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Digital transformation of land resource management and development of the national spatial data infrastructure using artificial intelligence

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Abstract. In the context of the digitalisation of the economy of the Kyrgyz Republic, the transformation of the land resource management system has become strategically important, as the efficient use of the national land fund is directly linked to ensuring the sustainable development of the agricultural sector, increasing the investment attractiveness of territories, and improving public regulatory mechanisms. The purpose of this study was to assess the role of artificial intelligence technologies and the national spatial data infrastructure in enhancing the efficiency of land resource management in the Kyrgyz Republic. The methodological framework of the study was based on system analysis, comparative analysis, economic and statistical methods, as well as geoinformation modelling and spatial data analysis. The research included a comprehensive assessment of the current state of digitalisation in the country's land resource management system and identified the main institutional and technological constraints, including fragmented information resources, insufficient integration of digital platforms, limited access to spatial data, and a shortage of qualified specialists in geoinformation

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technologies. The findings demonstrated that the implementation of artificial intelligence tools improves the accuracy of land resource monitoring, automates spatial data processing, supports forecasting of land-use changes, and enhances the validity of managerial decision-making. The results also indicated that integrating geographic information systems with intelligent algorithms increases the transparency of land resource management, reduces the risks of inefficient land use, and optimises government control and regulatory processes. Priority directions for the development of the national spatial data infrastructure had been identified, including the standardisation of information flows, integration of digital services, expansion of interagency cooperation, and improvement of access to geospatial information resources. The practical significance of the study lay in the possibility of applying its findings in the development and implementation of national digital strategies for land resource management in the Kyrgyz Republic

Keywords: geographic information systems; digital cadastre; intelligent data analysis; land relations; territorial monitoring; management automation

Introduction

Against the backdrop of the digital transformation of the economy and mounting global challenges linked to climate change, land degradation and the need to ensure food security, the issue of improving the efficiency of land resource management is becoming particularly pressing. For the Kyrgyz Republic, with its limited land resources and high dependence on the agricultural sector, effective management of the land fund is becoming a key factor in sustainable socio-economic development. In this context, the introduction of digital technologies, including artificial intelligence and spatial data infrastructure, is seen as a strategic approach to modernising the land resource management system and enhancing the transparency of decision-making. Recent research confirms the significant potential of artificial intelligence in the management of natural resources and agriculture. I. Bhat *et al*. (2025) emphasise that the use of machine learning algorithms enables the optimisation of data analysis and yield forecasting processes. A study by A. Mana *et al*. (2024) found that the integration of artificial intelligence with geographic information systems enables more accurate monitoring of land resources and improves the quality of management decisions. P. Ruksar *et al*. (2025) demonstrated that the use of big data analytics and artificial intelligence can significantly improve the accuracy of decision-making in agriculture, particularly in the face of climate uncertainty. Y. Yang & Y. Sun (2025) point out that digital platforms and spatial data play a key role in the development of sustainable agricultural systems. A study by S. Satpati (2026) highlights the need to develop inclusive artificial intelligence-based solutions tailored to smallholder farms, which is particularly relevant for countries with developing economies. At the same time, K. Chowdhury *et al*. (2025) note that one of the main barriers to the adoption of artificial intelligence is the inadequate level of digital infrastructure and limited access to high-quality data. A. Atapattu *et al*. (2024) highlight the problem of a lack of representative datasets, which reduces the effectiveness of artificial intelligence models in local contexts. Despite the rapid development of digital technologies, the scientific literature does not devote sufficient attention to the integration of artificial intelligence specifically into the land resource management system and the development of the national spatial data infrastructure in the Kyrgyz Republic. The lack of comprehensive studies that take regional characteristics into account limits the scope for the effective implementation of digital solutions and reduces their practical significance.

Recent research confirms the growing role of artificial intelligence in the development of digital agriculture and spatial analysis systems. For instance, A. Adewusi *et al*. (2024) note that artificial intelligence technologies make it possible to significantly improve the efficiency of spatial data processing by automating the analysis of satellite imagery, monitoring agricultural land and forecasting the state of natural resources. The authors concluded that the application of intelligent algorithms helps to improve the sustainability of agricultural production and optimise the use of land resources. In the study by L. Chen *et al*. (2023), it was established that artificial intelligence is an important tool for adapting to climate change, as it enables the modelling of land degradation scenarios, the analysis of the impact of natural factors, and the improvement of environmental risk management. The authors emphasise that digital technologies are becoming a key prerequisite for sustainable territorial development in countries experiencing high climate vulnerability. C. Ge *et al*. (2025) devote considerable attention to the application of artificial intelligence technologies in agriculture; they have established that the development of intelligent management systems helps to improve the accuracy of land monitoring, optimise water use and reduce production risks. The researchers emphasise that the most effective results are achieved by combining remote sensing, big data analysis and machine learning. K. Wu *et al*. (2025) reach similar conclusions, noting that the development of digital land resource management platforms is impossible without the integration of spatial data and intelligent analytical systems. Of particular significance to this study are the findings of the FAO (n.d.), according to which the digitalisation of the agricultural sector in the Kyrgyz Republic is at an advanced stage of development; however, the level of integration of spatial data and the adoption of intelligent technologies remains limited. The report emphasises the need to strengthen digital infrastructure, improve the digital literacy of professionals and refine mechanisms for managing agricultural resources.

Despite a significant increase in the number of studies devoted to the application of artificial intelligence in the agricultural sector, an analysis of the scientific literature shows that most studies focus primarily on precision farming, the automation of agricultural production and yield forecasting. At the same time, the issues surrounding the comprehensive use of artificial intelligence technologies in the development of the national spatial data infrastructure and the digital transformation of the land resource management system remain under-researched, particularly as they relate to the conditions in the Kyrgyz Republic. The aim of the study was to conduct a comprehensive analysis of the potential for the digital transformation of the land management system in the Kyrgyz Republic, based on the development of a national spatial data infrastructure and the implementation of artificial intelligence technologies aimed at improving the effectiveness of management decision-making.

Literature Review

In recent years, the digital transformation of the land management system has been regarded as one of the most promising avenues for improving the efficiency of public administration, ensuring sustainable land use and minimising the negative impact of climate change on the agricultural sector. Advances in artificial intelligence, geographic information systems (GIS), remote sensing, big data analysis and the national spatial data infrastructure (NSDI) are creating new opportunities for land monitoring, forecasting degradation processes and improving the quality of management decisions. In contemporary academic literature, research on the digitalisation of land management is primarily developing along several lines: the application of artificial intelligence in the agricultural sector, the use of spatial data and geoinformation technologies, the integration of decision-support systems, and the institutional and infrastructural constraints on digital transformation.

Research into the application of artificial intelligence in the agricultural sector confirms the significant potential of digital technologies to improve the efficiency of natural resource management. For instance, I. Gryshova *et al*. (2024) point out that the introduction of intelligent technologies helps to enhance the sustainability of agricultural production by automating information processing, optimising resource use and improving the adaptability of agricultural systems to climate change (Wu *et al.*, 2025). The authors emphasise that the use of analytical algorithms not only improves the efficiency of agricultural production but also minimises environmental risks. A similar view is held by I. Bhat *et al*. (2025), who regard artificial intelligence as a strategic tool for agribusiness management. According to the researchers, the use of machine learning algorithms significantly improves the analysis of spatial and production data, enabling the prediction of changes in crop yields, the identification of potential risks and the reduction of uncertainty in management decision-making (Srikanthnaik, 2024). At the same time, the author notes that the effectiveness of such technologies depends directly on the quality of the data and the level of digital maturity of the institutional environment. A. Mana *et al*. (2024) pay particular attention to the digitalisation of the agricultural sector; in their research, they analyse the integration of artificial intelligence with geoinformation technologies. The researchers concluded that the use of intelligent algorithms in conjunction with spatial data makes it possible to significantly improve the accuracy of land monitoring, identify changes in land use and develop more effective mechanisms for territorial management. P. Ruksar *et al*. (2025) emphasise that the combination of machine learning and GIS technologies opens up new opportunities for the rational management of land resources. L. Chen *et al*. (2023) have made an important contribution to research into the sustainable use of land resources, viewing artificial intelligence as a tool for adapting to climate change. The authors demonstrate that forecasting algorithms enable the modelling of land degradation scenarios, the analysis of desertification risks, and the assessment of the impact of climate change on the productivity of territories. According to the researchers, the application of intelligent systems is becoming particularly important for countries characterised by high natural and climatic vulnerability.

A separate area of research concerns the use of spatial data and the development of a national spatial data infrastructure. M. Nehrey (2023) notes that the digital transformation of land management is impossible without the integration of cadastral, statistical, environmental and geospatial databases into a single digital ecosystem. The author points out that the fragmentation of information systems significantly limits the scope for comprehensive analysis of territories and reduces the effectiveness of public administration of land resources. Continuing this line of research, K. Wu *et al*. (2025) emphasise that the effectiveness of land management depends directly on the quality of spatial information and the level of development of digital platforms. The researchers conclude that the integration of artificial intelligence technologies into spatial analysis systems enables the automatic processing of large volumes of data in real time, thereby significantly improving the quality of management decisions. A. Adewusi *et al.* (2024), who note that the use of satellite data in combination with artificial intelligence enables the automation of agricultural land monitoring processes, the identification of changes in soil condition and the prediction of potential risks of land degradation. The authors emphasise that intelligent image-processing systems provide greater analytical accuracy compared with traditional observation methods. Similar conclusions are presented in the work by S. Saha *et al.* (2024), which focuses on the use of neural networks in processing images obtained from unmanned aerial vehicles. The researchers note that modern computer vision technologies enable the effective analysis of spatial changes, the identification of land parcel boundaries, and the high-precision monitoring of land conditions. At the same time, A. Atapattu *et al.* (2024) acknowledge that technical limitations remain at present regarding the automated recognition of complex natural features.

Research focusing on big data analytics and decision support systems is of considerable interest. P. Ruksar *et al.* (2025) demonstrated that the application of big data analytics in combination with artificial intelligence can significantly improve the accuracy of forecasting under conditions of climate uncertainty. The authors note that intelligent platforms are capable of taking into account a multitude of interrelated factors, which makes land resource management more adaptive and sustainable. Similar results are demonstrated by Y. Yang & Y. Sun (2025), who view digital platforms as the foundation for the development of sustainable agricultural systems. The researchers concluded that spatial data and artificial intelligence algorithms can improve the efficiency of land resource management by creating a more transparent decision-making system that takes economic, environmental and social factors into account. At the same time, the limitations on the implementation of artificial intelligence technologies are widely discussed in contemporary academic literature. For instance, K. Chowdhury *et al.* (2025) note that digital inequality, caused by limited access to technological infrastructure and an insufficient level of digital literacy among specialists, remains one of the key barriers. The researchers emphasise that without the development of the digital environment and ensuring access to high-quality data, the effectiveness of intelligent systems is significantly reduced. This view is supported by A. Atapattu *et al.* (2024), who highlight the problem of a shortage of representative datasets for training intelligent models. According to the authors, most algorithms demonstrate high effectiveness in developed countries; however, their application in local contexts requires adaptation to take account of the natural, climatic and institutional characteristics of specific territories.

Issues relating to digitalisation are of particular relevance to the Kyrgyz Republic. According to the findings of the FAO (n.d.), the digital transformation of Kyrgyzstan's agricultural sector is gradually gaining momentum; however, the level of adoption of spatial platforms and smart systems remains insufficient. The organisation emphasises the need to modernise the information infrastructure, improve the digital literacy of specialists and integrate spatial data into the management of the agricultural sector. Furthermore, D. Sakkaraeva & M. Kumashev (2024) note that the development of the agricultural sector in the Kyrgyz Republic is hampered by a number of institutional constraints, including fragmented statistical data, limited digital platforms and insufficient integration of information systems. According to the researchers, these problems significantly limit the capacity for the operational management of the land fund and reduce the effectiveness of land resource monitoring.

Despite the significant body of research devoted to the application of artificial intelligence in agriculture and the digitalisation of the agricultural sector, an analysis of the scientific literature shows that the majority of studies focus primarily on precision farming, the automation of production processes and yield forecasting (Ye *et al.*, 2024). At the same time, issues relating to the comprehensive integration of artificial intelligence technologies into the land resource management system and the development of a national spatial data infrastructure – particularly as they apply to the conditions in the Kyrgyz Republic – remain under-researched. There is a limited number of studies in the scientific literature dedicated to assessing the effectiveness of the interaction between spatial data, digital platforms and intelligent algorithms within the state land resource management system, which highlights the need for further scientific analysis in this area (Polwaththa *et al.*, 2024). For their part, A. Hamrani *et al.* (2025), in analysing the application of robotic and intelligent technologies in the agricultural sector, note that the combination of robotics, sensor systems and artificial intelligence algorithms contributes to the development of fully digitalised agricultural land management systems. The authors emphasise that intelligent technologies enable a shift from traditional control methods to continuous, real-time monitoring of land resources. Analysing the prospects for the development of smart systems in the agricultural sector, G. Gupta & S. Pal (2025) concluded that the use of artificial intelligence is most effective when remote sensing technologies, cloud computing and geoinformation platforms are fully integrated. The researchers emphasise that it is spatial data that is becoming a key element of digital land management, as it enables the continuous updating of information on the state of the land resources.

Thus, an analysis of the current scientific literature shows that artificial intelligence technologies, spatial data and digital platforms are regarded as key tools for modernising the land resource management system. At the same time, the majority of existing studies focus primarily on precision farming, increasing crop yields and the automation of specific agricultural processes. Issues relating to the comprehensive integration of artificial intelligence into the land management system, the development of a national spatial data infrastructure and the establishment of digital decision-making mechanisms within the context of the Kyrgyz Republic remain under-researched. The lack of comprehensive studies that take into account regional characteristics, institutional constraints and the country's level of digital readiness highlights the need for further research into this issue and underlines the scientific significance of this study.

Materials and Methods

The study employed a comprehensive interdisciplinary approach, combining methods of economic and statistical analysis, geoinformation modelling, spatial analysis and artificial intelligence algorithms to assess the effectiveness of land resource management in the Kyrgyz Republic in the context of digital transformation. The study was conducted between 2015 and 2024 and covered agricultural areas in the Chui, Osh and Issyk-Kul regions, characterised by varying land-use specialisations, natural and climatic conditions, and levels of digitalisation of agricultural processes. The total area of the study sites amounted to over 120,000 hectares of agricultural land, comprising arable land, permanent crops, pastures and irrigated areas.

The study was based on official statistical and spatial data from the state authorities of the Kyrgyz Republic, as well as international information sources. The regulatory framework comprised the provisions of Law of the Kyrgyz Republic No. 153 (1998), as well as regulatory documents governing the maintenance of the state land cadastre, the digitisation of land records and the development of the national spatial data infrastructure. Statistical data were obtained from materials provided by the National Statistical Committee of the Kyrgyz Republic, the State Agency for Land Resources, Cadastre, Geodesy and Cartography, and open digital platforms (Open Data Portal of the Kyrgyz Republic, n.d.). In addition, analytical materials from the FAO (n.d.) were used, containing data on the state of land resources, levels of digitalisation in the agricultural sector and the prospects for the introduction of smart technologies in Kyrgyzstan's agriculture.

Geoinformation modelling methods based on the use of remote sensing data were applied to analyse the spatial characteristics of land resources (Bhat *et al.*, 2025). The study utilised multispectral satellite imagery from Sentinel-2 with a spatial resolution of 10 m and Landsat 8 with a spatial resolution of 30 m. These platforms were selected due to their high availability, regular image updates and the ability to analyse changes in land use over time. To minimise seasonal and atmospheric distortions, images acquired predominantly during the growing season (April-September) with cloud cover of less than 10% were used. The pre-processing of spatial data involved the stages of atmospheric correction, georeferencing, normalisation of spectral indices and noise removal. The processing was carried out using QGIS 3.28, ArcGIS Pro and the Google Earth Engine cloud analytics platform, which enabled the automation of work with large volumes of spatial data. Thematic GIS layers were generated from satellite imagery, including land-use types, the Normalised Difference Vegetation Index (NDVI), the level of land degradation, the degree of soil moisture, and the intensity of agricultural use. To identify spatial changes in land-use patterns, an overlay analysis method was applied, involving the sequential overlay of thematic maps from different time periods (Mana *et al.*, 2024). This approach made it possible to identify changes in the area of agricultural land, pinpoint areas of land degradation and determine zones of intensive land use (Rudoy *et al.*, 2023).

Artificial intelligence and machine learning algorithms were utilised for the automated processing of spatial data. In particular, the Random Forest algorithm was applied to classify land cover types and identify agricultural areas. This algorithm was chosen due to its high resistance to noise, its ability to process large datasets, and its high accuracy in classifying multidimensional spatial features. The input parameters used included spectral indices from satellite imagery, vegetation indices, and data on topography, soil types and land-use characteristics.

The model training procedure involved dividing the dataset into a training sample (70%) and a test sample (30%). Pre-annotated spatial features, identified using cadastral data and satellite imagery, were used for training. The model's robustness was verified using cross-validation, which ensured the reproducibility of results and minimised overfitting errors. Convolutional Neural Networks (CNNs) were used to segment agricultural fields and identify the spatial boundaries of land parcels. The algorithm was used for the automatic detection of land parcel boundaries in high-resolution satellite imagery. The neural network model was trained using a pre-annotated dataset of satellite images containing information on land-use types and land parcel characteristics. The quality of the classification was assessed by analysing the error matrix, the accuracy coefficient and the F1-score, which enabled an objective evaluation of the algorithms' effectiveness.

An economic and statistical analysis was carried out using correlation and regression modelling methods to assess the impact of digitalisation on the efficiency of land resource management. The dependent variable (Y) was an integrated indicator of the efficiency of land resource use, comprising indicators of crop yield, land productivity and the economic return on agricultural production. The independent variables were derived from statistical data and included: X_1 – the level of digitalisation in land resource management (proportion of digitalised cadastral processes, %); X_2 – intensity of land resource use (level of agricultural pressure per 1 ha); X_3 – investment in digital technologies (volume of financial investment in digital infrastructure, million KGS).

Geoinformation modelling involved conducting an overlay analysis to identify changes in land-use patterns, classifying land parcels by land-use type, and assessing degradation processes. Machine learning algorithms were used for the automated processing of spatial data. In particular, the Random Forest algorithm was used for land cover classification, whilst convolutional neural networks (CNNs) were used to segment agricultural fields based on satellite imagery. Classification accuracy was assessed using the accuracy coefficient and an error matrix. An economic and statistical analysis was carried out based on indicators of crop yields, production costs, and the use of water and land resources. To assess the impact of digital technologies on the effectiveness of land resource management, a multiple regression model was applied:

$$Y = 12.54 + 0.68X_1 + 0.43X_2 + 0.57X_3 + \varepsilon, \quad (1)$$

where Y is the indicator of land resource utilisation efficiency; X_1 is the level of digitalisation of management processes; X_2 is the intensity of land resource utilisation; X_3 is investment in digital technologies; ε is the random error of the model.

The results of the regression analysis demonstrated the statistical significance of the model: the coefficient of determination was $R^2 = 0.84$, indicating a high level of explanation of the variation in the dependent variable. A p-value of <0.05 confirmed the statistical significance of the model and the independent variables. The digitalisation level indicator had the greatest influence on the efficiency of land resource use ($\beta_1 = 0.68$), confirming the positive impact of digital technologies on the quality of land management. The Random Forest algorithm was applied for land-use classification, with n = 200 trees and a model depth of 15 levels. The training sample comprised 1,250 spatial objects. The model's accuracy was 91.4%, and the F1-score was 0.89. A convolutional neural network (CNN), trained on 3,200 images, was used to process the satellite images, achieving a final classification accuracy of 93.2%. Regression modelling yielded a coefficient of determination of $R^2 = 0.84$ and an RMSE of 0.18.

To test the model's robustness, diagnostics for multicollinearity were carried out, along with an analysis of the residuals and an assessment of the statistical reliability of the parameters. Statistical data processing was performed using the SPSS, Python (Scikit-learn, TensorFlow) and Microsoft Excel software packages. In addition, the study employed the SWOT analysis method, which enabled an assessment of the strengths and weaknesses of introducing artificial intelligence into land resource management, as well as the identification of institutional, technological and economic constraints on digital transformation. Logical modelling was used to systematise the results; on this basis, a conceptual model was developed for the integration of artificial intelligence technologies into the land resource management system and the national spatial data infrastructure of the Kyrgyz Republic (National Statistical Committee of the Kyrgyz Republic, n.d.).

A comparative analysis was carried out between traditional and digital approaches to land resource management based on the following criteria: yield (kg/ha), water consumption (m^3/ha), production costs (KGS/ha) and the level of digitalisation of processes (%). Aggregated data on more than 50 indicators for the period under review were used for the analysis. In addition, the SWOT analysis method was applied to assess the institutional, technological and economic factors involved in the implementation of artificial intelligence. To summarise the results, a logical modelling method was used, which enabled the development of a conceptual model for the integration of artificial intelligence into the land resource management system and the national spatial data infrastructure of the Kyrgyz Republic. Thus, the proposed methodology ensures the reproducibility of the research, enables a comprehensive analysis of spatial and statistical data, and allows for an objective assessment of the potential for the digital transformation of the land resource management system based on artificial intelligence technologies.

Results and Discussion

The results of the study indicate that the implementation of artificial intelligence technologies has a multifaceted impact on the effectiveness of land resource management in the Kyrgyz Republic. Analysis of spatial and statistical data has shown that the use of intelligent algorithms improves the accuracy of monitoring changes in land use, speeds up the processing of spatial information and reduces the error rate in cadastral registration. It has been established that the application of machine learning algorithms helps to improve the accuracy of yield forecasting by 12-15%, whilst simultaneously reducing the consumption of water resources and fertilisers, which is particularly important given the scarcity of natural resources. The results of applying the Random Forest algorithm showed an increase in land-use classification accuracy to 91.4%, as confirmed by a high F1-score (0.89). The use of a CNN enabled satellite image recognition accuracy of 93.2% to be achieved, particularly in the identification of degraded land. The regression model for yield forecasting demonstrated a high explanatory power ($R^2 = 0.84$), which indicates that the forecast results are reliable.

The results obtained are consistent with the research by I. Bhat *et al.* (2025), who demonstrated that the use of artificial intelligence improves the accuracy of yield forecasting and contributes to a more rational use of natural resources. Similar conclusions are presented by A. Mana *et al.* (2024), who highlight the effectiveness of integrating AI with geographic information systems (GIS) for analysing changes in land use. A. Adewusi *et al.* (2024) confirm that the automated processing of satellite data significantly reduces the time required to analyse agricultural areas and improves the accuracy of monitoring. In turn, D. Akhmatova (2023) points out that the low level of digital maturity in the countries of the Eurasian Economic Union is due to institutional constraints, whilst D. Sakkaraeva & M. Kumashev (2024) emphasise the need to modernise the digital infrastructure of Kyrgyzstan's agricultural sector. Through the use of intelligent algorithms, it has been possible to increase the accuracy of yield forecasts by 12-15%, as well as to reduce water and fertiliser consumption. This result demonstrates the high effectiveness of digital technologies when natural resources are limited. To assess trends in land use and the level of digitalisation in the Kyrgyz Republic, an analysis of statistical data for the period 2015-2024 was carried out (Table 1).

Table 1. Trends in land use in the Kyrgyz Republic (2015-2024)

Indicator	2015	2020	2024
Area of agricultural land, thousand hectares	10,650	10,720	10,830
Irrigated land, thousand hectares	1,020	1,045	1,060
Degraded land, thousand hectares	1,200	1,350	1,500
Proportion of land recorded digitally, %	25	45	65

Source: authors' calculations based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

An analysis of the data presented in Table 1 reveals a steady upward trend in the area of agricultural land, which is linked to the incorporation of new territories into agricultural use. At the same time, there has been an increase in the area of degraded land from 1,200 to 1,500 thousand hectares, which points to persistent environmental problems and inefficient land management. A significant development is the increase in the level of digital land registration from 25% to 65%, reflecting the gradual development of the national spatial data infrastructure in the Kyrgyz Republic. However, despite this positive trend, the level of digitalisation remains insufficient to ensure comprehensive monitoring and management of land resources. To quantitatively assess the effectiveness of the implementation of digital technologies and artificial intelligence, a comparative analysis of traditional and digital methods of land resource monitoring was carried out (Table 2).

Table 2. Effectiveness of land resource monitoring (traditional vs digital approach)

Indicator	Traditional approach	GIS+AI	Change
Accuracy of change detection	70-75%	85-95%	+15-20%
Data processing time	10-15 days	1-3 days	-80%
Data update frequency	Once a year	Monthly	↑
Cadastral data errors	15-20%	5-10%	-50%

Note: GIS – geographic information systems; AI – artificial intelligence
Source: authors' calculations based on analysis of Sentinel-2 satellite data and FAO (n.d.)

As can be seen from Table 2, the use of geographic information systems and artificial intelligence algorithms makes it possible to significantly improve the accuracy of identifying land-use changes – from 70-75% to 85-95%. At the same time, there is a significant reduction in data processing time – by up to 80% – which is critical when analysing large areas. There is also a reduction in errors in cadastral data of approximately 50%, confirming the effectiveness of automated methods for processing spatial information. The results obtained indicate that digital technologies enable a shift from sporadic land monitoring to systematic and continuous monitoring. In order to identify systemic issues limiting the development of digital land resource management, an analysis of institutional and technological factors was carried out (Table 3).

Table 3. Key challenges in land resource management in the Kyrgyz Republic

Challenge	Manifestation	Consequences
Data fragmentation	Disparate departmental databases	Poor coordination
Lack of standards	GIS incompatibility	Analytical errors

Table 3. Continued

Challenge	Manifestation	Consequences
Staff shortages	Shortage of GIS specialists	Limited implementation of AI
Restricted access to data	Closed databases	Reduced transparency
Land degradation	Erosion, salinisation	Reduced crop yields

Note: GIS – geographic information systems; AI – artificial intelligence
Source: developed by the authors

The data in Table 3 show that the key barriers are data fragmentation and the lack of uniform standards for data processing. This leads to inconsistencies between government bodies and reduces the effectiveness of geoinformation systems. Another significant problem is the shortage of qualified specialists in the fields of GIS and artificial intelligence, which limits the adoption of modern technologies. Furthermore, the issue of land degradation is highlighted, which requires the implementation of monitoring systems based on satellite data and intelligent analysis. Thus, the identified constraints are complex in nature and require a systematic approach to their resolution. A SWOT analysis was carried out to assess the strategic prospects for the implementation of artificial intelligence in land resource management (Table 4).

Table 4. SWOT analysis of the implementation of AI in land resource management in the Kyrgyz Republic

Strengths (S)	Weaknesses (W)
Improved monitoring accuracy	Shortage of specialists
Automation of the land register	High costs
Improved data analysis	Limited data
Opportunities (O)	**Threats (T)**
Development of the National Spatial Data Infrastructure (NSDI)	Cyber risks
Attracting investment	Technological dependence
Digitalisation of management	Social inequality

Note: NSDI – National Spatial Data Infrastructure
Source: developed by the authors

The results of the SWOT analysis show that the main advantages of implementing artificial intelligence are improved monitoring accuracy and the automation of data processing. At the same time, the weaknesses relate to the high cost of implementing the technology and a shortage of skilled personnel. Opportunities for development include the digitalisation of public administration and the integration of the National Land Use Plan, which could significantly improve the transparency and efficiency of land resource management. However, risks relating to cybersecurity and technological dependence remain, necessitating the development of a comprehensive strategy for AI implementation. A comparative analysis was carried out to contrast traditional and modern approaches to land resource management (Table 5).

Table 5. Comparison of traditional and digital land resource management systems

Criterion	Traditional system	Digital (GIS + AI)
Data management	Paper-based/disparate	Centralised
Monitoring	Manual	Automated
Accuracy	Average	High
Processing speed	Low	High
Decision-making	Intuitive	Data-driven

Note: GIS – geographic information systems; AI – artificial intelligence
Source: developed by the authors

An analysis of Table 5 shows that a digital management system based on the use of geoinformation technologies and artificial intelligence significantly outperforms traditional methods across all key parameters. In particular, process automation enables faster data processing and improves the quality of decision-making. Furthermore, digital systems provide a higher level of accuracy and transparency, which is particularly important for public land management. This confirms the need to transition to digital management platforms. To assess the potential for applying artificial intelligence in the land management system, a model of the impact of digital technologies was developed (Table 6).

Table 6. Potential impact of AI technologies on land resource management in the Kyrgyz Republic

Indicator	Without AI	With AI	Change
Accuracy of change monitoring	70-80%	85-95%	+15-25%
Data processing time	100%	10-30%	-70-90%
Errors in cadastral data	100%	40-60%	-40-60%
Data update speed	Low	High	↑
Identification of land degradation	Limited	Automated	Significant improvement

Note: AI – artificial intelligence
Source: authors' calculations based on the Open Data Portal of the Kyrgyz Republic (n.d.), National Statistical Committee of the Kyrgyz Republic (n.d.)

As can be seen from Table 6, the implementation of artificial intelligence technologies enables the accuracy of land-use change monitoring to be increased by 15-25%, which significantly improves the quality of spatial data analysis. The most significant benefit is a 70-90% reduction in data processing time, enabling a rapid response to changes in land use. There is also a 40-60% reduction in errors in cadastral data, which increases the reliability of information and reduces the risks associated with management decisions. Furthermore, the use of AI enables the automated detection of land degradation, which is an important tool for the sustainable management of natural resources (Skvortsov, 2020). Furthermore, the analysis carried out has shown that the application of artificial intelligence technologies in the land resource management system of the Kyrgyz Republic has significant potential, but requires systematic implementation within the framework of the national spatial data infrastructure. In particular, the use of satellite data and machine learning algorithms enables the automation of processes for identifying changes in land use, including illegal land use, soil degradation and changes in the structure of agricultural land (Srinivasu *et al.*, 2026).

It has been established that the integration of artificial intelligence into cadastral systems helps to improve data reliability through the automatic verification of information and the identification of inconsistencies. This is particularly important in the context of data fragmentation and the absence of a unified digital platform. Furthermore, the use of predictive models makes it possible to forecast the risks of land degradation and optimise land resource management processes based on the analysis of spatial and statistical data. Unlike traditional methods based on periodic monitoring, the use of intelligent algorithms ensures continuous, real-time analysis of the state of land resources. This enables more timely management decision-making and reduces the incidence of human error (Eze *et al.*, 2025).

Particular attention should be paid to the identified opportunities and limitations of AI applications, including an analysis of their strengths and weaknesses, as well as potential threats and prospects, which is consistent with the findings of I. Gryshova *et al.* (2024) and P. Srinivasu *et al.* (2026). For example, a case study analysis shows that artificial intelligence helps to increase productivity and product quality, whilst reducing production costs (Likhota, 2025). Nevertheless, the widespread adoption of AI faces a number of constraints, such as slow rates of technology adoption, which highlights the need for further study of these limitations (Skvortsov, 2020). Research points to the need to develop institutional support and improve financial and credit mechanisms to stimulate the adoption of innovations in the agricultural sector of the Kyrgyz Republic (Sakkaraeva & Kumashev, 2024). It is important to note, however, that the use of AI not only improves agricultural production through real-time crop monitoring, but also opens up new opportunities for the digital transformation of agriculture, including the optimisation of resource use and increased profitability (Bhat *et al.*, 2025). In this context, AI enables agricultural enterprises to monitor climate change and fluctuations in market demand in real time, whilst optimising resource utilisation and inventory management through modelling, forecasting and intelligent analytics (Zhang *et al.*, 2026). Furthermore, the capabilities of AI include the ability to self-learn, which is particularly relevant for recognising uncalibrated objects or building models of agricultural development that depend on various factors (Skvortsov *et al.*, 2020). Furthermore, the integration of AI with the IoT and robotic systems enables the automation of processes, reduces labour costs and minimises environmental impact (Lebid *et al.*, 2023; Shevchenko *et al.*, 2024).

Artificial intelligence applied to the sustainable development of agricultural systems encompasses a wide range of technologies, such as satellite data, soil sensors and weather data, enabling the precise management of farms (Bhat *et al.*, 2025). In particular, systems based on machine learning and deep neural networks help to improve the accuracy of yield forecasting and optimise irrigation schedules, which is critically important for water-stressed regions (Bachu *et al.*, 2024).

Such technologies also deliver significant reductions in fertiliser use of up to 28% and water use of 22%, whilst increasing crop yields by up to 25%, as noted by O. Ugwu *et al.* (2025). Such intelligent systems make it possible to identify the optimal time for harvesting, minimise waste and effectively monitor soil and crop conditions (Mana *et al.*, 2024). Consequently, AI helps to improve the adaptability of agricultural systems to climate change through the introduction of new plant varieties resistant to weather anomalies and the application of precision irrigation methods (Perekhodov, 2025). The integration of AI with Internet of Things and machine vision tools enables the collection and analysis of large volumes of data, allowing farmers to make more informed decisions regarding resource management and risk minimisation (Akintuyi, 2024). The use of machine learning algorithms to predict crop behaviour under various environmental conditions, based on the analysis of large volumes of data generated by IoT sensors and climate information systems, contributes to a significant improvement in the efficiency of agricultural production (Yparraguirre *et al.*, 2026). These intelligent systems can also analyse data to optimise business models within agri-food systems, thereby reducing their carbon footprint and enhancing their overall sustainability, as noted by D. Olawade *et al.* (2024). However, in order to generate instructions, information, forecasts and support for decision-making, AI requires data from its computing environment, which is most often provided via IoT sensors, satellites and weather stations (Assis *et al.*, 2024). Furthermore, AI can be used to reduce the use of herbicides, pesticides and other fertilisers by 25-35%, whilst increasing crop yields by 3-4%. These figures highlight the significant potential of AI in achieving more sustainable and productive agriculture, particularly in the context of resource constraints and the need to adapt to changing climatic conditions (Sherstiuk, 2025). AI also enables the optimisation of fertiliser application by analysing soil composition, nutrient levels and historical yield data, thereby helping to reduce environmental impact and improve economic efficiency (Adewusi *et al.*, 2024; Truflyak & Ragozin, 2025). The use of AI also allows for more precise application of pesticides, targeting only affected areas, which significantly reduces the overall chemical load on the ecosystem and preserves biodiversity (Lebid *et al.*, 2023; Polwaththa *et al.*, 2024). Such technologies enable a differentiated approach to field management, minimising losses and maximising the efficiency of every resource invested (Gryshova *et al.*, 2024; Çokkızgın *et al.*, 2025). Furthermore, the integration of Internet of Things (IoT) sensors with artificial intelligence systems is transforming precision farming, enabling intelligent monitoring and adaptive management of agricultural processes, as noted by V. Eze *et al.* (2025). This enables farmers to obtain continuous data on soil conditions, crop growth and environmental conditions, which, combined with advanced machine learning algorithms, facilitates predictive analytics and real-time decision-making to optimise resource use (Wei *et al.*, 2024). Thanks to its predictive analytical capabilities, AI is becoming the 'cornerstone' of decision-support systems, analysing historical data, weather conditions and crop-specific parameters, thereby providing valuable insights for resource optimisation and contributing to the long-term sustainability of agricultural systems (Truflyak & Ragozin, 2025). The use of AI also facilitates more accurate forecasting of plant diseases and pests, enabling a rapid response to minimise crop losses and reduce the need for pesticides, as noted by O. Lebid *et al.* (2023). For example, the use of AI systems to identify and predict the spread of pests makes it possible to reduce pesticide use by more than 50%, thereby minimising environmental damage (Ye *et al.*, 2024). K. Polwaththa *et al.* (2024) also argue that this approach not only enhances the efficiency of agricultural production but also contributes significantly to achieving the Sustainable Development Goals by conserving natural resources and biodiversity. This transition to an AI-driven agricultural model promises significant benefits for both agricultural productivity and environmental sustainability, as traditional farming methods often result in the inefficient use of resources.

A study by L. Chen *et al.* (2023) has shown that the implementation of artificial intelligence has a positive impact on the efficiency and sustainability of agricultural systems. The study's findings indicate that intelligent algorithms can improve the accuracy of crop yield forecasts by 12-15%. Furthermore, their use enables a significant reduction in resource consumption: water use is reduced by 22%, and fertiliser use by 28%. An increase in crop yields of 20-25% was also observed. This is due to more precise management of agricultural processes and rapid decision-making based on data analysis. Through the use of machine learning, IoT sensors and predictive analytics, it is possible to monitor soil conditions, plant health and weather conditions in real time (Yparraguirre *et al.*, 2026). A study by P. Perekhodov (2025) also identified key areas where AI can be effectively applied in agriculture. These include irrigation management, soil condition monitoring, forecasting climate-related risks, and the automation of plant protection processes. The findings confirm that AI is a valuable tool for increasing crop yields and the sustainability of agriculture. However, there are constraints hindering the large-scale adoption of these technologies. The most significant of these include a lack of digital infrastructure, limited access to reliable data, and low levels of digital skills among agricultural producers (Sakkaraeva & Kumashev, 2024).

Research by A. Adewusi *et al.* (2024) confirms the high effectiveness of using artificial intelligence in agriculture, and the results obtained are fully consistent with these findings. Increased yields and reduced resource costs point to a transition towards a more sustainable and economically viable model of agriculture (Mana *et al.*, 2024). However, the limitations identified highlight the need for a comprehensive approach to the implementation of AI. To this end, it is necessary to develop digital infrastructure, create agricultural databases and enhance staff skills (Wu *et al.*, 2025). Only by addressing these challenges will it be possible to fully realise the potential of digital technologies. The convergence of artificial intelligence with Internet of Things technologies and big data analytics systems opens up new opportunities for the creation of smart agricultural systems. Such systems are capable of adapting to climate change and market fluctuations. This is particularly important for the Kyrgyz Republic, where agriculture is of strategic importance for ensuring food security. The study has shown that artificial intelligence plays a key role in the digital transformation of the agricultural sector. However, the successful implementation of AI requires institutional support, investment and the development of tailored solutions that take into account the specific characteristics of agriculture in different regions.

Conclusions

The study conducted has established that the digital transformation of the land management system in the Kyrgyz Republic is a prerequisite for improving the efficiency of land use and ensuring sustainable socio-economic development. The findings revealed that the existing management system is characterised by data fragmentation, insufficient integration of information resources and a limited level of digitalisation, which significantly reduces the quality of monitoring and management decision-making. Analysis of spatial data and the results of geoinformation modelling has confirmed that the implementation of artificial intelligence technologies makes it possible to significantly improve the accuracy of land-use change monitoring (by 15-25%), reduce data processing time (by 70-90%) and lower the error rate in cadastral information (by 40-60%). This demonstrates the high effectiveness of using machine learning algorithms and satellite data in land resource management systems. It has been established that the development of a national spatial data infrastructure plays a key role in enhancing the transparency and consistency of public administration. The integration of geographic information systems and digital platforms provides access to up-to-date information, reduces data duplication and contributes to the creation of a unified information space. The study identified the main barriers to digital transformation, including the lack of uniform data processing standards, inadequate digital infrastructure and a shortage of qualified specialists in the fields of GIS and artificial intelligence. These constraints require a comprehensive solution at the level of public policy and institutional reform.

The practical significance of this study lies in the development of recommendations for improving the land resource management system in the Kyrgyz Republic, including the introduction of intelligent spatial data analysis systems, the development of a national spatial data infrastructure, the standardisation of geoinformation resources, and the enhancement of human resource capacity. Implementing the proposed measures will improve the efficiency of land use, ensure environmental sustainability and accelerate the digital transformation of the agricultural sector. Prospects for further research include the development of applied artificial intelligence models for predicting land degradation, as well as the creation of integrated digital platforms for land resource management at the national level.

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Conflict of Interest

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Аннотация. Кыргыз Республикасынын экономикасын санариптештирүү шарттарында жер ресурстарын башкаруу системасын трансформациялоо стратегиялык мааниге ээ болууда, анткени жер фондун натыйжалуу пайдалануу агрардык сектордун туруктуу өнүгүшүн камсыз кылуу, аймактардын инвестициялык жагымдуулугун жогорулатуу жана мамлекеттик жөнгө салуу механизмдерин өркүндөтүү менен түздөн-түз байланыштуу. Изилдөөнүн максаты жасалма интеллект технологияларынын жана улуттук мейкиндиктик маалыматтар инфраструктурасынын Кыргыз Республикасынын жер ресурстарын башкаруунун натыйжалуулугун жогорулатуудагы ролун баалоо болгон. Изилдөөнүн методологиялык негизин системалык, салыштырма жана экономикалык-статистикалык талдоо ыкмалары, ошондой эле геомаалыматтык моделдөө жана мейкиндиктик маалыматтарды талдоо ыкмалары түздү. Изилдөөнүн жүрүшүндө өлкөдөгү жер ресурстарын башкарууну санариптештирүүнүн учурдагы абалына комплекстүү баа берилип, негизги институционалдык жана технологиялык чектөөлөр аныкталды. Аларга маалыматтык ресурстардын бөлүнүп-жарылышы, санариптик платформалардын интеграциясынын жетишсиз деңгээли, мейкиндиктик маалыматтарга жеткиликтүүлүктүн чектелиши жана геомаалыматтык технологиялар жаатындагы квалификациялуу адистердин жетишсиздиги кирет. Жасалма интеллект инструменттерин киргизүү жер ресурстарына мониторинг жүргүзүүнүн тактыгын жогорулатууга, мейкиндиктик маалыматтарды иштетүү процесстерин автоматташтырууга, жер пайдалануудагы өзгөрүүлөрдү болжолдоого жана башкаруучулук чечимдердин негиздүүлүгүн жогорулатууга өбөлгө түзөрү аныкталды. Изилдөөнүн жыйынтыктары көрсөткөндөй, геомаалыматтык системаларды жана интеллектуалдык алгоритмдерди интеграциялоо жер ресурстарын башкаруунун ачыктыгын жогорулатууга, аларды натыйжасыз пайдалануу тобокелдиктерин азайтууга, ошондой эле мамлекеттик көзөмөлдөө жана жөнгө салуу процесстерин оптималдаштырууга мүмкүндүк берет. Улуттук мейкиндиктик маалыматтар инфраструктурасын өнүктүрүүнүн артыкчылыктуу багыттары жалпыланып, алар маалымат агымдарын стандартташтырууну, санариптик сервистерди интеграциялоону, ведомстволор аралык өз ара аракеттенүүнү кеңейтүүнү жана геомаалыматтык ресурстардын жеткиликтүүлүгүн жогорулатууну камтыйт. Изилдөөнүн практикалык мааниси алынган жыйынтыктарды Кыргыз Республикасынын жер ресурстарын башкаруу чөйрөсүндөгү мамлекеттик санариптик стратегияларды иштеп чыгууда жана ишке ашырууда колдонуу мүмкүнчүлүгү менен аныкталат

Негизги сөздөр: геомаалыматтык системалар; санариптик кадастр; маалыматтарды интеллектуалдык талдоо; жер мамилелери; аймактарга мониторинг жүргүзүү; башкарууну автоматташтыруу

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Аннотация. В условиях цифровизации экономики Кыргызской Республики трансформация системы управления земельными ресурсами приобретает стратегическое значение, поскольку эффективное использование земельного фонда напрямую связано с обеспечением устойчивого развития аграрного сектора, повышением инвестиционной привлекательности территорий и совершенствованием механизмов государственного регулирования. Целью исследования являлась оценка роли технологий искусственного интеллекта и национальной инфраструктуры пространственных данных в повышении эффективности управления земельными ресурсами Кыргызской Республики. Методологическую основу исследования составили методы системного, сравнительного и экономико-статистического анализа, а также методы геоинформационного моделирования и пространственного анализа данных. В ходе исследования проведена комплексная оценка современного состояния цифровизации управления земельными ресурсами страны, выявлены основные институциональные и технологические ограничения, включая фрагментацию информационных ресурсов, недостаточный уровень интеграции цифровых платформ, ограниченность доступа к пространственным данным и дефицит квалифицированных специалистов в области геоинформационных технологий. Установлено, что внедрение инструментов искусственного интеллекта способствует повышению точности мониторинга земельных ресурсов, автоматизации процессов обработки пространственной информации, прогнозированию изменений землепользования и повышению обоснованности принимаемых управленческих решений. Результаты исследования показали, что интеграция геоинформационных систем и интеллектуальных алгоритмов позволяет повысить прозрачность управления земельными ресурсами, снизить риски их неэффективного использования, а также оптимизировать процессы государственного контроля и регулирования. Обобщены приоритетные направления развития национальной инфраструктуры пространственных данных, предусматривающие стандартизацию информационных потоков, интеграцию цифровых сервисов, расширение межведомственного взаимодействия и повышение доступности геоинформационных ресурсов. Практическая значимость исследования заключается в возможности применения полученных результатов при разработке и реализации государственных цифровых стратегий в сфере управления земельными ресурсами Кыргызской Республики

Ключевые слова: геоинформационные системы; цифровой кадастр; интеллектуальный анализ данных; земельные отношения; мониторинг территорий; автоматизация управления