыптастырылды. Әдістеме атмосфералық кедергілер мен бұлттылықты маскалауды, композиттерді құруды, жер пайдалану санаттары мен топырақ типтері бойынша NDVI-дің аймақтық статистикасын есептеуді, сондай-ақ жұмыс үдерісінің тиімділігін дәлдік, жеделдік, еңбек сыйымдылығы және интероперабельділік көрсеткіштері бойынша бағалауды қамтиды. Нәтижесінде агроландшафттардың жай-күйін сипат-

тайтын картографиялық және аналитикалық материалдар алынып, агроэкологиялық стресс аймақтары анықталды. Сонымен қатар ауыл шаруашылығы жұмыстарымен байланысты өсімдік жамылғысы белсенділігінің уақытша төмендеуін жайылымдардың ықтимал тұрақты деградация белгілерінен ажырату мүмкіндігі көрсетілді. Зерттеудің ғылыми жаңалығы Sentinel-2 NDVI деректерін, ауыл шаруашылығы жерлерін пайдалану санаттарын және цифрлық топырақ ақпаратын бірыңғай ГАЖ ортасында кешенді түсіндіруге негізделеді. Практикалық маңыздылығы әдістеменің қайталанымдылығымен, деректерді тұрақты түрде жаңарту мүмкіндігімен және алынған кеңістіктік ақпаратты ауыл шаруашылығы жерлерін мониторингілеу мен басқаруда қолдануға жарамдылығымен айқындалады.

Түйін сөздер: ГАЖ, ауыл шаруашылығы жерлерін мониторингілеу, NDVI, Sentinel-2, қашықтан зондтау, топырақ картографиясы, жер ресурстарын басқару, агроэкологиялық стресс, жайылым деградациясы, Қазақстан.

Ж. М. Жуматаева*[1] , Ж. К. Мукалиев[2], К. Ж. Касымханова[3], С. Р. Турганалиев[4]

[1] *PhD докторант (Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; ***zhazka06@gmail.com***)
[2] Старший преподаватель (Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; *Zh.mukaliyev@kaznu.kz*)
[3] Магистрант (Казахский национальный исследовательский технический университет им. К. И. Сатпаева, Алматы, Казахстан; *kamila-k@bk.ru*)
[4] К. э. н., доцент (Международная образовательная корпорация, Алматы, Казахстан; *S.Turganaliev@mail.ru*)

КОМПЛЕКСНАЯ ГЕОИНФОРМАЦИОННАЯ ОЦЕНКА СОСТОЯНИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЕЛЬ ВОСТОЧНОГО КАЗАХСТАНА НА ОСНОВЕ ДАННЫХ SENTINEL-2 NDVI И ПОЧВЕННОЙ ИНФОРМАЦИИ

Аннотация. Оценивается эффективность геоинформационных инструментов для мониторинга и управления сельскохозяйственными землями на примере области Абай и Восточно-Казахстанской области. Топографическая основа, цифровые почвенные карты и спутниковые данные Sentinel-2 интегрированы в единую геобазу данных. На основе спутниковых данных сформированы композиты в естественных цветах, нормализованный разностный вегетационный индекс (NDVI) и тематические слои сельскохозяйственного землепользования. Методология включает маскирование атмосферных помех и облачности, формирование композитов, расчет региональной статистики NDVI по классам землепользования и типам почв, а также оценку эффективности рабочего процесса по критериям точности, оперативности, трудоемкости и интероперабельности. В результате получены картографические и аналитические материалы, характеризующие состояние агроландшафтов, выявлены зоны агроэкологического стресса и показана возможность разграничения временного снижения вегетационной активности, связанного с проведением сельскохозяйственных работ, и потенциально устойчивых признаков деградации пастбищ. Научная новизна заключается в комплексной интерпретации данных Sentinel-2 NDVI, классов сельскохозяйственного землепользования и цифровой почвенной информации в единой ГИС-среде. Практическая значимость определяется воспроизводимостью методики, возможностью регулярного обновления данных и применимостью полученной пространственной информации для мониторинга и управления сельскохозяйственными землями.

Ключевые слова: ГИС, мониторинг сельскохозяйственных земель, NDVI, Sentinel-2; дистанционное зондирование, почвенное картографирование, управление земельными ресурсами, агроэкологический стресс, деградация пастбищ, Казахстан.