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GIS TECHNOLOGY ROLE IN THE MANAGEMENT OF ARABLE LANDS IN KAZAKHSTAN

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SUMMARY

The presented study explored approaches on the formation of cartographic and attribute information using the GIS technology for management of arable lands. This research included the development of advanced methodology for organizing agriculture lands using modern geoinformation technology through developing a digital cartographic environment. It further contained the database for agro-ecological soil properties, thematic maps for land management, and creation of a plan for using land in the study area. The latest research also revealed the foundation of the methodology for the land management of modern agro-formations, considering the requirements of the landscape approach to land use. An analysis of the agro-ecological state of the soil cover also ensued, obtaining the data from the analysis of thematic maps and land structure. The study revealed that 52.5% of the total assessed area consisted of chestnut ordinary soils, and 43.1% were floodplain meadow-chestnut soils. The proposed approach of arable land management can also apply in other regions of Kazakhstan for improving soil fertility and reducing degradation levels.

Keywords: GIS technology, geographic information systems, land management, agricultural lands, thematic maps, attribute data, data formation

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Key findings: Using modern geoinformation technologies helped develop a methodology for organizing the arable lands. A digital cartographic environment developed included thematic layers of cartographic information for the study area. Generating a database containing analysis of agro-ecological soil properties also resulted.

INTRODUCTION

Currently, the development of all industries operating with spatial information was through geoinformation technologies to enhance the efficiency of their production processes (Bekezhanov *et al*., 2021). The geographic information system (GIS) has a pivotal role in land surveys, updating and integrating planning and cartographic materials, developing land management projects, and conducting geodetic work (Borodina *et al*., 2023; Shayakhmetova *et al*., 2023). The huge information volume becomes unmanageable without the application of GIS technologies needed to process land management.

Consistently, GIS technologies are beneficial for drafting territorial plans, processing the information about territories, and generating final reports. Consequently, GIS technology is an indispensable element in developing consolidated information for land resource management across Kazakhstan, providing support for taxation, property rights registration, and interaction with other automated systems (Salikhov, 2017). These can also perform various agrochemical studies required for implementing precision agriculture in industry (Larionov *et al*., 2021). The use of satellite observations to determine the spatial-temporal distribution of areas with different nutrient contents and soil agrochemical research enables the use of GIS for managing arable lands.

The key advantages of GIS include the user-friendly display of spatial data in three-dimensional form, which is most convenient for perception, simplifying query construction, and subsequent analysis and integration (Savin *et al*., 2019). Notably, modern GISs also operate with geographic data models enriched with statistical information and software application for data processing, analysis, forecasting, and visualization (Salikhov *et al*., 2018a, b; Nugmanov *et al*., 2023).

Thus, the relevance of this research lies with increasing the efficiency of arable lands through GIS technology application. The novelty of the presented research relies for the first time on the formation of GIS data. This data resulted on the integration of structural elements of the agro-landscape and the spatial location of soil slopes, considering their natural properties and degree of erosion. The important aspects were the consideration of the soil cover and the terrain features of the targeted territory.

The latest research comprised the following objectives:

- Development of a methodology for systematic management of the arable lands using GIS technology;
- Development of a digital cartographic environment for the target area using thematic layers of cartographic information;
- Conduct of a detailed analysis of the agro-ecological properties of the soils;
- Development of thematic cartographic materials that serve as basis for agro-landscape land management; and
- Drafting the final plan for using the land in the studied area.

The said study contained a review of literature related to the GIS technology for managing arable lands, research methods, results and discussion, theoretical and practical conclusions, and limitations of the study.

Review of literature

Past studies enunciated geoinformation technologies are the foundation for formulating an information system on the management of arable land resources (Salikhov and Salikhova, 2018, 2019). The GIS technologies serve as an effective tool for obtaining operational, spatially coordinated information regarding the functional designation and ownership of land resources, and forecasting the ecological, economic efficiency, and feasibility of their use. The GISs have developed feasible conditions for creating geoinformation mapping, as geospatial databases, of which, demand is rapidly growing (Salikhov *et al*., 2018a), particularly in the area of specific information required for decision-making (Salikhov, 2018b).

In the fields of cartography and arable land management through GIS, these involve mastering software functions and their application. They also define different approaches to form the conceptual and theoretical foundations of land resource management, generalize mapping principles, and develop a system of attribute data, spatial information display, data selection, and range development (Studenkova *et al*., 2021). Therefore, it is essential to consider the quality of attribute information and the relationship between the map attributes and physical data.

Literature sources related to the current issues of the GIS data formation established the quality of cartographic and attribute data as an indicator of effectiveness for land use planning. Successful land resource management necessitates the development of global-scale geographic maps. For the coordinated interaction of all services in various economic sectors, scientists emphasize the considerable significance of mapping ecosystem quality indicators, such as, vegetation cover, soil fertility, and the presence of recreational areas.

In organizing digital data for managing the natural conditions of agro-landscapes, it is essential to ensure the profitable farming through dynamic and adaptable management of local conditions (Salikhov, 2018a and b). Sustainable landscape formation is possible based on detailed studies of the natural conditions of the territory, and considering the agro-ecological properties of soils (Ivantsova and Komarova, 2021). Researchers highlighted the need for theoretical foundations of landscape ecological-economic classification of arable land suitability and the importance of land use typification based on ecological and economic factors. In land management, researchers prefer monitoring land use distant closer to urban areas. Economic issues also take precedence, such as, farmers abandoning low-fertility areas, monitoring land use near large cities, and managing land resources to maintain ecological safety amid increasing urbanization rates.

Previous studies proposed using an 'integrated index of ecological importance assessment of regional space' in forming GIS data (Kantarbayeva *et al*., 2017). These territories include river basins, wetlands, nature reserves, parks, and scenic areas. In measuring the 'integrated soil quality index,' scientists use GIS data on the different indicators. These are the pH, electrical conductivity, organic matter, cation exchange capacity, percentage of equivalent $CaCO_3$, heavy metals content (Cd, Co, Pb, Cr), and the soil erosion coefficient. Some researchers link the degradation of the soil's agro-ecological state to intensive land use and climate change, emphasizing the need to develop watershed area models using GIS (Elhakeem *et al*., 2018). A methodology for assessing erosion using the vegetation cover coefficient was a proposal for scientific practice. The regulation of this factor can be through the land management of arable areas, serving as a tool for developing land use scenarios and determining priority directions for GIS data formation.

With limited resources available to researchers and the desirability of conducting additional studies on this issue necessitated the publication of the presented results to attract other researchers and promote the discussion within the scientific community in the agro-industrial sector. For this study, the authors selected a specific case in the agro-industrial sector, as described below. The research aimed to identify approaches to forming cartographic and attribute information in the GIS software environment for implementing the landscape method of land management.

MATERIALS AND METHODS

Research approach

The theoretical basis of sustainable land use is the practical functioning of agroecosystems formed on the bioenergetic connections inherent to natural habitats, where the presented study relied upon the landscape approach (Bugubaeva *et al*., 2023). The recent approach involved restoring land resources by optimizing land use by reducing the degree of plowing, limiting intensive use of ecologically vulnerable lands, and conserving the low-productivity and highly waterlogged areas. Additionally, the research also incorporated the analysis of the current state of agro-landscapes and the adaptation of land use to agro-ecological soil groups as per their suitability for agricultural use (Neverov *et al*., 2023).

In the GIS environment, for developing the specified methodology for managing arable lands based on the landscape approach, a qualitative–quantitative thematic research strategy appeared most appropriate. This approach provides more informative and comprehensive data than purely quantitative research, as it ensures a higher level of data, facilitating the collection of information necessary for developing the specific methodology. However, one should note this method has certain limitations, and the primary task of the latest research was to obtain qualitatively new knowledge about specific arable lands.

Empirical context and case selection

The pertinent study proceeded in the context of managing arable lands for crop production practices. Given that Kazakhstan is a country with a vast territory and rapidly changing terrain and soil composition, the presented research focused on arable lands of the Pavlodar region, Kazakhstan. The implementation of the crop development program is in progress there, conducting eroded soils reclamation (Yakovlev *et al*., 2024). This research transpired in 2023 on the land use areas within the Zhambyl rural district of the Akkulin district in the Pavlodar region.

In the Akkulin District, Kazakhstan, the enterprises developed no economic activity in major industries, such as, energy, metallurgy, mining, oil refining, and chemical industries. Therefore, the primary sector of the economy is agriculture, which includes livestock and crops production. Arable lands occupy a significant part of the study area that divides into the following (Tabyldinov and Ghalymzhan, 2019):

- Arable land used for cultivating spring cereals (wheat, millet, and corn);
- Improved sown pastures and hayfields, formed through reclamation and by sowing perennial forage crops; and
- Fallow pastures and vegetable gardens.

The study area terrain is a lowland with absolute elevations of approximately 150–180 meters above sea level. The area is a gently undulating steppe with feather grass and fescue vegetation (Kantarbayeva *et al*., 2017). The susceptibility to wind erosion results in deep gullies and ravines, particularly in the northern and central parts of the studied area (Nurgaliyeva *et al*., 2022; Babkenov *et al*., 2023).

The southern part of the study area comprised a gently undulating outwash plain (sandur) characterized by variations in elevation and a developed micro-relief, with numerous shallow closed depressions (Yesmagulova *et al*., 2023). The most common features are hollows and gullies (Ainebekova *et al*., 2023). Therefore, the terrain of the northern and central parts of the study area is prone to erosion and sharply differed from the southern saline areas (Karynbayev *et al*., 2023).

Overall, the soil structure highly varied, with complex boundaries and configurations of soil contours (Figure 1). Consequently, geoinformation systems significantly facilitate decision making regarding the use of each soil contour and the design of arable land boundaries (Nasiyev *et al*., 2021). The most widespread slopes were the chestnut soil types, as widely used in agriculture (Turbekova *et al*., 2023). The total area of slopes was 947.9 hectares (52.5% of the total study area), with chestnut ordinary soils (50.1%), floodplain meadow-chestnut soils (43.1%),

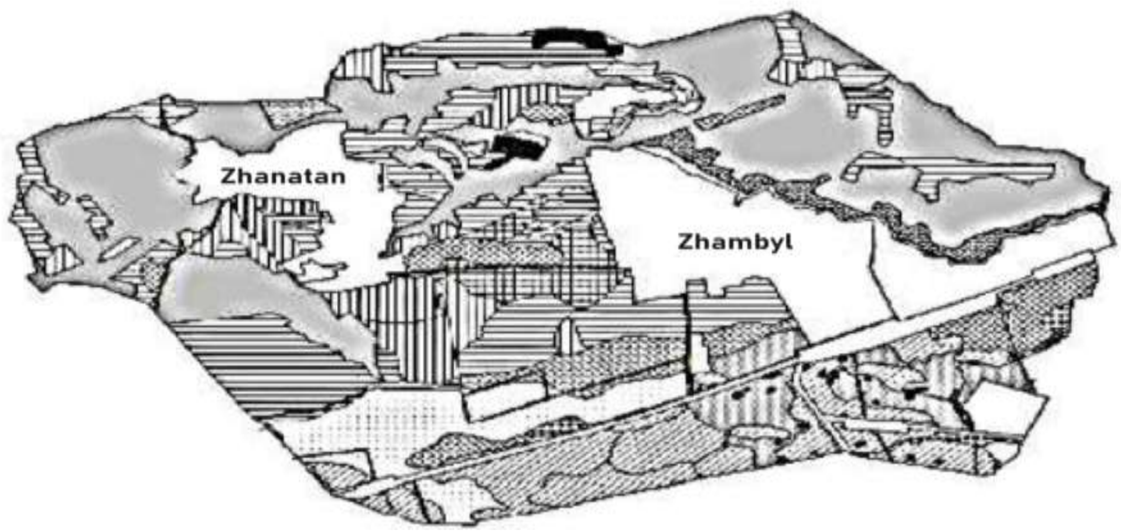

Figure 1. Soil Cover Structure.

	Chestnut ordinary soils		Solonetz
	Floodplain meadow-chestnut soils		Meadow-steppe solonetz
	Ordinary meadow-chestnut soils		Dark-chestnut meadow solonetz
	Saline meadow-chestnut soils		Steppe solonetz
	Saline meadow soils		Meadow solonchaks
	Saline meadow-bog soils		Near-sor solonchaks
	Medium-chestnut solonetz soils		Sor solonchaks

ordinary meadow-chestnut soils (5.4%), and saline meadow-chestnut soils (1.4%).

Data collection

All data collection occurred from September 10 to November 10, 2023, through a desktop study. The process of forming digital data in the GIS environment for organizing agricultural lands in the study area included the following stages:

- Research and detailed analysis of the natural parameters of the agro-landscape;
- Mapping: spatial distribution of soil-forming rocks, vegetation cover, terrain, soils, and land use;
- The data collected on particle size distribution, erosion, soil acidity, and groundwater level;
- Creation of thematic maps (cartograms) of slopes and degrees of waterlogging; and
- Correlation of obtained spatial and attribute data and the application of cartographic overlay methods. A land suitability cartogram with a land use organization plan drawn from this map.

Cartographic materials developed through the Mapinfo Professional environment helped analyze the present state of the study area. These materials include cartograms of the soil-forming rocks distribution, soil cover structure, arable land structure, slope cartogram with gradation for contour-reclamation organization, and soil cartogram.

Obtaining the source cartographic materials employed the digitizing raster maps. In particular, digitization of the contour lines used the TopoTracer module. Corresponding attribute information tables' construction continued for all the spatial objects. Land use adaptation to soil-ecological conditions also proceeded using geographic overlay methods of the original cartographic materials, with consideration of grouping land based on its suitability to use.

Data analysis

The analysis of the natural properties of the study area first had a cartogram of the spatial distribution of soil-forming rocks drawn, with an attribute table formed comprising different columns (rock name, particle size distribution, agrochemical composition, and groundwater level) (Kussainova *et al*., 2023). The study area had chestnut soils. Crop production progressed on chestnut sandy loam and sandy soils of a gently undulating plain with a groundwater table depth of six meters or more.

Soil-forming rocks included lacustrine-alluvial deposits and ancient alluvial deposits with complex structures and light mechanical compositions (Tabyldinov and Ghalymzhan, 2019). As a result, these soils have high filtration and low water retention capacities. Typically, with a light mechanical composition helped form chestnut soils on rocks. The soil-forming rocks of the closed depressions consisted of lacustrine-alluvial deposits with layered structures. The presence of highly soluble salts in rocks was the source of salinization for the resulting solonchak, solonetz, and saline meadow soils.

The terrain characteristics determination of the study area relied on the digital topographic map with height data for each contour line in the attributes table. Based on the relief map of the study area, construction of a thematic map, the 'slope cartogram,' also emerged. The attributes' information database corresponding to the soil cartogram contains the following data for each soil contour: contour number, soil type, particle size distribution, parent rock, groundwater level, humus content, nutrient content, acidity, and the land use. Thus, the study analysis results depended upon the original cartographic information in soil-forming rock distribution, a soil cartogram, a topographic map, thematic maps of slopes, and degrees of waterlogging.

RESULTS AND DISCUSSION

The arable land use plan's development resulted from the comparison of spatial and attributes data. This plan considers the suitability of each soil contour for agricultural use, the level of waterlogging, and erosion. Additionally, the summarized tables characterized the current land use (Table 1), having developed the projected state of the studied territory (Tables 2 and 3). At the present stage of societal development, the use of GIS technologies for managing arable lands is a demand of the times. Therefore, it is crucial to fully utilize GIS technologies to ensure the rational use of land resources in Kazakhstan.

The use of a specific algorithm organized arable lands in the Zhambyl Rural District, Kazakhstan, through digital cartographic and attribute data. This algorithm ensures land use aligns with the agro-ecological state. Notably, the soil degradation levels and salinity were a consideration. Previous studies have suggested slightly eroded and non-eroded soils on slopes' use should apply the contour-reclamation organization methodology (Salikhov *et al*., 2018 a, b). For waterlogged and swampy areas, planning forage lands considered soil lightness and particle size distribution, which were consistent with the findings of Larionov *et al*. (2021). Accordingly, the hayfield's arrangement was better on saline meadow and saline meadow bog soils. The following textures were options for soils lighter in particle size composition, i.e., medium-chestnut solonetz and meadow-steppe, meadow, and steppe solonetz soils.

Therefore, authors believe the practical application of this model for the management of agricultural enterprise will enable the

Table 1. Soil slopes on arable land by steepness.

Slope	Soil Type	Area (ha)
1-3°	floodplain meadow-chestnut soils	291.0
	chestnut ordinary soils	432.0
	saline meadow-chestnut soils	12.5
Total		735.5
3-5°	floodplain meadow-chestnut soils	45.5
	chestnut ordinary soils	43.1
Total		88.8
5-7°	ordinary meadow-chestnut soils	33.7
	floodplain meadow-chestnut soils	72.2
Total		105.9
>7°	ordinary meadow-chestnut soils	17.7
Total		947.9

Table 2. Land suitability for use.

Soil Suitability Group	Area (ha)
Lands suitable for all crops	262.4
Lands suitable for all crops with cross-slope tillage	545.3
Lands suitable for broadcast seeding	87.8
Slope lands needing grassing	101.4
Lands for hayfields	409.5
Lands for pasture	398.0
Total	1804.4

Table 3. Structure of agricultural lands.

Land Use	Current State		Projected State	
	ha	%	ha	%
Arable Land	1397.0	77.4	895.5	49.6
Hayfields	169.3	9.4	309.5	17.2
Pastures	238.1	13.2	498.0	27.6
Grass on Slopes	-	-	101.4	5.6

consideration of the suitability of each soil contour for agricultural use. The presented research has led to several theoretical and practical conclusions. Specifically, the research article has two theoretical implications:

- For managing agricultural lands, it contributes to the literature on developing methodological foundations for data formation in the GIS environment. However, this issue had previous active study within agricultural management, needing further investigations considering the specifics of agribusiness in Kazakhstan. On the study's best knowledge, the latest research represents one of the first attempts to analyze the accumulated experience in managing arable lands based on the landscape approach and its further testing in the context of Kazakhstan's conditions.
- The presented methodology justifies the need for the step-by-step formation of digital cartographic and attributes data for organizing arable lands.

The authors proposed the use of game theory, as shown in this study, which can enhance the ability of agricultural enterprises to make informed decisions based on the available data, enhanced crop production profitability, and mitigate potential weather risks. This phenomenon allows for developing scenarios for various weather conditions and effectively forecasting future yields (Kussainova *et al*., 2023).

As previously mentioned, the article also presents practical conclusions:

- Present results should require considerations by representatives of the agro-industrial sector and governmental bodies influencing its development. This confirms what the literature has demonstrated, the necessity of tools that optimize land resources use in crop production (Turbekova *et al*., 2023).
- The presented methodological approaches contribute to the formation of ecologically sustainable agro-landscapes in any region of Kazakhstan. These significantly slow soil degradation, enhance soil fertility, and develop land consolidation projects that maintain the integrity of land masses to support satisfactory ecological conditions of agro-landscapes and increase crop production efficiency.

CONCLUSIONS

Considering soil degradation levels and salinity in the Zhambyl District, Kazakhstan, the algorithm used for developing digital maps and attributes data managed the arable lands. The practical significance of this research lies with its potential for the following reasons: forming ecologically sustainable agro-landscapes in any region of Kazakhstan, developing land consolidation projects to maintain the integrity of land masses, and creating regional programs for arable land use and protection. However, the presented study happened only in one district, necessitating further research. The summarized studies in various regions of Kazakhstan will allow for a more comprehensive assessment of the presented methodology.

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