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# THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR USING SPATIAL DATA, DIGITAL CARTOGRAPHIC BASES AND GEODATABASES IN THE DESIGN OF LAND MANAGEMENT PLANS

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### Abstract

This article examines the theoretical and methodological foundations for using spatial data, digital cartographic bases and geodatabases in the design of land management plans. A land management plan is interpreted not merely as a graphical project document, but as a spatial information model integrating land parcel boundaries, land-use categories, environmental and reclamation conditions, infrastructure, legal restrictions and decision-support indicators. Based on international frameworks and practices such as FAO VGGT, UN-GGIM FELA, INSPIRE, LADM and fit-for-purpose land administration, an integrated methodological model is proposed. The model organizes data acquisition, georeferencing, quality control, topological validation, spatial analysis, plan production and monitoring within a single geodatabase environment.

**Keywords:** Land management, spatial data, digital cartographic base, geodatabase, GIS, cadastre, geoportal, LADM, INSPIRE, land monitoring.

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### 1. Introduction

The design of land use plans plays an important role in the rational use of land resources, the scientific organization of agricultural and residential areas, the definition of land boundaries, the coordination of land categories and types of use, and the management of territorial development. In the traditional approach, a land use plan is often considered as a cartographic image and explanatory inscription, but in modern conditions it is becoming a multi-layered spatial information model. In such a model, the boundaries of the land plot, relief, soil, hydrography, infrastructure, land reclamation, environmental restrictions, legal status, and monitoring results are expressed in an interconnected manner [1], [2]. Globally, the digital transformation of land management is associated with the formalization of land ownership and use rights, the development of open geodata infrastructure, updating cadastral maps, and the transition to a data-driven system of territorial planning. According to the World Bank, only about 30 percent of the world's population has registered property rights, and in Africa this figure may be less than 10 percent [4]. Therefore, providing land registration, cadastre, and spatial planning processes with a digital cartographic basis is not only a technical issue, but also a socio-economic one.

Important factors affecting the quality of land use drawings include coordinate accuracy, topological integrity, attribute completeness, timeliness, metadata provision, and compatibility of layers from different sources. If the map, orthophoto, cadastral contour, soil map, and infrastructure layers used for the drawing are in different coordinate systems or have different update dates, design decisions may be made incorrectly. Therefore, modern methods involve not only drawing data, but also managing, verifying, versioning, and reusing it at the geodatabase level [8], [13].

The purpose of this article is to develop theoretical and methodological foundations for the use of spatial data, digital cartographic foundations, and geodatabases in the design of land use plans, analyze world experience, and

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substantiate an integrated approach that can be applied in the conditions of Uzbekistan.

### 2. Literature review

Among the international methodological approaches to land governance, the FAO Voluntary Guidelines for the Responsible Governance of Land, Fisheries and Forest Resources (VGGT) are of particular importance. This document promotes the principles of security of land rights, transparency, equitable tenure and institutional accountability [1]. In the preparation of land development plans, these principles serve to ensure the legal status of the land plot, use restrictions, stakeholder participation and the soundness of project decisions.

The Framework for Effective Land Administration (FELA), developed by UN-GGIM, offers a strategic approach that links spatial data, standards, innovation, governance, collaboration and sustainability for effective land administration [2]. In the FELA concept, land administration is interpreted as a system that manages land rights, constraints, responsibilities, value, use and development processes in a single geospatial environment, rather than just a cadastral register.

The European Union's INSPIRE directive aims to create a spatial data infrastructure, interoperability of public authorities' data and support environmental policy. The INSPIRE concept is based on the standardization of data themes, metadata, network services and rules for data exchange [3]. This experience is important for the design of land use maps, in order to maintain layers based on uniform metadata and formats, to present them through a geoportal and to reduce data duplication.

The fit-for-purpose land administration approach proposes to organize land administration based on a phased, rapid and low-cost solution that is appropriate to the circumstances, rather than the expensive and time-consuming classical cadastral model [6]. The experience of Rwanda shows the practical effectiveness of this approach: in 2009-2013, more than 10.4 million land parcels were

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demarcated and 8.8 million land title deeds were issued across the country [10]. This shows that it is possible to create a comprehensive land information system through digital contours, collective identification and a simple geodatabase. The experiences of the Netherlands, Germany, Estonia, Singapore and the USA in digital cadastre and geoportals also have a direct impact on modern land planning methodologies. For example, the Estonian e-Land Register portal allows for quick verification of registered real estate, area, owners, restrictions and mortgages in an electronic environment [9]. In Singapore, the provision of state geodata, digital cadastral data, road networks and building contours through digital services strengthens the data-driven model of land planning [12].

Table 1. International concepts related to land management and digital land administration

Concept / system	Main content	Methodological significance for land surveying
FAO VGGT	Principles of responsible management of land, fisheries and forest resources	Ensures legal transparency, stakeholder participation, and equitable access
UN-GGIM FELA	A strategic framework linking land administration with geospatial infrastructure	Helps interpret drawing, cadastre, value, use and monitoring in a single system
INSPIRE	European Spatial Data Infrastructure, Metadata and Network Services	Ensures compatibility, interchangeability, and openness of digital layers
LADM / ISO 19152	Land Rights, Restrictions, and Liabilities Modeling Standard	Connects land parcel, subject, and legal relationships in a data model
Fit-for-purpose LA	Appropriate, phased and affordable land administration	Creates a rapid digital inventory and project database across large areas

### 3. Materials and methods

The research methodology was based on systematic analysis, comparative study of international experiences, GIS modeling, digital cartographic analysis,

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conceptual design of geodatabases and spatial decision-making approaches. The process of designing land use plans on a digital basis was considered in three interrelated blocks: data block, analytical-modeling block and design-legal result block.

The data block collects satellite imagery, UAV orthophotos, GNSS field measurements, topographic maps, digital elevation models, soil and property data, land reclamation maps, infrastructure layers, cadastral contours, and legal attributes. All of these layers should be georeferenced in a single coordinate system and provided with metadata. Metadata describes the origin of the layer, its accuracy, update date, responsible organization, attribute descriptions, and usage restrictions [3], [8].

In the analytical-modeling block, data is entered into the geodatabase, topological errors are checked, GIS analysis methods such as overlay, buffer, network, suitability, zonal statistics and multi-criteria evaluation are used. In the land survey drawing, parcel boundaries, road and irrigation networks, easements, environmental restrictions and types of use must correspond to each other. This ensures semantic compatibility between the graphic representation of the drawing and the legal data in the attributive database.

The project-legal result block includes the formation of a land development plan, explanatory notes, land balances, boundary marking materials, digital layers to be integrated into the cadastre, and monitoring indicators. At this stage, the project result is not just a static map, but a geodataset that can be updated, analyzed, and reused in the decision-making process in the future.

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Figure 1. Theoretical and methodological scheme for designing land development drawings

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Table 2. Required spatial data layers and quality requirements for a land survey drawing

Information layer	Main attributes	Quality requirement	Project task
Cadastral contours	Cadastral number, area, type of right	Topologically closed contour, coordinate accuracy	Identification of land plots
Digital cartographic framework	Scale, coordinate system, relief	Single projection and actual information	Geodetic-cartographic base for drawing
Orthophoto / DZZ	Image date, pixel resolution	Cloud/quality control, georeferencing	Checking real-world usage
Digital terrain model	Height, slope, exposure	Vertical accuracy, hydrological correction	Erosion, drainage and road design assessment
Soil and quality	Soil type, quality score, salinity	Compatibility with laboratory and field data	Land assessment and agrotechnical zoning
Infrastructure	Road, canal, electricity, gas, water networks	Topological dependence and complete attribute	Easement, ease of use and cost assessment
Legal restrictions	Conservation zones, easements, regimes	Relationship with regulatory documents	Legal certainty and conflict prevention

A geodatabase is the core information of a land use plan. It integrates graphic layers, attribute tables, topological rules, domains, relationships, metadata, and versioning mechanisms into a single system. When a digital plan is linked to a geodatabase, the area, land type, use mode, constraint, easement, soil property, monitoring status, and decision attributes for each contour are stored together.

Theoretically, a geodatabase is based on the object-attribute-relationship principle. An object can be a land plot, a road, a canal, a building, a protected area, or a terrain contour. An attribute can be the cadastral number, area, soil index, type of use, or legal status of an object. A relationship represents the topological, semantic, and legal relationship between objects. For example, a land plot can be connected to an irrigation network, intersect with a protected area, or have a certain restriction regime [7], [9].

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When designing a geodatabase for a land use plan, it is advisable to adhere to at least five principles: 1) a unified coordinate and classifier system; 2) a hierarchical structure of layers; 3) mandatory metadata; 4) topological and attributive validation; 5) compatibility with export and exchange formats. These principles increase not only the cartographic beauty of the plan, but also its legal and management value.

The technical structure of the geodatabase should be such that the project result can be reused in different organizations, imported into the cadastral system, placed in a geoportal, and updated for monitoring. This is especially important when linking land use plans with the state cadastre, agricultural planning, water management, environmental control, and investment projects.

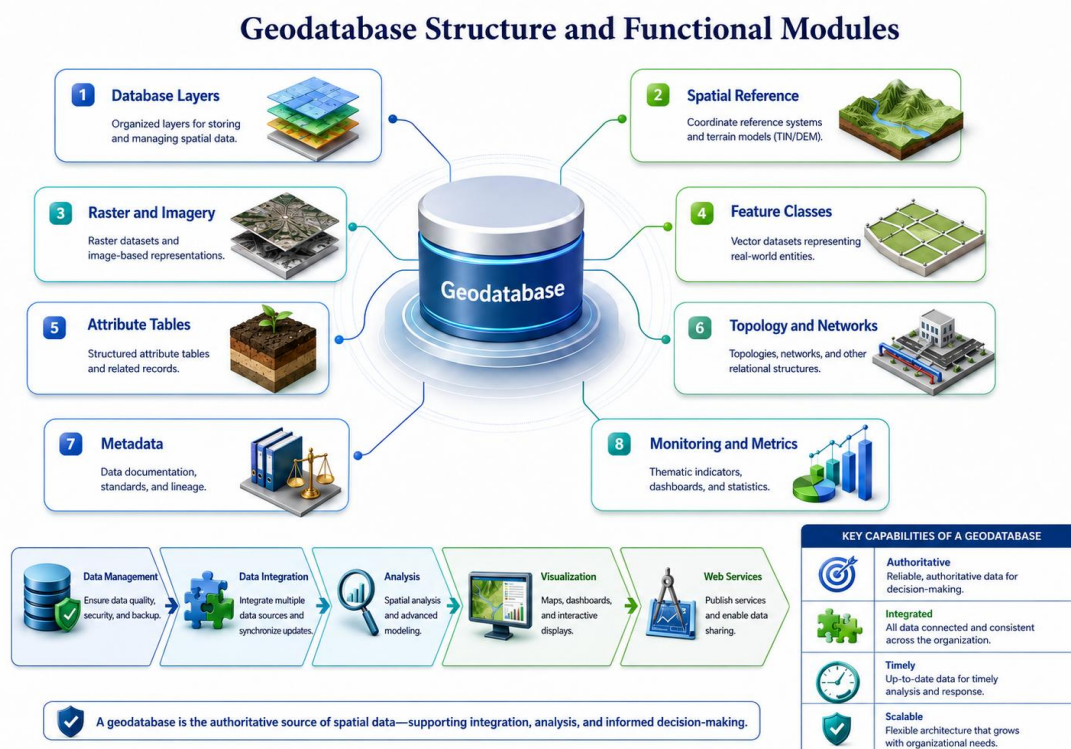


Figure 2. Digital cartographic foundations and structural structure of a geodatabase

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Table 3. Technical and methodological requirements used in the design of a geodatabase

Demand	Content	Practical result
Coordinate unit	Maintaining all layers on a single geodetic basis and projection	Layer displacement and field errors are reduced
Topological control	Checking for contour closure, intersection, gap and duplicates	The boundaries of the land plot will be reliable
Attributive completeness	Required fields: ID, area, land type, right, date, source	Search, analysis, and reporting are automated
Metadata	Information source, accuracy, update date, and responsible organization	Data quality and origin are controlled
Versioning	Historical storage of project and monitoring changes	The possibility of conducting an audit of decisions will be created.
Interoperability	Formats such as GML, GeoJSON, SHP, Geopackage, WMS/WFS	Inter-agency information exchange becomes simpler

The proposed methodology views the preparation of a land use plan as a five-step system:

- 1) collection of initial spatial data;
- 2) data standardization and formation of a geodatabase;
- 3) spatial analysis and suitability assessment;
- 4) development of a project drawing;
- 5) Monitoring and updating. Each stage is linked to a feedback mechanism and a review of the results of the previous stage.

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The difference in accuracy between different sources is taken into account when collecting primary data. For example, GNSS field measurements provide high coordinate accuracy, UAV orthophotos show the real use of land plots, and satellite images allow monitoring of vegetation, moisture, construction and land cover changes over large areas. Topographic plans, DEMs and soil maps form the natural-geographic basis of the project drawing [13], [15].

During the suitability assessment phase, each project solution is analyzed against several criteria: current land use, environmental constraints, soil fertility, proximity to infrastructure, irrigation potential, slope, erosion risk, legal constraints, and economic efficiency. Such a multi-criteria analysis increases the scientific validity of the land use plan and reduces the share of subjective decisions.

Methodologically, the spatial compatibility index of a land development project can be expressed in the following generalized form:  $FMI = w_1K + w_2T + w_3R + w_4I + w_5H + w_6E$ . Here, K is cadastral and legal compatibility; T is soil-bonite potential; R is relief and natural constraints; I is infrastructure provision; H is current land use status; E is ecological sustainability;  $w_1...w_6$  are weight coefficients determined depending on the characteristics of the territory. This model serves to optimize the contours of the drawing according to various priorities.

When developing a project drawing, the final results should be prepared in digital and analog form. In digital form, the drawing consists of vector layers, attribute tables, metadata, style files, and a geodatabase package. In analog form, a cartographic project document is prepared with a specified scale, legend, symbols, coordinate grid, explanatory notes, and approval details.

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Table 4. Integrated stages of land use planning design

Stage	Main works	Software tools	Result
1. Data collection	GNSS, UAV, DZZ, topographic and cadastral material collection	GNSS receiver, UAV, GIS	Initial spatial data set
2. Standardization	Coordinate system, format, metadata, and attribute customization	ArcGIS/QGIS, DBMS	Unified geodatabase
3. Spatial analysis	Overlay, buffer, suitability, topological validation	GIS analytical tools	Compatibility maps and error list
4. Drawing design	Development of parcel boundaries, zoning, easements, and use plan	GIS/CAD integration	Digital land surveying drawing
5. Monitoring	Change tracking, versioning, and release to geoportal	Geoportal, dashboard	Updated project information

### 4. Results and discussion

The results of the analysis show that the design of land use plans based on a geodatabase has several significant advantages over the traditional approach to drawing. First, the outlines of the plan are formed on the basis of coordinates and the area calculation is automatically controlled. Second, all attributes are linked by a single identifier and graphic, legal and technical information on the land plot is stored in one place. Third, the validity of design decisions is confirmed by the results of GIS analysis.

Statistically, digital land administration systems are characterized by the experience of countries that have achieved widespread results. In the case of Rwanda, the demarcation of over 10.4 million land parcels and the issuance of 8.8 million title deeds demonstrate that a fit-for-purpose approach works

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effectively across large areas [10]. The World Bank's Land 2030 program emphasizes that formalizing land rights is linked to global sustainable development, climate adaptation, gender equality, and investment security [4], [5].

In countries with well-developed digital cadastre and spatial data infrastructure, the life cycle of land surveying drawings is shortened. If the database already exists, the project specialist can inspect, analyze and adapt existing layers to the project solution rather than redrawing contours. This saves time, reduces errors and facilitates interdepartmental acceptance of project results.

Another important result of using a geodatabase is the creation of a continuous link between the drawing and monitoring. In a traditional drawing, the data quickly becomes outdated after the project is approved. In a digital model, the drawing layers are regularly updated based on orthophotos, remote sensing images, field measurements and cadastral updates. This turns the project document from a static map into a dynamic management system.

In the conditions of Uzbekistan, the expansion of the geodatabase approach to the design of land use plans solves several practical issues: it reduces the inconsistency of land parcel boundaries, identifies the gap between cadastral and actual use, improves planning related to irrigation and road networks, and incorporates soil quality and environmental constraints into design decisions. In particular, GIS-based assessment of crop rotation, land reclamation measures, and infrastructure location on agricultural lands is effective.

However, there are certain limitations in implementing this approach. These include the fragmentation of data across organizations, the obsolescence of some layers, incomplete metadata management, incompatible formats, insufficient skills of local specialists in working with geodatabases, and the costs associated with software licenses. Therefore, the methodology should be implemented not only as a technical software solution, but also in conjunction with institutional cooperation, standards, and personnel training.

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Table 5. Comparative analysis of traditional and geodatabase-based land use plans

Criterion	Traditional approach	Geodatabase-based approach
Information form	Paper drawing, separate files and tables	Single geodatabase, vector/raster layers
Boundary accuracy	Graphic drawing and manual inspection	Coordinate and topological validation based verification
Attributes	In an explanatory note or in a separate table	As an attribute attached to each object
Update	Redrawing and manual editing required	Upgrades incrementally through versioning and monitoring
Analysis capability	Limited, mostly descriptive	Overlay, buffer, suitability, statistical and scenario analysis
Legal certainty	There may be a discrepancy between the document and the drawing.	Legal attributes are linked to spatial objects.
decision making	The percentage of subjective evaluation is high	Evidence-based spatial decision-making
Interdepartmental exchange	There are many format and standard inconsistencies.	Easy exchange based on open format and metadata

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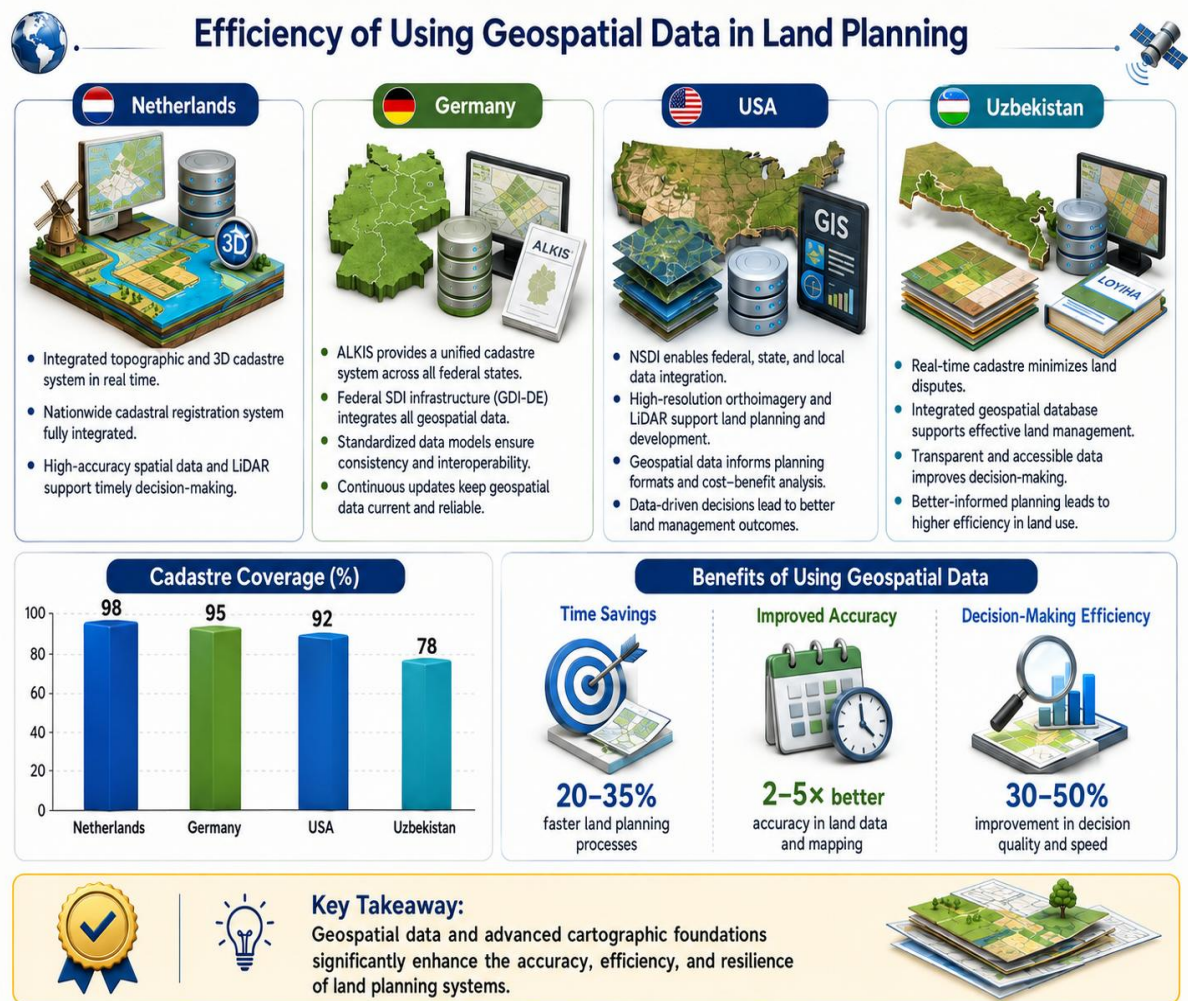


Figure 3. World experience and the effectiveness of using geodata in land development projects

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Table 6. Expected scientific and practical benefits from the digital approach

Efficiency direction	Expected change	Reasoning factor
Project accuracy	Can increase by 20-35%	Coordinate basics, orthophoto and topological control
Data refresh rate	Can be accelerated up to 2-5 times	Geodatabase, versioning and geoportal
Analysis capability	Can expand 30-50%	Multi-layer GIS analysis and automatic reports
Conflict reduction	Boundary and attribute mismatches are reduced	Integration of cadastral contour and legal attributes
Management transparency	A system of open and traceable decisions is formed	Metadata, audit trail, and user roles

### Methodological recommendations

First, a unified spatial data standard for the preparation of land use maps should be developed and implemented. This standard should cover layer names, attribute fields, coordinate system, metadata, symbols, topological rules, and export formats. As a result, land use maps prepared in different regions will be compatible and have the same information structure.

Secondly, a geodatabase should be considered a mandatory component of a land development project. At the end of each project, not just a PDF or paper drawing, but a complete digital package with vector layers, attribute tables, metadata, conditional symbols and monitoring indicators should be delivered. This will facilitate the integration of the project result into cadastral, geoportal and monitoring systems.

Third, it is recommended to regularly use remote sensing and UAV orthophoto materials in the design of land use plans. This method is effective in verifying the real land use status, identifying illegal changes, clarifying contours and controlling area accounting. In particular, DZZ data is an important source of

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information in identifying crop types, perennial tree plantations, vacant land and degradation zones in agricultural lands [13], [16].

Fourth, spatial decision-making models should be introduced in land development projects. In this case, indicators such as soil fertility, irrigation potential, proximity to infrastructure, environmental constraints, and legal status are evaluated on a point system along the contour of the land plot or project. This will allow project solutions to be defended on the basis of numerical evidence, along with expert opinion.

Fifth, the training of specialists working with geodatabases requires special attention. Students studying in the fields of land surveying, cadastre, geodesy and geoinformatics should master in-depth skills in working with GIS, DBMS, remote sensing, topological control, metadata and standards. This will ensure the stable operation of digital land management systems in the future.

### Conclusion

The use of spatial data, digital cartographic foundations and geodatabases in the design of land management drawings constitutes the theoretical and practical basis of modern land management. The results of the study show that the formulation of the drawing not as a simple graphic document, but as a multi-layer spatial-information model increases the accuracy of the design, legal reliability, monitoring capabilities and decision-making efficiency.

World experience - FAO VGGT, UN-GGIM FELA, INSPIRE, LADM, fit-for-purpose land administration, Rwanda, Estonia, the Netherlands and Singapore practices - show that the preparation of land use plans based on digital data has become a global trend. In particular, data standardization, metadata, open services, geodatabases and inter-agency integration dramatically increase the quality of project documentation.

The integrated methodology proposed in the article is based on the organization of data collection, standardization, geodatabase formation, spatial analysis,

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project drawing development and monitoring stages in a single system for land development planning. This methodology is of practical importance in the conditions of Uzbekistan for accelerating the digital transformation of land development projects, rational use of land resources, regulation of cadastral and legal relations, and scientific substantiation of territorial planning.

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