Application of Geoinformation Databases in the Digital Monitoring and Rational Use of Land Resources in Kazakhstan

Yerzhan Zhusupov [1], Timur Rafikov[1], Aizhan Zhildikbaeva[2*] and Virginija Gurskiene[3]

[1] Kazakh National Agrarian Research University, Republic of Kazakhstan, 050010, Almaty region, Almaty, Abaya Ave. 8
[2*] Department of Land Resources and Cadastre; Kazakh National Agrarian Research University; Republic of Kazakhstan, 050010, Almaty region, Almaty Abaya Ave. 8
[3] Department of Land Management and Geomatics, Faculty of Engineering, Vytautas Magnus University, Kaunas, Lithuania

Received:15.04.2026 Accepted: 21.05.2026 Published: 27.05.2026
https://doi.org/10.54414/WMVF7775

Abstract

In the context of the ongoing digital transformation of land administration systems in the Republic of Kazakhstan, geoinformation databases are becoming a key instrument for land monitoring and rational land resource management. The purpose of this study is to substantiate and evaluate the application of geoinformation databases as the core of land monitoring systems, as well as to develop a methodological approach for their use in spatial analysis and decision support. The study is based on the application of modern geoinformation technologies, including ArcGIS Pro, spatial analysis tools, and visual geoprocessing modeling using ModelBuilder. The research focuses on the development of a structured geoinformation database that ensures data consistency, integrity, and reproducibility of analytical results. An analytical land-use monitoring model was developed to automate spatial data processing, including spatial selection, overlay analysis, area calculation, and the generation of summary statistics. The proposed approach was practically tested using data stored in the geoinformation database, which made it possible to assess its applicability for analyzing land-use structure and identifying spatial changes in land resources. The results demonstrate that the integration of geoinformation databases with automated analytical models significantly improves the efficiency of land monitoring, enhances result comparability, and reduces the influence of subjective factors in spatial analysis. The findings of this study confirm that geoinformation databases, combined with spatial analysis and automated geoprocessing tools, provide a solid methodological and technological basis for the development of regional and national land monitoring systems. The proposed framework can be used to support rational land resource management and spatial planning in Kazakhstan.

Keywords: geographic information systems, geoinformation database, land resources, land monitoring, land use, spatial analysis, ArcGIS Pro, ModelBuilder

1. Introduction

In the context of the digital transformation of public administration and the development of spatially oriented information systems, geoinformation technologies are becoming a key tool for monitoring and the rational management of land resources. In many countries, geoinformation databases serve as the foundation for modern spatial analysis systems, ensuring the integration of diverse information, increased transparency in land use, and well-founded management decisions. For the Republic of Kazakhstan, which possesses land resources that are vast in area and diverse in structure, the development of effective geoinformation solutions is relevant (D'Acunto et al., 2024).

In recent years, Kazakhstan has been implementing several programs aimed at introducing geographic information systems, Earth remote sensing technologies, and web-based platforms into the fields of land management and spatial planning. Cadastral information systems, regional geoportals, and land-use monitoring services are being established and developed. Numerous studies show that the use of GIS contributes to improving the accuracy of land valuation, identifying changes in land cover, and supporting management decision-making in the fields of agriculture, ecology, and land management. At the same time, a significant portion of existing solutions is focused primarily on the visualization of spatial data and its reference use (Blanche, M.F. et al., 2024).

International experience shows that geoinformation databases form the technological core of modern spatial data infrastructures, ensuring long-term storage, processing, and analysis of geographic information. Using databases as the foundation of GIS enables a systematic approach to land resource management, including spatial analysis, modeling, mapping, and decision support. The widespread adoption of open geoinformation solutions further expands the possibilities for creating scalable and replicable land monitoring systems (Asam, S. et al., 2025).

In this context, the development and application of geoinformation databases focused on the tasks of monitoring and rational management of Kazakhstan's land resources represent a pressing scientific and practical challenge. The object of the study is a land resource monitoring system based on geoinformation technologies. The subject of the study is the structure, principles of formation, and functional capabilities of geoinformation databases used for the analysis and management of land use (Shokparova D.K. et al., 2025).

The aim of this study is to develop and justify a geoinformation database as the foundation for monitoring and rational management of land resources in the Republic of Kazakhstan. To achieve this aim, the study will address the following objectives:

• analyze current approaches to the use of geoinformation databases in land resource management;

• develop the structure of a geoinformation database that integrates spatial and attribute data on land use;

• assess the potential applications of the developed database for analysis, monitoring, and supporting management decisions.

The structure of the article includes a theoretical review and analysis of existing approaches, a description of the source data and methodological solutions, a presentation of the developed geoinformation database, and a discussion of the results of its application in the tasks of monitoring and rational land resource management.

2. Materials and Methods

The methodological framework of the study is based on the comprehensive use of geographic information systems, spatial databases, and Earth remote sensing methods, aimed at creating a unified geographic information database for monitoring and the rational management of land resources in the Republic of Kazakhstan. A systematic approach was applied in this work, ensuring the integration of heterogeneous spatial and attribute data within a unified logical structure oriented toward analytical support for management decisions (Sabljić, L. et al., 2024; Dubovyk, O., 2017).

The source materials used included digital spatial data from various sources, such as information on the boundaries of administrative-territorial units, land-use patterns, natural features, and infrastructure elements, as well as medium-resolution Earth remote sensing data. All source datasets underwent mandatory preprocessing, including transformation to a unified coordinate system, correction of geometric and topological errors, unification of attribute fields, and verification of the spatial consistency of layers. This ensured data comparability and improved the reliability of subsequent spatial analysis (FAO, Land resources planning for sustainable land management).

The methodology placed particular emphasis on the creation of vector datasets as a key component of the geodatabase. The process of selecting, refining, and vectorizing spatial information was carried out based on an analysis of available sources, the interpretation of satellite imagery, and comparison with existing cartographic materials (Figure 1). This stage facilitated the transition from disparate spatial sources to structured vector layers suitable for storage and analysis in a geodatabase.

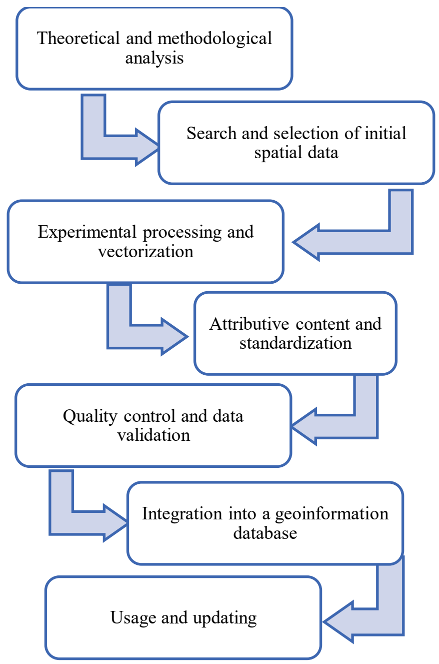

Figure 1. The process of selecting vector data for the development of a geodatabase

**Compiled by the author*

The geodatabase was designed in accordance with the principles of relational-spatial organization, ensuring data integrity, scalability, and the ability to update data. The structure of the geodatabase included interconnected thematic layers reflecting administrative divisions, land categories, land use types, natural conditions, and infrastructure elements. Logical relationships between objects made it possible to account for the spatial and temporal dynamics of land use, as well as to perform a comprehensive analysis of changes in land resources.

Methods of spatial analysis and cartographic modeling were used for analytical data processing, with the aim of identifying the structure and dynamics of land use. The analysis of remote sensing data included preliminary image correction and the calculation of spectral indices characterizing the condition of the land cover. The results obtained were integrated into a geographic information database, ensuring their compatibility with cadastral and thematic layers and expanding the system's analytical capabilities (Zhumataeva J. et al., 2024).

The developed geoinformation database was tested using typical usage scenarios characteristic of land resource monitoring and management tasks. The ability to update data in real time, execute spatial queries, and generate thematic maps necessary to support management decisions was evaluated. The results of the testing confirmed the feasibility of using geoinformation databases as a functional foundation for the monitoring and rational management of land resources.

3. Results and Discussion

During the study, a geographic information database was developed and tested, designed to address the tasks of monitoring and rational management of land resources in the Republic of Kazakhstan. The results confirm that using a structured geodatabase as the core of a geographic information system allows for a transition from fragmented storage of spatial data to a comprehensive, logically connected model of spatial analysis and management decision support (G. Kabzhanova et al., 2023; Reynolds, J. F., 2023).

Based on the developed structure of the geoinformation database, logical models of its practical use were formed, reflecting the main scenarios of user interaction with spatial information. These models are implemented as functional diagrams ("builder models") demonstrating the sequence of data acquisition, processing, storage, and analysis within a unified geoinformation environment. This approach made it possible to formalize the processes of working with the geodatabase and ensure the reproducibility of analytical operations when solving land monitoring tasks (Zhu, Z., Woodcock, C. E., 2014).

As part of the modeling process, scenarios for integrating vector and raster data were implemented, in which spatial information from various sources is sequentially converted and stored in a geographic information database. The geodatabase serves as the central element of the system, ensuring the accumulation, updating, and logical linking of information on land resources. The use of a unified attribute structure and standardized spatial relationships ensured data comparability and minimized information duplication (Tucker, C. J., 1979).

Figure 2 presents a generalized diagram of the application of a geoinformation database in a land resource monitoring system, illustrating the key stages of working with spatial information-from the creation of vector layers to their use in analytical and management tasks.

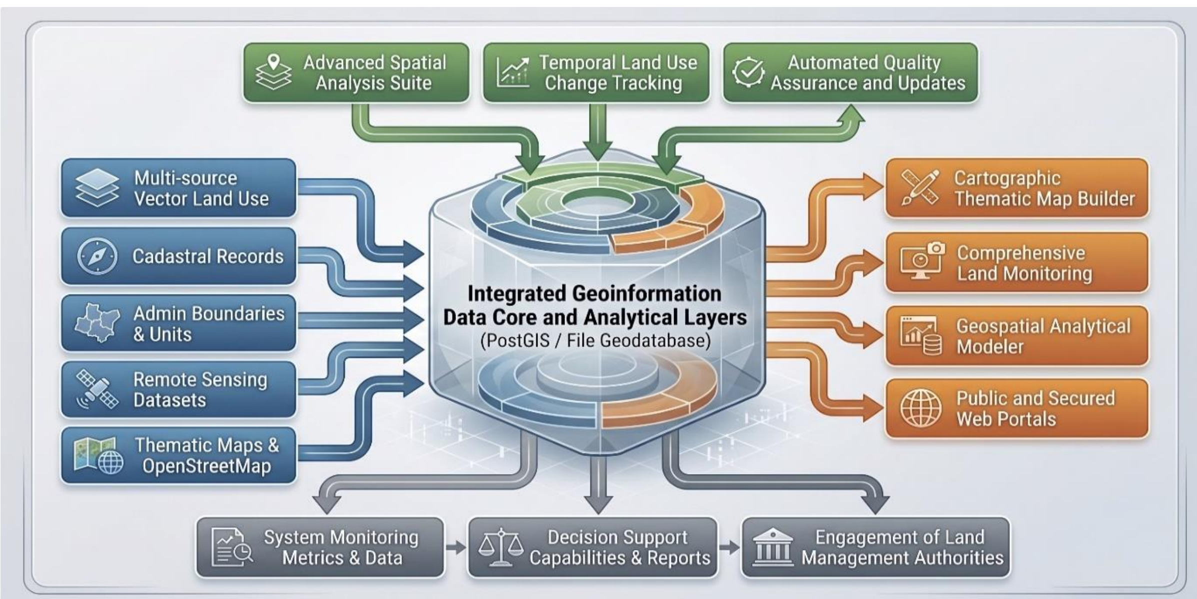

Figure 2. *Model of the use of a geographic information database in a land resource monitoring system* (G. Kabzhanova et al., 2023)

The model of geoinformation database usage presented in Figure 2 reflects the systematic and comprehensive nature of land resource monitoring. Within this model, the geoinformation database serves as a central integrating element, ensuring the consolidation of diverse spatial and attribute data, their consistency, and analytical processing. The model clearly demonstrates the interrelationship between the main sources of spatial information, analytical procedures, and application modules, the interaction of which results in cartographic and analytical products used to support management decision-making in the field of rational land use.

The structure shown illustrates that the geoinformation database is not limited to the function of storing information but serves as an active element of the monitoring system, ensuring the implementation of spatial analysis, assessment of land-use changes, and data quality control. Integrating the geodatabase with analytical and cartographic modules enables the creation of reproducible analysis scenarios designed to address both operational and strategic land resource management tasks.

To provide a more detailed explanation of the practical aspects of implementing the proposed model, we will now examine the architecture of the analytical and cartographic modules that operate based on a geoinformation database. Attention is paid to issues related to the organization of the geodatabase structure, the interaction of individual thematic datasets, and the mechanisms for their use in the process of spatial analysis and mapping. It is shown how the structured data of the geodatabase are applied in a desktop GIS environment to automate geoprocesses, generate thematic layers, and prepare analytical materials used in the land resource monitoring system.

The interface fragment presented below clearly illustrates the organization of the geodatabase and the principles of interaction between analytical and cartographic modules within a single software environment. This allows one to trace the logical connection between the conceptual model of using the geoinformation database and its practical implementation, as well as to emphasize the applied focus of the developed approach.

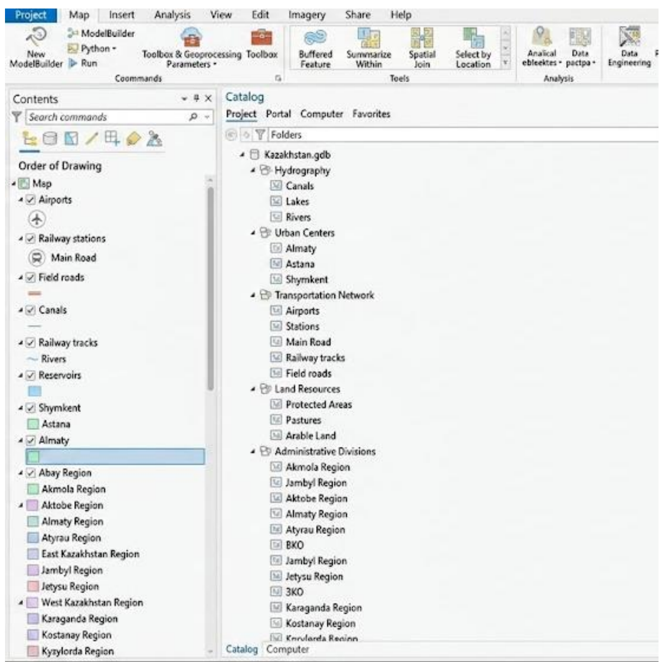

Figure 3. *Architecture of analytical and mapping modules based on a geoinformation database*
**Compiled by the author*

The results of modeling and field testing have shown that the developed geographic information database can be effectively used as a core for implementing various analytical and cartographic scenarios. In particular, its application enables the analysis of land-use patterns, the identification of spatial changes in agricultural land, and the comparison of cadastral data with remote sensing results. These scenarios are implemented through the modular architecture of the geodatabase, which supports the reuse of spatial layers and analytical procedures across various application modules without altering the underlying data structure.

To systematize the results of the design and practical application of the geoinformation database, Table 1 summarizes the main functional components of the system and their role in the process of monitoring and rational management of land resources.

***Table 1.** Functional components of a geographic information database and their purposes*

System component	Main content	Functional purpose
Vector layers	Administrative boundaries, land parcels, land use categories	Пространственная основа мониторинга и анализа
Raster data	Satellite images, land cover indices	Assessment of Land Dynamics and Condition
Attribute database	Cadastral and descriptive characteristics of land	Analytical support for management decisions
Analytical modules	Spatial queries, overlay, classification	Identifying changes and patterns
Cartographic billboards	Thematic maps, visualization of results	Data Presentation and Decision Support

The functional components presented in the table form a comprehensive system in which the geographic information database serves not only as a repository for spatial information but also as a key element of the analytical infrastructure for land resource monitoring. The integration of structured spatial data with analytical and cartographic modules enables comprehensive land-use analysis, the identification of spatial patterns, and the formulation of informed management decisions regarding the rational use of land.

The practical implementation of these functions is based on the use of tools for the visual modeling of geoprocesses, which allow for the formalization of a sequence of analytical operations and ensure their automated execution. The use of the ModelBuilder environment enables the construction of reproducible analytical chains based on data from the geoinformation database, including stages of spatial selection, overlay, classification, and calculation of quantitative indicators. This approach ensures the standardization of data processing procedures and improves the comparability of monitoring results when calculations are performed repeatedly.

In this study, ModelBuilder was used as a tool for integrating geospatial data with applied land resource monitoring tasks, enabling a shift from one-off analytical operations to formalized analysis scenarios. The implemented models provide automated processing of spatial information, the generation of final cartographic materials, and the derivation of analytical indicators necessary for assessing the structure and dynamics of land use.

The developed geoprocessing workflow based on ModelBuilder clearly illustrates the architecture for using a geodatabase in a land resource monitoring system and demonstrates the relationship between source data, analytical procedures, and the results of spatial analysis. The concept and logic behind the construction of this model are presented in Figure 4.

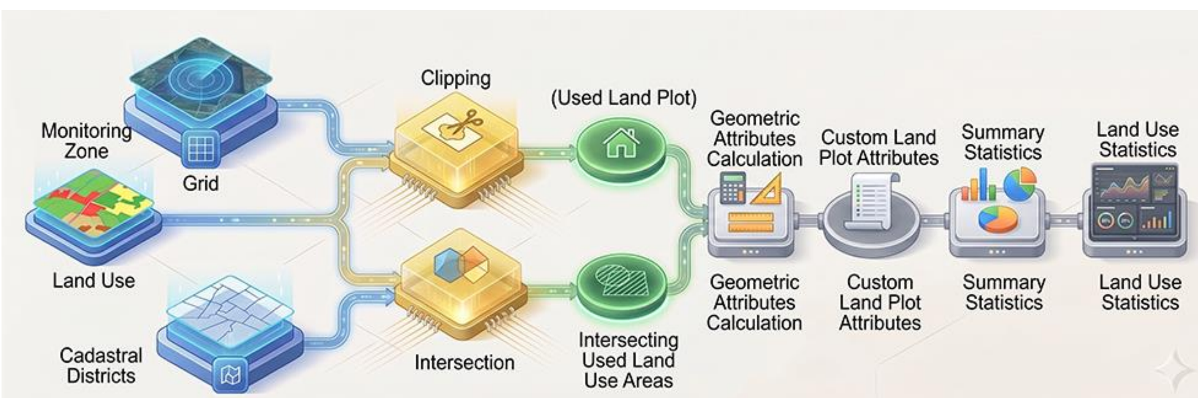

***Figure 4.** An analytical model for land-use monitoring based on a geoinformation database, implemented in the ModelBuilder environment (created with ArcGIS Pro)*

The analytical model presented here clearly demonstrates the practical application of a geoinformation database in a land resource monitoring system. The formalization of the sequence of geoprocesses in the ModelBuilder environment enables the automation of spatial analysis operations, including data selection for the monitoring area, analysis of intersections with cadastral units, and calculation of quantitative land-use indicators. This allows for reproducible and comparable results, eliminating the influence of subjective factors during analytical operations.

The implementation of monitoring based on the developed model confirms that a geoinformation database can be effectively used not only as a repository of spatial information but also as a foundation for building applied analytical tools. The use of visual modeling of geoprocesses ensures the standardization of data processing procedures and creates conditions for their repeated application within the framework of various territorial and thematic tasks.

The results obtained indicate that integrating a geoinformation database with analytical modules improves the effectiveness of land-use monitoring and enhances the capacity to support management decisions. This, in turn, forms the methodological basis for the further development of the land monitoring system and its scaling up to the regional and national levels, which determines the main conclusions and prospects for further research.

4. Conclusion

In accordance with the research objectives and tasks outlined in the introduction, this study confirms the effectiveness of using geographic information databases as a foundation for monitoring and rational management of land resources in the Republic of Kazakhstan. The study showed that a structured geoinformation database ensures the integrity, comparability, and timeliness of the spatial information necessary for land use analysis and to support management decisions.

The primary objective of the study-the development and testing of a geoinformation database designed for land resource monitoring-has been achieved. The structure of the geodatabase ensures the integration of vector and raster data, accounts for the spatio-temporal characteristics of land use and allows for multiple analytical uses of the data without altering its underlying architecture.

As part of the study, an analytical model for land-use monitoring was implemented using the ModelBuilder environment within the ArcGIS Pro software suite. The use of visual modeling of geoprocesses made it possible to formalize and automate the sequence of spatial operations, including spatial selection, intersection analysis, calculation of area indicators, and generation of summary statistics. This ensured the reproducibility and comparability of monitoring results, as well as reduced the influence of subjective factors during the performance of analytical procedures.

The results confirm that integrating a geoinformation database with analytical and cartographic modules expands the functional capabilities of land monitoring systems. The use of a modular approach and the reuse of spatial layers allow for the effective analysis of land-use patterns, the identification of spatial changes in agricultural land, and the comparison of cadastral data with remote sensing data.

The developed approach demonstrates the practical applicability of geographic information systems as a tool for supporting the rational use of land resources and territorial planning. The results obtained can be used in the activities of land resource management agencies, research and design organizations, as well as in the development of regional and national land monitoring systems.

Overall, the research results confirm that the use of geoinformation databases in combination with spatial analysis tools and automated geoprocessing creates a methodological and technological foundation for the further development of land resource monitoring systems. The proposed approach has the potential to be scaled up to the regional and national levels and can serve as the basis for the formation of a unified spatial data infrastructure for the Republic of Kazakhstan.

References

1. D'Acunto, F., Marinello, F., & Pezzuolo, A. (2024). Rural land degradation assessment through remote sensing: Current technologies, models, and applications. *Remote Sensing*, 16(16), 3059. https://doi.org/10.3390/rs16163059
2. Blanche, M. F., Dairou, A. A., Juscar, N., et al. (2024). Assessment of land cover degradation due to mining activities using remote sensing and digital photogrammetry. *Environmental Systems Research*, 13, 41. https://doi.org/10.1186/s40068-024-00372-5
3. Asam, S., Schwarzenbacher, F., Marshall Ingram, D., & Bachmann, M. (2025). Detection of land degradation risk in Azerbaijan by combining fractional cover estimates based on DESIS data with multi-decadal Landsat NDVI trends. *International Journal of Remote Sensing*, 1–32. https://doi.org/10.1080/01431161.2025.2536884
4. Shokparova, D. K., Sirazhitdinova, M., Bissenbayeva, S. B., & Patel, N. (2025). Remote sensing and GIS-based land assessment in Zhanaarka region of Ulytau oblast, Kazakhstan. *Frontiers in Environmental Science*, 13, 1516460. https://doi.org/10.3389/fenvs.2025.1516460
5. Sabljić, L., Lukić, T., Bajić, D., Marković, S. B., & Delić, D. (2024). Application of remote sensing in monitoring land degradation: A case study of Stanari municipality (Bosnia and Herzegovina). *Open Geosciences*, 16(1), 20220671. https://doi.org/10.1515/geo-2022-0671
6. Dubovyk, O. (2017). The role of remote sensing in land degradation assessments: Opportunities and challenges. *European Journal of Remote Sensing*, 50(1), 601–613. https://doi.org/10.1080/22797254.2017.1378926
7. FAO. (2017). *Land resources planning for sustainable land management*. FAO Land and Water Discussion Paper 14. Rome: FAO. https://www.fao.org/3/i5937e/i5937e.pdf
8. Zhumataeva, Zh., Serikbaeva, G., Turganaliev, S., Mukaliev, Zh., & Rafikov, T. (2024). Povyshenie ekologo-ekonomicheskoi effektivnosti ispol'zovaniya zemel'nykh resursov. *Izdenister Natigeler*, 2(102), 360–369. https://doi.org/10.37884/2-2024/35 [in Russian]
9. Kabzhanova, G., Kurmasheva, A., Alibaeva, M., & Bisembaev, A. (2023). Izuchenie prostranstvennogo raspredeleniya tipov pastbishch sukhostepnoi zony Pavlodarskoi oblasti po dannym DZZ. *Vestnik*, 2(1), 63–72. [in Russian]
10. Reynolds, J. F., (2007). Global desertification: Building a science for dryland development. *Science*, 316(5826), 847–851. https://doi.org/10.1126/science.1131634
11. Zhu, Z., & Woodcock, C. E. (2014). Continuous change detection and classification of land cover using all available Landsat data. *Remote Sensing of Environment*, 144, 152–171. https://doi.org/10.1016/j.rse.2014.01.011
12. Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0