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DIGITAL TECHNOLOGIES IN GEODESY AND LAND MANAGEMENT IN THE CONTEXT OF THE CURRENT STATE AND PROSPECTS FOR DEVELOPMENT

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The article examines modern digital technologies and their role and significance in the field of geodesy and land management. The implementation of digital transformations in the production process of managerial decision-making in the field

of territorial development is considered, driven by increasing requirements for the accuracy, timeliness, and interoperability of spatial data. The aim of the study is to analyze the effectiveness of implementing digital technologies, including GNSS technologies, UAV photogrammetry, GIS, artificial intelligence, and others, in the land management production cycle, as well as to determine their development prospects in this field. The evolutionary development of the technical equipment of the industry is presented. A substantial increase in the informativeness of spatial data was achieved through the transition from traditional total station surveying methods to digital technologies. An analytical justification for the effectiveness of using digital tools in geodesy and land management has been developed, based on a system of indicators of accuracy, productivity, and economic feasibility. The proposed workflow was tested, confirming the advantages of using UAVs and GNSS receivers in terms of labor intensity, productivity, and spatial data detail during the land inventory of a 10.7154 ha land parcel located within the Zoryanska Territorial Community, Rivne District, Rivne Region. The prospects for the development of the industry are identified, particularly those related to the implementation of artificial intelligence for predictive analytics of land resources, Digital Twins technologies for territories, and blockchain solutions to ensure data security in cadastral registers. Future vectors for the development of geodesy and land management have been defined. They involve a transition from discrete measuring instruments to autonomous intelligent systems, along with the need for a corresponding transformation of the professional training system and the expansion of specialists' skills in spatial modelling and intelligent data management.

Keywords: *geospatial data, geographic information systems (GIS), GNSS, unmanned aerial vehicles (UAVs), photogrammetry, remote sensing, artificial intelligence, digital twins, blockchain.*

Problem Statement. The development of geodesy and land management at the present stage is determined by increasing requirements for the accuracy, completeness, relevance, and interoperability of spatial data. These parameters directly influence the

effectiveness of decision-making in the field of land administration and the formation of a geospatial information database. In the context of Ukraine's European integration, digital technologies provide the foundation for harmonising the national geospatial data system with the requirements of Directive 2007/2/EC INSPIRE [1], which provides for the standardisation, accessibility, exchange, and interoperability of spatial information [2].

Analysis of recent research and publications. The current development of geodesy and land management is closely connected with global digitalization, which necessitates a reconsideration of traditional approaches to the collection, processing, and management of geospatial data. A key aspect of the digital transformation of the industry is the automation of management processes. The studies by O. Stupen, N. Prokopenko, and S. Shevchuk [3] emphasize that the digital transformation of the land management system is an essential condition for the effective protection and use of land resources. In the context of Ukraine's national challenges, O. Nesterenko and P. Yatsuk [4] analyze geographic information systems as a key element of the national information infrastructure, ensuring effective management of territories, natural resources, defense, and security. The relationship between geodetic support and the functioning of GIS for improving land management in Ukraine is examined in detail in the work of M. Kukhar and co-authors [5], where the importance of categorical data modelling is substantiated. D. Bulysheva [6] and T. Movchan [7] emphasize the importance of applying innovative approaches to recreational land resource management, land monitoring, and the development of digital territorial passports, which contributes to improving the quality of designing and substantiating measures aimed at achieving the expected outcomes.

Technological advances in geodetic surveying methods have significantly expanded the capabilities of spatial analysis. In particular, the use of unmanned aerial vehicles (UAVs) for high-precision terrain modeling, as described in [8], is gaining widespread practical application for modern cadastral needs. Furthermore, the study analyzes the current state of digital transformation in Ukraine and the principles of its implementation in geodesy and land management [9]. The field under study cannot

exist without digital technologies, as land management surveys—including engineering-geodetic, engineering-geological, engineering-economic, engineering-hydrometeorological, and engineering-technical surveys—are carried out using modern digital equipment, while the processing of their results is performed with specialized software, confirming the high adaptability of these technologies to specific sectoral tasks [10], such as cultural heritage preservation in the context of current urbanization trends [11] and the efficient use of land resources across natural and agricultural zones [12].

The issue of implementing the concept of Digital Twins as a tool for land resource management, based on the experience of South Korea [13], demonstrates a high level of real-time data integration. At the same time, the application of machine learning methods within the Land Administration Domain Model (LADM) and structural topic modelling [14] opens up new prospects for the automation of complex administrative procedures.

The purpose of the study is to analyze the effectiveness of implementing digital technologies, including GNSS technologies, UAV photogrammetry, GIS, artificial intelligence, and others, in the land management production cycle, as well as to determine their development prospects in this field. To achieve the aim, the following objectives were set: 1) to analyse the evolution of digital tools; 2) to conduct an experimental comparison of the methods at a test site; and 3) to assess the advantages and limitations of using UAVs and GNSS technologies during the inventory of a land parcel.

Materials and methods of research. The source base of the study comprised publications by Ukrainian and international authors on land management, geodesy, and geoinformatics. The study employed general scientific and specialised methods, including deduction for the systematisation of knowledge, the analytical method for reviewing the literature on GIS, remote sensing, and artificial intelligence in land administration, and comparative analysis for comparing traditional and digital methods. The practical component of the study was based on a pilot experiment conducted under real-world operational conditions.

Study object. The study object was a municipally owned agricultural land parcel with an area of 10.7154 ha, located within the Zoryanska Territorial Community, Rivne District, Rivne Region.

Hardware and instrumentation. GNSS equipment. GNSS equipment: a high-precision A-GEO GeoPuls GNSS receiver supporting RTK measurements, with a specified accuracy of $\pm(8 \text{ mm} + 1 \text{ ppm})$ horizontally and $\pm(15 \text{ mm} + 1 \text{ ppm})$ vertically [15]. A DJI Mavic 3 Pro quadcopter UAV equipped with a Hasselblad main camera featuring a 4/3 CMOS sensor and a resolution of 20 MP [16]. Geodetic equipment: a Sokkia CX-105 electronic total station with a specified angular measurement accuracy of $5''$ and prism distance measurement accuracy of $\pm(2 \text{ mm} + 2 \text{ ppm} \times D)$, which was used for control and conventional total station surveys during the parallel comparative experiment [17].

Software. Agisoft Metashape was used for the photogrammetric processing of aerial imagery, image alignment, dense point cloud generation, and the creation of a high-resolution orthophoto. The Digitals software package was used for office processing, interpretation of aerial imagery, vectorisation of boundaries, and preparation of land management documentation. AutoCAD was used to edit vector data, construct boundaries, and prepare the land parcel plan. The DJI Fly mobile application was used to configure UAV parameters and monitor its operation, while 3Dsury Pilot was used to plan the flight mission, define the boundaries of the study area, and generate the aerial survey route.

Experimental procedure and work stages: the comparison of conventional and digital methods was conducted by performing the work in parallel on a test site according to the following step-by-step algorithm:

1. Establishment of survey points and geodetic control. A local survey network was established using the A-GEO GeoPuls GNSS receiver in RTK mode, with reference to the national geodetic network and subsequent operation in the SK-63 coordinate system, Zone X2, to ensure a common coordinate framework. The root mean square errors of the boundary coordinates obtained from satellite measurements did not exceed 2.0 cm in the horizontal position (maximum horizontal RMSE = 0.020

m) and 3.1 cm in the vertical position (maximum vertical RMSE = 0.031 m), which met the applicable technical accuracy requirements for this type of geodetic work.

2. Aerial survey of the study area. The flight mission was planned in the 3Dsurvey Pilot mobile application by defining the boundaries of the study area, flight altitude, image ground sampling distance, and UAV route. The forward image overlap was 80%, the side overlap was 70%, and the calculated GSD was 1.3 cm/pixel. The aerial survey was carried out using the DJI Mavic 3 Pro UAV in automated mode. In parallel, control measurements were performed using a Sokkia CX-105 electronic total station.

3. Office processing. The aerial imagery and the coordinates of the ground control points were imported into Agisoft Metashape. Office processing included image alignment, georeferencing of the photogrammetric model, dense point cloud generation, creation of a digital surface model, and orthophoto generation. The accuracy of the resulting materials was assessed from the coordinate residuals at the check points.

4. Vectorisation and analysis. Based on the orthophoto, the boundaries of the land parcel and the internal land-use contours were vectorised in Digitals and AutoCAD, and their areas were calculated. The results of the digital method were compared with the total station survey data in terms of the horizontal position of characteristic points, parcel area, field and office labour intensity, and total person-hours.

Results and Discussion. Over the past decades, the development of geodesy and land management has been characterized by a gradual transition from basic digitalization to the formation of intelligent geospatial ecosystems (Table 1). [1;2;18-22].

Table 1. Evolution of digital technologies in geodesy and land management

2000-2005 Beginning of digitalization	2006-2012 Formation of digital infrastructure	2013-2019 Integration and automation	2020-2025 Digital transformation	2026-2035 Intelligent geospatial ecosystem
Transition from analogue to electronic instruments; use of GPS; creation of digital plans in CAD systems;	Use of GNSS with dual-frequency receivers; creation of networks of continuously	Widespread use of UAVs and aerial photography; development of LiDAR and 3D modelling; cloud computing and	Artificial intelligence and machine learning; automatic object recognition; digital twins of territories; integration of BIM	Full integration of AI, IoT, 5G/6G, Edge and cloud technologies; autonomous data collection systems, including drones,

emergence of the first GIS platforms.	operating reference stations; development of GIS and spatial databases; digital photogrammetry; laser scanning as an emerging technology..	services; integration of GIS with cadastres and registers; mobile GIS and field applications; automation of data processing..	and GIS; Big Data and analytics; Internet of Things in land monitoring; blockchain for land rights registration..	ground robots and sensors; hyperautomation of geodetic and land management processes; global open geodata and interoperability; sustainable development and green monitoring; implementation of the Smart Land Management concept..
Stage result: The State Programme for the Development of Topographic and Geodetic Activities was approved, and the establishment of a digital cartographic framework was initiated.	Stage result: The regulatory and technological foundations for the operation of the State Land Cadastre as a unified geoinformation system were established.	Stage result: The automated State Land Cadastre system was implemented, and the Public Cadastral Map of Ukraine was launched..	Stage result: The legal and technical foundations for the National Geospatial Data Infrastructure and the interoperability of geoinformation resources were established..	Stage result: The formation of an integrated intelligent geospatial ecosystem with automated data updating and analysis is expected..

Source: systematised by the authors based on Ukrainian regulatory documents and scientific publications [1;2;18-22].

At the present stage, digital technologies encompass the entire cycle of geodetic and land management activities aimed at creating a unified digital environment of reliability, in which each coordinate position has a verified origin and each measurement procedure possesses metrological validity and legal relevance [18]. Geographic information systems (GIS) are among the key digital technologies that support the visualisation and analysis of spatial data, the creation of electronic maps, the justification of land allocation, and the detection of changes in land-use structure. Remote sensing and the use of satellite data are important tools for modern land monitoring [9]. These tools make it possible to obtain high-precision data on the condition of remote areas, sites with complex terrain or unfavourable conditions, and territories affected by military operations without requiring the physical presence of specialists at the site.

Modern GNSS receivers supporting RTK, Network RTK, and PPP technologies make it possible to determine coordinates with centimetre-level accuracy in real time, which significantly expands the functional capabilities of land resource management and urban development systems [18]. An example of successful implementation is represented by integrated networks in Serbia, which have demonstrated progress in geodetic infrastructure that is vital for consistent data collection. The combination of aerial photogrammetry and GNSS data provides highly detailed and up-to-date information on the condition of agricultural and forest lands, ensuring high reliability of land monitoring results [23]. In addition, GNSS helps monitor geodynamic processes, which contributes to a better understanding of environmental changes and reduces the risks of natural disasters. Scientific studies confirm that, compared with traditional geodetic methods, the use of GNSS equipment for slope deformation monitoring enables high-precision observations of shore protection structures, the identification of active landslide zones, and the development of recommendations regarding the conditions and specific features of further monitoring [24].

Unmanned aerial vehicles (UAVs) are becoming an integral tool in the fields of geodesy and land management. Aerial surveying significantly improves the efficiency of spatial analysis, reduces the time required for office processing of survey data, and ensures a high level of detail in the surveyed objects. Using automated photogrammetric processing software such as Pix4D, ContextCapture, Photoscan, and others, aerial photographs are converted into high-precision continuous orthophoto images or digital terrain models, eliminating geometric distortions and ensuring high-quality materials. The integration of modern methods such as automated geodata processing and GIS tools has become a key condition for the effective management of land resources [25]. The use of GNSS technologies and UAVs makes it possible to create high-precision orthophoto plans and digital elevation models, thereby improving the accuracy and economic efficiency of cadastral and land management works. Such materials provide the necessary level of detail in cartographic data for water fund lands, where traditional geodetic methods are ineffective due to complex terrain and unfavourable environmental conditions [18].

Laser scanning (LiDAR) is regarded as an advanced technology for collecting spatial data, enabling the creation of high-precision 3D models regardless of terrain or vegetation conditions. The operation of the system is based on the principle of measuring the return time of laser pulses reflected from the Earth's surface. Synchronization of sensor data with navigation systems (GPS/INS) during the movement of the carrier enables the conversion of distances into an array of three-dimensional coordinates, known as a point cloud, with detailed visualization of objects. LiDAR technology has found wide application in monitoring transport bridges for dynamic loads, vibrations, and cyclic deformations that may lead to structural failure. In the monitoring of residential and public buildings, the main focus is on identifying defects in load-bearing structures, monitoring foundation settlement, and assessing the impact of climatic factors and the degradation of building materials [26]. This research area is particularly relevant for identifying damage to real estate objects caused by the consequences of military actions [27]. In particular, the use of LiDAR technology significantly increases the effectiveness of urban morphology analysis and assessment of the condition of green spaces [14;27].

The integrated use of remote sensing and GIS technologies makes it possible to carry out digital modelling of community lands based on up-to-date data, while ensuring high accuracy of the work. A digital land-use model is applied for the effective management of land resources, assessment of the condition of water bodies, monitoring of forest dynamics, and monitoring of agricultural lands, among other purposes. Geoinformation modelling makes it possible to identify cases of improper land use or unauthorized occupation of land plots. This, in turn, allows tax revenues to be optimized, proper environmental supervision of protected zones to be ensured, and transparent mechanisms for land resource management to be implemented at the level of territorial communities [28].

Cloud computing technologies, as a direction of digital transformation, are intended for the centralized storage of large volumes of geospatial data, ensuring their backup, synchronization, and remote access regardless of the location where the work is performed. Cloud services are focused on the functioning of unified digital land

management platforms, the integration of state cadastral information systems, geoportals, and open data services. Digital databases act as a key tool for transparent land relations and effective administration, providing unrestricted access to cadastral information. Since every operation in an electronic system is subject to clear monitoring, this makes it possible to significantly reduce the bureaucratic burden and eliminate the prerequisites for corruption [29].

Land resource management requires the development of an integrated system for registering land plots and rights to them. This task can be addressed through the implementation of blockchain technology, which makes it possible to minimize the shortcomings of existing registration systems. The decentralized architecture of blockchain with a distributed ledger provides a high level of cryptographic data protection, eliminating the possibility of data falsification. The system enables authorized participants to carry out transparent monitoring of transactions, changes in the status of objects, and imposed restrictions. However, the key technological challenge remains ensuring the efficient processing of large volumes of spatial and cadastral data within such a system [30].

The implementation of Big Data technologies is an optimal tool for analytics and the adoption of well-founded management decisions. This technology ensures the comprehensive processing of structured and unstructured data and is characterized by high processing speed, dynamic updating, and a variety of information presentation formats [4].

One of the most promising trends is the formation of Digital Twins of territories, which are integrated digital models of real objects or territories with the possibility of continuous real-time updating [11]. Digital Twins ensure the integration of geodetic measurement data, remote sensing data, sensor monitoring, cadastral information, and spatial analysis results into a single information environment. The term “Digital Twin” describes the process of creating a large virtual copy of a real object or environment [13;31].

The introduction of artificial intelligence (AI) and machine learning algorithms opens up new opportunities for the automation of geodetic processes. Modern AI

algorithms make it possible to automatically classify objects based on remote sensing and aerial photography materials, identify land parcel boundaries, monitor land use, predict land-use changes, and detect violations of land legislation. The advantages of applying AI include reduced processing time for geospatial information, increased accuracy of analysis, and minimized subjective influence of the operator [3;18]. Algorithms such as Random Forest (RF), Convolutional Neural Networks (CNN), and Support Vector Machines (SVM) are most suitable for classifying and analyzing patterns in Earth observation data. Generative Adversarial Networks (GANs) are used for modelling urban patterns. In addition, algorithms such as cellular automata, spatial logistic regression, and agent-based modelling are used to study urban growth, land-use changes, and settlement pattern analysis [32].

Current studies on the evolution and future prospects of digital technologies indicate their growing popularity worldwide and their significant potential in supporting a four-level production cycle in geodesy and land management, ranging from field data collection to cloud-based management. The implementation of technologies such as blockchain, Big Data, and artificial intelligence ensures the rapid, technically substantiated, and economically efficient solution of complex sectoral tasks. The first stage of digital innovations in the industry alone made it possible to reduce production time costs by 40–60% [6;11;14]. Based on the current state of development of land-use planning tools and taking into account the dynamics of emerging technologies in the industry, the key prospects for the future of digital tools have been identified (Table 2) [9;18;27;33]:

Table 2. Integration of the Technological Workflow and Development Forecasts

Level / Stag	Current state	Promising technologies and development vectors
Field	GNSS, UAVs, laser scanning	Autonomous robotic complexes, real-time sensors (IoT)
Office / Processing	Photogrammetry, point cloud processing	Hyperautomation, cloud-based processing “on the fly” (Edge Computing)
Analytica	GIS modelling, monitoring	AI analytics, predictive models of land-use changes

Management	Web portals, cloud services	Digital twins, blockchain-based registries, open geospatial data (Open Data), and Smart Land Management*
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Source: [27].

The widespread implementation of geospatial technologies is evident. Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), and remote sensing technologies are increasingly being used to improve the accuracy and efficiency of land management and mapping. These technologies provide high-precision data, facilitate real-time data collection and analysis, and stimulate demand for more advanced land-use planning tools.

The synthesis of AI, machine learning, and Big Data analytics has opened new horizons in land resource management, enabling the processing of complex datasets with exceptional accuracy and the creation of predictive models for analysing and forecasting land-use changes, as well as optimizing investment projects for communities. Virtual reality (VR) and augmented reality (AR) technologies improve or transform real-world experiences through interactive environments, expanding the functionality of land-use planning tools, particularly in the modelling of development projects. The application of Digital Twin technology will focus on the formation of 4D models that take into account spatial structure and dynamic changes over time, such as landscape transformation, the impact of development, and spatial changes. The prospective use of autonomous robotic complexes, or hyperautomation, involves surveying territories without the direct presence of an operator. This will help minimize the influence of the human factor and enable round-the-clock monitoring [32].

A new level of geodata interoperability is based on the concept of Open Data and the standardization of interstate cadastral data exchange protocols using 5G/6G networks. This will ensure rapid access to high-resolution spatial data. Replacing conventional databases with distributed ledgers, or blockchain, for the automated registration of property rights will make it possible to eliminate the risks of fraud through smart contracts, which are automatically executed when cadastral data comply with legal regulations [32]. The evolution of digital technologies requires not only technical modernization but also the improvement of professional training. A modern

specialist in geodesy and land management should be not only an operator of measuring instruments but, above all, a strategist with skills in spatial analytics and intelligent systems management. Thus, the prospects for the development of the industry lie in the convergence of engineering knowledge and information technologies.

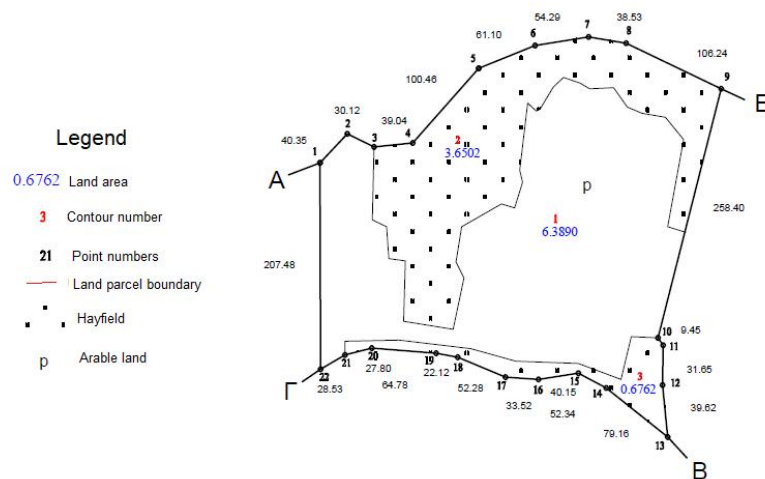
At present, the application of digital technologies in geodesy and land management can be assessed in terms of their effectiveness. Such an assessment takes into account objective economic principles and a system of relevant quantitative indicators, including accuracy, time, relative cost level, and quality of integration (Table 3). The relative cost level was determined using a five-point scale, where 1 represents the lowest and 5 the highest total costs. The assessment considered fieldwork, equipment depreciation, software, and office-based data processing. The score was derived from a generalised evaluation of equipment specifications, the duration of field and office work, and the need for specialised software and qualified personnel. It does not represent a calculation of the actual cost of the work.

Table 3. Comparative characteristics of geospatial data collection methods with evaluation indicators

Data collection method	Accuracy (mm)	Productivity (ha/shift)	Relative level of total costs (1–5 points)	Processing complexity (score 1–5)
Total station / Tacheometer (classical)	1–5	2–5	800–1200	1
GNSS receivers (RTK)	8–15	50–100	150–300	2
UAVs (photogrammetry)	10–30	200–500	50–100	4
LiDAR (ground-based))	2–10	1–2	2000–5000	5

The effectiveness of the cycle is verified by carrying out work in parallel using the traditional method and the method of integrated digital modelling, followed by a statistical comparison of the obtained spatial data according to the criteria of accuracy and time costs. For testing the proposed production cycle, a municipally owned agricultural land plot located in the Zoria territorial community of Rivne district, Rivne

region, was selected. An inventory of this land plot is planned in order to form it for the sale of lease rights at land auctions in the form of an auction (Fig. 1). The choice of this plot was determined by the need to verify the accuracy of UAV data integration under conditions of heterogeneous land use.



Boundary delineation	Based on the results of individual measurements	Based on the orthophoto and point cloud	Reduced risk of omitting boundary details
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*The office labour intensity of the total station method was estimated based on the typical sequence of operations, including data transfer and verification, coordinate calculations, boundary delineation, and preparation of graphical materials. For the digital method, only the operator's active involvement during photogrammetric processing was considered, without fully accounting for autonomous computer processing time.

In the present study, the duration of fieldwork was reduced from two working shifts to 1.5–2 hours, representing an approximately 8–10-fold decrease. However, when photogrammetric image processing, point cloud generation, orthophoto production, and boundary vectorisation were taken into account, the reduction in total labour intensity was smaller and amounted to approximately 4.5–7 times. This result confirms that the greatest time savings are achieved during the field stage, whereas the office processing of UAV data remains relatively time-consuming and requires specialised software. The results obtained are generally consistent with the findings of other researchers regarding the reduction in the labour intensity of geodetic and land management works through the use of UAVs. In particular, V. Tarnavskiy [8] notes that unmanned technologies can significantly reduce the duration of the field stage while simultaneously increasing the level of detail of spatial data. O. Braslavskaya [31] also emphasises the advantages of automated aerial surveying over conventional ground-based surveying, particularly in terms of productivity, completeness of territorial coverage, and the possibility of reusing the acquired materials.

The differences between the results obtained in this study and the findings of other researchers [8; 31] may be attributed to the area and configuration of the site, the number of boundary turning points, terrain openness, field crew composition, the method of geodetic control, flight parameters, and the processing capacity of the equipment used for photogrammetric analysis. In this study, the substantial reduction in field labour intensity was associated with the relatively small area of the site—10.7154 ha—its open terrain, and the possibility of covering the entire area in a single automated aerial survey flight. By contrast, under conditions of more complex terrain, dense development, forest cover, or the need for repeated flights, the advantages of the digital method may be less pronounced.

Conclusions. During the study, digital technologies in the field of geodesy and land management were analyzed. Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), and remote sensing technologies ensure the acquisition of high-precision data, facilitate their collection and analysis in real time, and create demand for more advanced land-use planning tools. The integration of artificial intelligence (AI), machine learning (ML), and spatio-temporal Big Data algorithms makes it possible to create high-precision terrain plans, maps, and digital elevation models. This optimizes the processes of object recognition, image classification, and predictive analysis of land resource use. Blockchain technology creates a transparent and reliable system for registering ownership rights to land plots. Its use ensures data exchange through a unified platform for public authorities, landowners, and project developers, preventing fraud and disputes. Overall, digital technologies improve the quality of geodetic works and contribute to saving time and resources, creating conditions for the transition from traditional methods of data collection to intelligent land administration systems. In such systems, autonomy, analytics, prompt decision-making, and full real-time digital integration are priorities. It has been demonstrated that the use of UAVs helps minimise errors associated with omitted boundaries in areas with complex configurations. The pilot study established that the application of UAVs and GNSS reduced the duration of the field stage from two working shifts to 1.5–2 hours. Taking office processing into account, the total labour intensity of the digital method was 5.5–8 person-hours, compared with an estimated 36–38 person-hours for the total station method, representing an approximately 4.5–7-fold reduction.

Further research on the implementation of digital technologies in the field of geodesy and land management should focus on their practical application in ensuring the sustainable development of territories, combating climate change, and overcoming the consequences of military actions.

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ЦИФРОВІ ТЕХНОЛОГІЇ У ГЕОДЕЗІЇ ТА ЗЕМЛЕУСТРОЇ В КОНТЕКСТІ СУЧАСНОГО СТАНУ І ПЕРСПЕКТИВ РОЗВИТКУ

***Анотація.** У статті досліджено сучасні цифрові технології та їхню роль і значення у галузі геодезії та землеустрою. Розглянуто впровадження цифрових трансформацій у виробничий процес прийняття управлінських рішень у сфері територіального розвитку, що зумовлено зростанням вимог до точності, оперативності та інтероперабельності просторових даних. Метою дослідження є аналіз ефективності впровадження цифрових технологій (GNSS-технологій, БПЛА-фотограмметрії, ГІС, штучного інтелекту тощо) у*

виробничий цикл землеустрою та визначення їхніх перспектив розвитку у цій сфері. Представлено еволюційний розвиток технічного оснащення галузі. Відзначено суттєве підвищення інформативності просторових даних завдяки переходу від традиційних тахеометричних методів до цифрових технологій. Розроблено аналітичне обґрунтування ефективності використання цифрових інструментів у геодезії та землеустрої, яке базується на системі показників точності, продуктивності та економічної доцільності. Проведено апробацію виробничого циклу, яка підтвердила переваги використання БПЛА та GNSS-приймачів за показниками трудомісткості, продуктивності та деталізації просторових даних під час проведення інвентаризації земельної ділянки (площею 10,7154 га) Зорянської територіальної громади Рівненського району Рівненської області. Виокремлено перспективи розвитку галузі, які пов'язані з впровадженням штучного інтелекту для предиктивної аналітики земельних ресурсів, технологій «цифрових двійників» (Digital Twins) територій та блокчейн-рішень для гарантування безпеки даних у кадастрових реєстрах. Визначено майбутні вектори розвитку геодезії та землеустрою, які передбачають перехід від дискретних вимірювальних інструментів до автономних інтелектуальних екосистем, з потребою відповідної трансформації системи професійної підготовки кадрів та розширення навичок фахівців у сфері просторового моделювання та управління інтелектуальними даними.

Ключові слова: геопросторові дані, геоінформаційні системи (ГІС), GNSS, безпілотні літальні апарати (БПЛА), фотограмметрія, дистанційне зондування Землі, штучний інтелект, цифрові двійники, блокчейн.