ISSN 2518-7325 (Online), ISSN 2306-1677 (Print)
Land Management, Cadastre and Land Monitoring
Received: 07.09.2026; Accepted: 21.09.2026; Published: 30.12.2026;
http://dx.doi.org/10.31548/zemleustriy2026.04.13

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UDC 528.4:332.3.

THE DIGITALIZATION OF GEODESY AND LAND MANAGEMENT AS A DIRECTION FOR THE DEVELOPMENT OF MODERN GEOINFORMATION TECHNOLOGIES

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Abstract *The article examines the role of geoinformation technologies in the digital transformation of modern geodesy and land management. Digital workflows for processing spatial data within a unified information and technological cycle are presented. The functional capabilities of GIS were practically tested using a municipally owned agricultural land parcel with an area of 21.9068 ha, located within the Diadkovychi Territorial Community, Rivne District, Rivne Region. The study involved a set of geodetic measurements using GNSS technologies in RTK mode,*

unmanned aerial vehicle (UAV) aerial surveying, and photogrammetric processing of the acquired materials. In the QGIS software environment, heterogeneous spatial data were integrated to obtain the coordinates of the turning points of the land parcel boundary, an orthophoto map, a digital elevation model (DEM), a slope steepness map, engineering infrastructure objects (35 kV overhead power lines and their protection zone), as well as agro-production soil groups. The role of modern GIS is substantiated not only as a mapping tool, but also as an integrated environment for automating design solutions, spatial analysis, and land-use monitoring. The research results can be used to improve digital workflows in land management, land cadastre maintenance, and land resource management within territorial communities.

Keywords: *geodesy, land management, digital transformation, geoinformation technologies, geospatial data, spatial analysis, QGIS*, *agro-production soil groups.*

Problem Statement. Traditional methods of geodesy and land management were primarily based on direct ground-based measurements, astronomical observations, and the use of satellite positioning systems, including GPS and GNSS. Although these methods provide a high level of accuracy, they often require considerable time and resources. However, the emergence of geographic information systems (GIS) has led to a significant transformation in the field of geodesy, enabling more efficient, accurate, and integrated analysis of spatial data. GIS technologies make it possible to collect, analyze, and visualize geodetic data in a more efficient and dynamic manner.

At the same time, the digital transformation of the sector is not limited to the transition from analogue instruments and paper-based materials to digital measurement tools and electronic maps. It involves a deeper transformation of workflow organization, in which the acquisition, control, processing, structuring, analysis, and subsequent use of spatial information form a unified information and technological cycle. This approach contributes to reducing the number of manual operations, decreasing labor intensity, increasing the efficiency of data processing, enabling the repeated use of generated geospatial datasets, and reducing the time required to produce topographic maps and models, while simultaneously improving processing

efficiency, data consistency, and quality control of spatial information. In addition, through the integration of data such as satellite imagery, LiDAR, and GNSS measurements, GIS provides a basis for comprehensive geospatial analysis that was previously unavailable using traditional methods.

At the same time, the development of digital technologies creates new requirements for the quality, interoperability, and reliability of geospatial information. Important issues include the harmonization of coordinate reference systems, standardization of data formats, ensuring the accuracy of geodetic measurements, control of the topological correctness of spatial object representation, organization of information exchange between different information systems, and training specialists to work in an integrated digital environment. Therefore, research on the digital transformation of geodesy and land management should address not only the characteristics of modern technical tools but also the assessment of changes in the very structure and organization of professional workflows.

Analysis of recent research and publications. The digital transformation of geodesy and land management is currently a complex process encompassing a wide range of geodetic, legal, and environmental aspects [1]. The introduction of digital technologies into land management activities is associated not only with the improvement of methods for acquiring spatial data, but also with the need for their regulatory, informational, and organizational harmonization. The automation of management processes in the field of land use and protection remains a priority area of scientific research, as it directly affects the efficiency of the entire land management system and creates the prerequisites for a transition from fragmented processing of land information to its systematic use in a digital environment [2].

The development of geographic information systems (GIS) is recognized by researchers as a key technological innovation strategy that extends beyond traditional digital mapping [3]. Accordingly, the development of GIS can be considered one of the key drivers in transforming the technological model of geodetic and land management activities. However, the implementation of these technologies, particularly in the modernization of electronic geodetic networks for the needs of

territorial community cadastres, requires overcoming a number of technological barriers and taking societal imperatives into account. At the same time, the reliability of spatial information directly depends on the accuracy and coordinate consistency of the source data [4]. Remote geodetic monitoring is also becoming one of the major tools for sustainable land resource management [5]. The use of remote observation technologies expands the possibilities for systematic monitoring of territorial conditions, detection of spatial changes, and accumulation of time-series geospatial data, which is particularly important for operational land management and land-use monitoring.

Researchers have shown considerable interest in the applied aspects of geodesy in addressing the challenges of sustainable urban development, particularly in the context of spatial planning [6]. The practical application of digitalization in the field is widely discussed in scientific studies focused on automating the creation and updating of digital topographic maps [7; 8]. The automation of cartographic processes is one of the characteristic manifestations of digital transformation, as it reduces the number of manual operations, ensures the structured organization of geospatial data, and facilitates their subsequent updating and use.

Another important direction in the development of the field is the digital transformation of geotechnical investigations, where new methods and strategic roadmaps are being actively introduced [9]. The expansion of digital methods in related engineering fields confirms the trend toward the formation of an integrated information environment in which the results of field investigations are combined with tools for digital analysis and modeling. At the same time, higher geodesy and engineering geodetic surveys continue to serve as a metrological basis for the verification of satellite monitoring data [10]. Separate studies are devoted to the integration of geodetic methods and Earth remote sensing data to provide high-quality cartographic support for urban planning documentation [11].

The purpose of the study is to substantiate the role of geoinformation technologies in the digital transformation of geodesy and land management and to test

their functional capabilities through the formation, spatial analysis, and cartographic representation of a land parcel.

Materials and methods of research. The methodological basis of the study was the comprehensive application of a geoinformation approach for the processing, integration, analysis, and cartographic representation of geodetic and land management data. The practical validation involved testing the functional capabilities of geographic information systems (GIS) during the creation of a spatial model of a land parcel, its attribution with descriptive data, spatial analysis, and the preparation of cartographic and land management materials.

The study object was a municipally owned agricultural land parcel with an area of 21.9068 ha, located within the Diadkovychi Territorial Community, Rivne District, Rivne Region.

Source materials: coordinates of the turning points of the land parcel boundary, results of geodetic measurements, cadastral and cartographic materials, orthophotographic data, information on the composition of land-use categories, agro-production soil groups, and materials of normative monetary valuation. This set of data formed the information basis for geoinformation modeling and spatial analysis of the study area.

Hardware and instrumentation: A high-precision Trimble R8 GNSS (Model 2) receiver with RTK capability was used for field geodetic surveys, with a specified accuracy of ±(8 mm + 1 ppm) horizontally and ±(15 mm + 1 ppm) vertically (RMS). For control geodetic measurements, a SOUTH NTS-355R+ electronic total station was used, with a specified angular accuracy of 5″ and prism distance measurement accuracy of ±(2 mm + 2 ppm × D), where D is the measured distance. Its use provided additional verification of the geometric parameters of the constructed boundary and consistency between the field measurement results and the coordinate model of the land parcel. A DJI Mavic 3 Pro quadcopter UAV equipped with a digital camera suitable for aerial photography was used for aerial surveying of the study area. The main camera parameters were as follows: 4/3 CMOS sensor; lens field of view: 84°; aperture: f/2.8–

f/11; ISO sensitivity: 100–12,800 for video and 100–12,800 for photographs; image resolution: 5280 × 3956 pixels.

Office processing: the results of geodetic measurements, vectorization of spatial objects, and preparation of individual components of land management documentation were carried out using the Digitals software package. The QGIS geoinformation environment was used to import and edit vector data, delineate the land parcel boundaries, populate object attributes, integrate heterogeneous geospatial data, perform spatial operations, and visualize the results cartographically. The DJI Fly mobile application was used to configure UAV parameters and monitor its operation, while 3Dsurvey Pilot was used for flight mission planning, delineation of the study area, and generation of the aerial survey route.

The study employed geodetic, geoinformation, cartographic, and spatial-analytical methods. The geodetic method was used to determine the coordinates of the land parcel boundaries; the geoinformation method was used to create and process point and polygon spatial objects; the cartographic method was applied to represent the results in the form of plans and thematic maps; and spatial analysis methods were used to determine the geometric characteristics of the land parcel, verify its geometry, analyze the spatial relationships between objects, and combine thematic layers.

The practical validation of GIS functionality was carried out sequentially. At the first stage, a set of geodetic works was performed to determine the coordinates of the boundary markers of the study object. Next, the coordinates of the turning points were imported and a point layer was created. Based on these points, a closed polygon representing the land parcel boundary was constructed, its area and perimeter were determined, and its geometric correctness was verified. The next stage included aerial surveying, photogrammetric processing, and the creation of an orthophoto map and a digital elevation model. This was followed by the attribution of the spatial object with information on its area, designated land use, land-use composition, and other characteristics. To expand the analytical capabilities of the geoinformation model, the land parcel boundary was integrated with cadastral, orthophotographic, and thematic

materials. Particular attention was paid to analyzing the spatial distribution of agro-production soil groups within the study area and their relationship with the materials used for normative monetary valuation. Spatial overlay of thematic layers made it possible to determine the location of the corresponding soil contours within the land parcel and to produce their cartographic representation.

The overall sequence of geoinformation processing can be represented as a technological workflow extending from geodetic measurements to the cartographic representation of the results (Fig. 1).

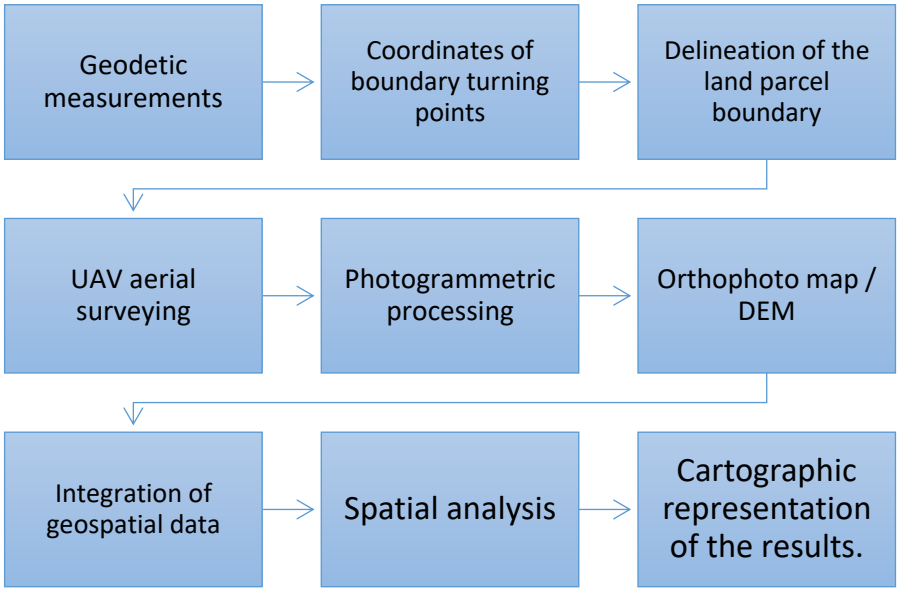


Fig. 1. Workflow of Geoinformation Processing of Geodetic Survey Results.
Source: developed by the authors.

Results and Discussion. According to recent studies, the integration of GNSS, remote sensing, and GIS reduces the labor intensity of individual geodetic processes and expands the capabilities of spatial analysis [9, 12, 13]. In view of this, the functional capabilities of GIS were practically tested on the study land parcel.

The practical validation of geoinformation technologies was carried out on a municipally owned land parcel with an area of 21.9068 ha, located within the Diadkovychi Territorial Community, Rivne District, Rivne Region (Fig. 2). Observations were performed in real-time (RTK) mode using reference GNSS stations of the ZAKPOS network. The connection to the network server was established via mobile Internet (GPRS), while correction data were transmitted in RTCM v3.x format. Network RTK Master Auxiliary Corrections (MAX) technology was used to generate

the corrections. This technology utilizes data from a master base station and auxiliary base stations, which are selected automatically depending on the receiver position. The corrections were calculated using the Trimble GNSS Spider v4.3 software package.

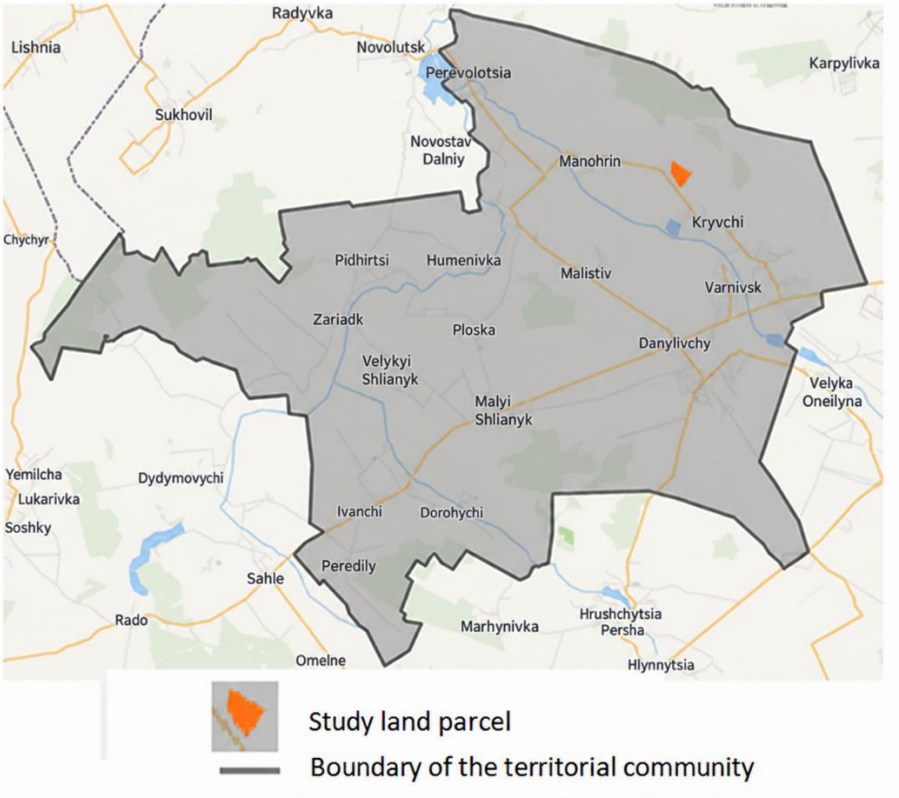


Fig. 2. Location of the study land parcel on the OpenStreetMap cartographic base. Source: compiled by the authors.

The differential field of the ZAKPOS RTK network was checked at the Synev, Dibrova, and Pulko points of the State Geodetic Network (SGN) using coordinates obtained from the Administrator of the Geodetic Data Bank. The discrepancies in the coordinate values of the control points did not exceed 0.5 m, which complies with Clause 8 of the «Procedure for the Use of the State Geodetic Reference Coordinate System USK-2000 in Land Management Works» [15]. Based on the RTK observations, the turning points of the land parcel boundary were georeferenced to the points of the State Geodetic Network (SGN), as shown in Fig. 3a. The coordinates of the turning points of the study land parcel boundary were determined from GNSS observations (Fig. 3b) and served as the initial spatial basis for subsequent geoinformation processing.

At the next stage, the coordinate data were imported into the QGIS software environment, where a polygonal boundary of the land parcel was created from the point layer of characteristic points. The geometric characteristics of the land parcel were determined, the correctness of its geometry was verified, and attribute information was generated. For visual control of the spatial position of the boundary, the land parcel contour was overlaid on the orthophoto base.

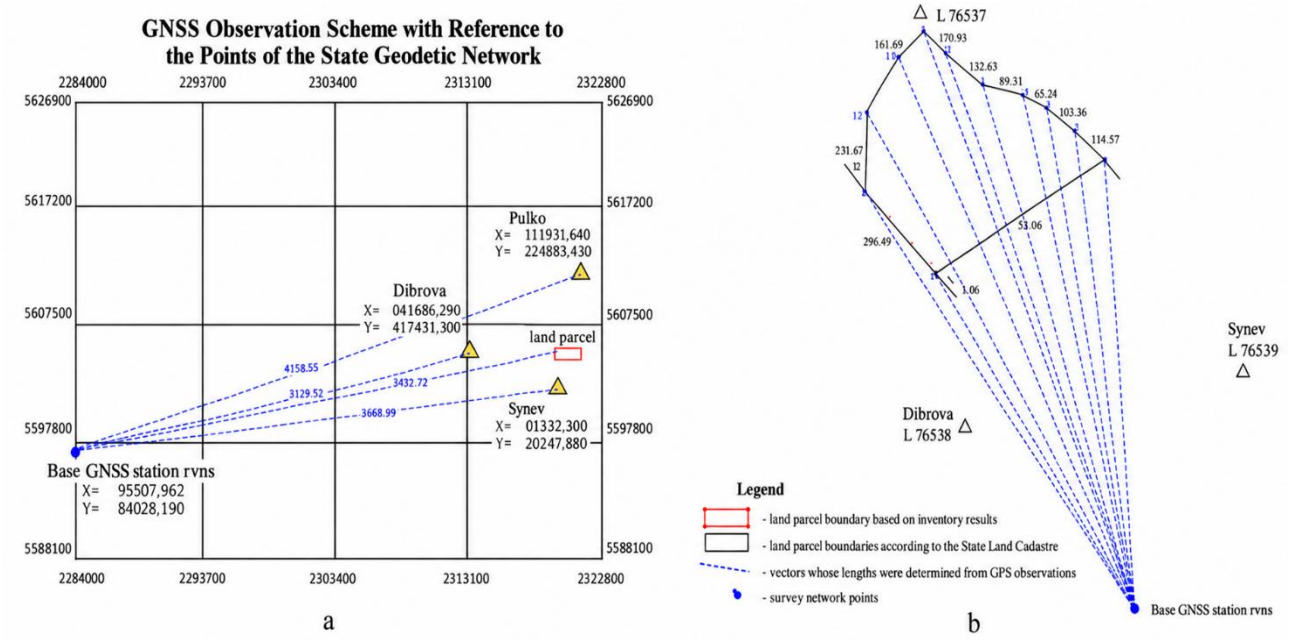


Fig. 3. Geodetic support for determining the land parcel boundaries: a – scheme of georeferencing to points of the geodetic network; b – scheme for determining the coordinates of the boundary turning points of the land parcel. Source: compiled by the authors.

UAV-based aerial surveying was carried out to enhance the information content of the geoinformation model and to obtain an up-to-date, detailed spatial basis for the study area. During flight mission planning, the configuration of the land parcel was taken into account to ensure complete coverage of the study area. The total number of planned photographs was 652, with a calculated flight altitude of 100 m, a flight speed of 8 m/s, and an approximate route length of 7.36 km. The designed aerial survey route (Fig. 4a) provided the source materials required for subsequent photogrammetric processing and integration of the results into the geoinformation environment.

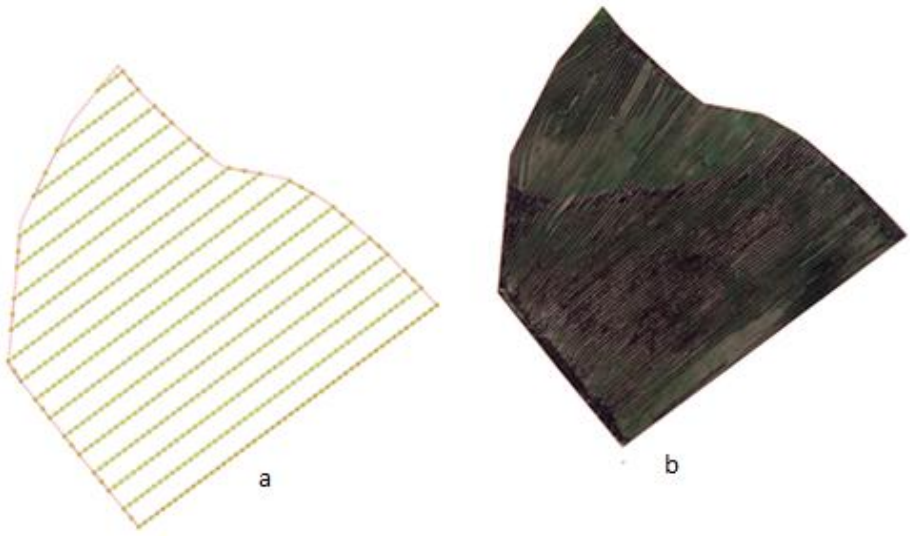


Fig. 4. Aerial surveying of the study land parcel: a – UAV flight route scheme; b – orthophoto map based on photogrammetric processing results. Source: compiled by the authors.

As a result of the photogrammetric processing of the aerial survey materials, an orthophoto map of the study area was generated (Fig. 4b). The integration of the orthophoto map into the GIS environment made it possible to overlay the vector boundaries of the land parcel onto the actual image of the terrain and to visually verify its spatial position relative to land-use contours, the road network, and other territorial elements. As a result, a hypsometric matrix of the relief of the study area was constructed (Fig. 5a), and the spatial differentiation of the relief was represented in digital form as a digital elevation model (DEM) (Fig. 5b). Further morphometric analysis of the land parcel area made it possible to compile a slope steepness map. The resulting map provides a basis for assessing the conditions of agricultural use of the territory and for carrying out land management works (Fig. 5c).

A 35 kV overhead power line (PL) passes through the study land parcel and was identified during the geoinformation processing of the spatial data. The power line was represented as a separate thematic layer, which made it possible to examine in detail its spatial position relative to the boundaries of the land parcel and adjacent objects (Fig. 6).

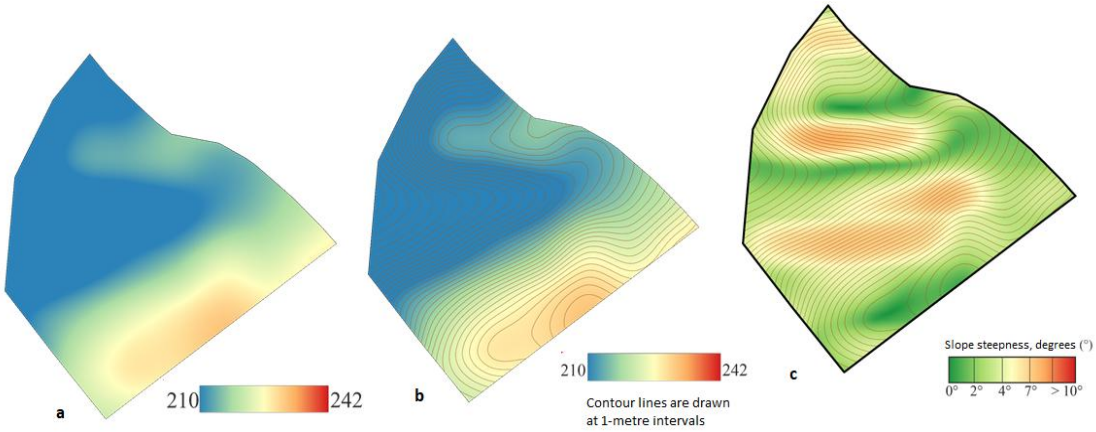


Fig. 5. Morphometric characteristics of the relief of the study land parcel: a – elevation matrix derived from photogrammetric processing of UAV data; b – digital elevation model with contour lines; c – slope steepness map. Source: compiled by the authors.

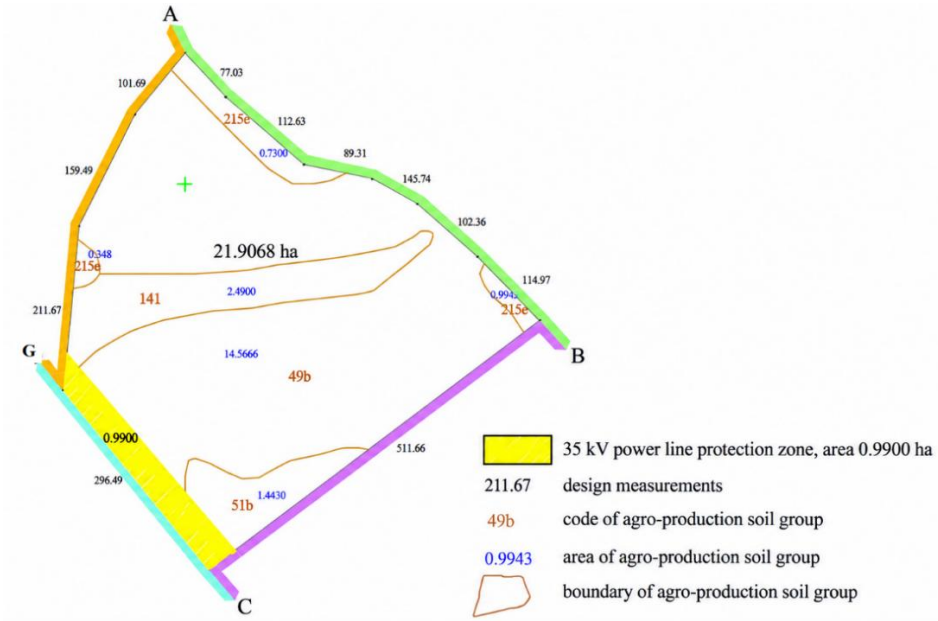


Fig. 6. Spatial location of the 35 kV power line and its protection zone within the study land parcel. Source: compiled by the authors based on data from the Public Cadastral Map of Ukraine, layer "Agro-Production Soil Groups" [16].

A separate layer representing the power line and its protection zone made it possible to determine the part of the land parcel subject to the relevant land-use restrictions. For 35 kV overhead power lines, the protection zone is established at a distance of 15 m on both sides from the outermost conductors in their undeflected position [14]. As a result of the spatial overlay of the layers, a part of the land parcel with an area of 0.9900 ha was identified as being subject to the protection zone regime

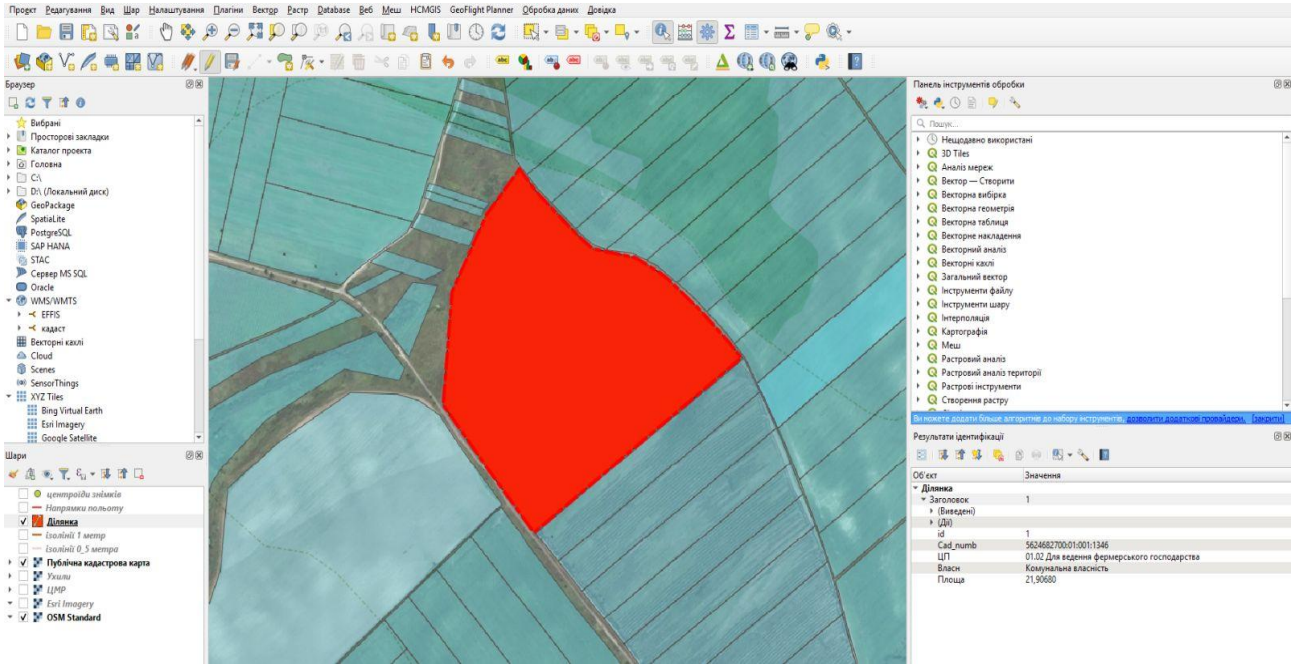
of the 35 kV power line. The use of GIS enables spatial accounting of land-use restrictions associated with engineering infrastructure facilities.

Attribute information on the cadastral number, area, ownership form, designated land use, land-use type, and existing restrictions was linked to the created polygon model (Table 1). Thus, GIS makes it possible to combine the spatial geometry of the land parcel with its key land management characteristics in the form of a system of thematic layers for subsequent use in spatial analysis (Fig. 7).

1. Structure of the Thematic Layers of the Geoinformation Project for the Study Land Parcel

Layer	Geometry Type	Main Content	Functional Purpose
land_parcel	polygon	land parcel	formation of the spatial contour, area calculation, and spatial analysis
turning_points	points	boundary turning points	storage of coordinates of characteristic points and control of boundary position
parcel_boundary	line	land parcel boundary	representation of boundary configuration and determination of boundary segment lengths
orthophoto	raster	orthophoto base	visual control of the spatial position of objects and actual land use
DEM	raster	elevation model	analysis of elevation characteristics and landform features
slope	raster	slope steepness	determination and mapping of the spatial distribution of slopes
power_line_35kv	line	35 kV power line	representation of the location of an engineering infrastructure object
protection_zone	polygon	35 kV power line protection zone	identification and analysis of areas subject to land-use restrictions
soil_groups	polygon	agro-production soil groups	analysis of soil cover and determination of soil-contour areas

Source: compiled by the authors.



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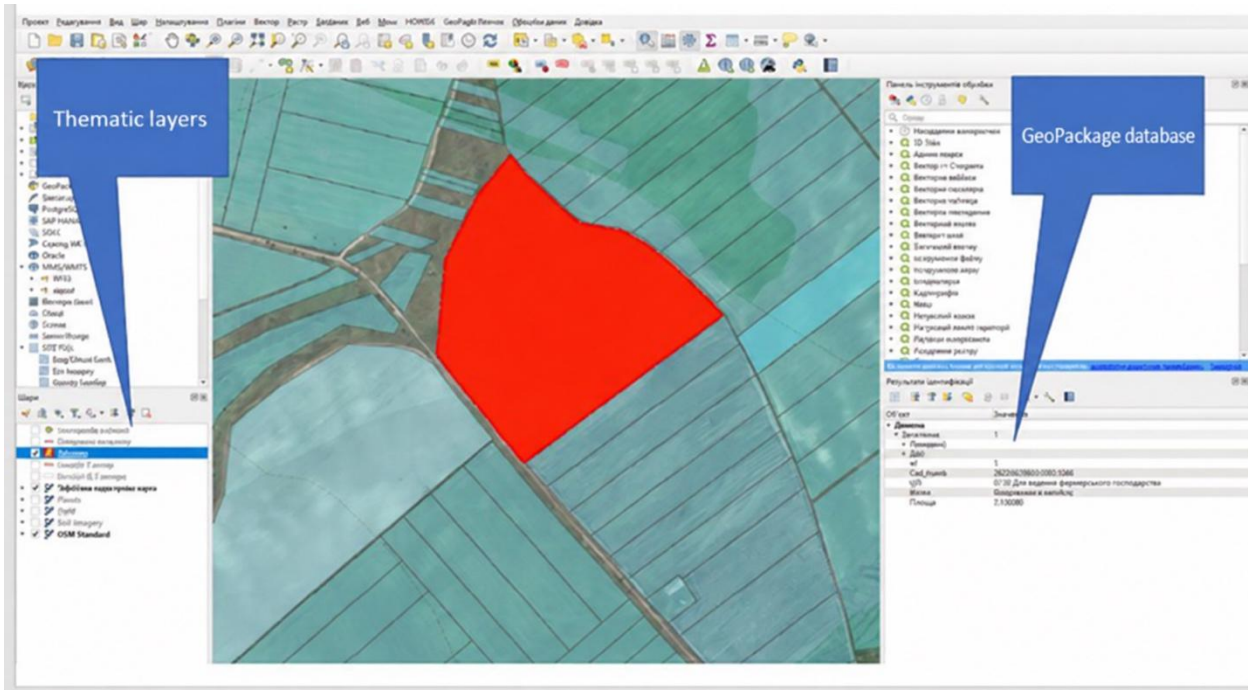

b

Fig. 7. Organization of spatial and attribute data of the land parcel in the QGIS environment: a – representation of the land parcel polygon and its attribute characteristics; b – structure of thematic layers and the geospatial database. Source: compiled by the authors.

The spatial overlay of the land parcel polygon with the thematic layer of agro-production soil groups enabled the integration of soil data. The boundaries of individual soil contours within the study area were identified using geoinformation

analysis, and their areas were calculated. This made it possible to combine the geometric characteristics of the land parcel with the qualitative characteristics of the soil cover within a unified geoinformation structure (Fig. 8).

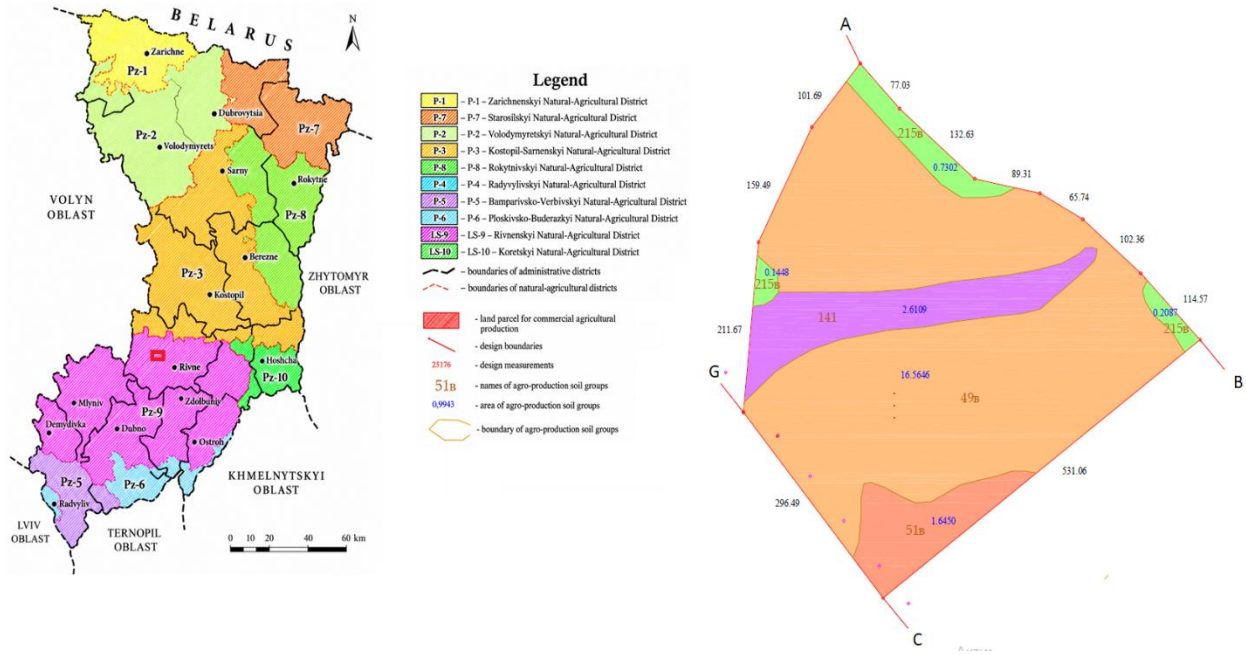

Fig. 8. Soil-spatial characteristics of the study area: a – scheme of natural-agricultural zoning of Rivne Region; b – spatial distribution of agro-production soil groups within the land parcel. Source: compiled by the authors based on data from the Public Cadastral Map of Ukraine, layers “Agro-Production Soil Groups” and “Natural Agricultural Zoning” [16]

To determine the affiliation of the study land parcel with the corresponding natural-agricultural district, the natural-agricultural zoning of Rivne Region was used [16;17]. Overlaying the land parcel boundaries with the layer of agro-production soil groups forms a spatial basis for applying normative monetary valuation indicators. Geoinformation processing makes it possible to measure the areas of individual soil contours and integrate them with the corresponding valuation characteristics. Thus, GIS ensures the spatial consistency of cadastral, soil, and valuation data required for the preparation of normative monetary valuation materials.

The preparation of land management cartographic materials was carried out at the final stage of geoinformation processing. The generated spatial layers formed the basis for preparing the graphical materials of land management documentation, detailing the

geometry of the land parcel, its boundaries, land-use composition, and spatial characteristics. This approach ensured the consistency of geodetic, cadastral, and thematic data and made it possible to use a unified spatial basis for preparing the graphical component of land management documentation. As a result, GIS serves not only as a tool for cartographic visualization but also as a unified environment for the comprehensive integration and presentation of the results of land management activities.

Conclusions. Based on the results of the study, the digital transformation of geodesy and land management should be regarded as a transition toward the integration of heterogeneous spatial data within a unified geoinformation environment. The use of GIS enables the integration of the coordinates of boundary turning points, land parcel boundaries, cadastral information, orthophotographic materials, agro-production soil groups, and information on land-use restrictions. The practical validation resulted in the generation of an orthophoto map and a digital elevation model, analysis of slope steepness, integration of soil characteristics, and identification of 0.9900 ha of land subject to the protection zone of the 35 kV power line. This result reflects the development of GIS as a fundamental tool for the analysis and visualization of geospatial information. At the same time, the use of high-precision geodetic data as the initial spatial basis demonstrates the importance of modernizing geodetic support for cadastral and land management activities. This demonstrates the transition from individual measurements to comprehensive geoinformation processing of the study object.

Further development of the digital transformation of geodesy and land management should be associated with improving the automated integration of heterogeneous geospatial data, expanding spatial analysis capabilities, and developing standardized digital workflows for land management tasks.

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ЦИФРОВІЗАЦІЯ ГЕОДЕЗІЇ ТА ЗЕМЛЕУСТРОЮ ЯК НАПРЯМ РОЗВИТКУ СУЧАСНИХ ГЕОІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ

***Анотація**. У статті розглянуто роль геоінформаційних технологій у цифровій трансформації сучасної геодезії та землеустрою. Представлено цифрові робочі процеси опрацювання просторових даних у єдиному інформаційно-технологічному циклі. Практично апробовано функціональні*

можливості ГІС на земельній ділянці комунальної власності сільськогосподарського призначення площею 21,9068 га, розташованій на території Дядьковицької територіальної громади Рівненського району Рівненської області. Під час дослідження виконано комплекс геодезичних вимірювань із використанням GNSS-технологій у режимі RTK, аерофотознімання за допомогою безпілотного літального апарата (БПЛА) та фотограмметричне опрацювання матеріалів. У середовищі програмного комплексу QGIS реалізовано інтеграцію різнотипних просторових даних для отримання координат поворотних точок межі земельної ділянки, ортофотоплану, цифрової моделі рельєфу (ЦМР), картограми крутизни схилів, об'єктів інженерної інфраструктури (ПЛ 35 кВ та її охоронної зони), а також агровиробничих груп ґрунтів. Обґрунтовано роль сучасних ГІС не лише як засобу картографування, а як комплексного середовища для автоматизації проєктних рішень, просторового аналізу та контролю землекористування. Результати дослідження можуть бути використані для вдосконалення цифрових робочих процесів у сфері землеустрою, ведення земельного кадастру та управління земельними ресурсами територіальних громад.

Ключові слова: *геодезія, землеустрій, цифрова трансформація, геоінформаційні технології, геопросторові дані, просторовий аналіз, QGIS, агровиробничі групи ґрунтів.*