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FEATURES OF THE APPLICATION OF GEOINFORMATION SYSTEMS TO INCREASE THE YIELD OF AGRICULTURAL LAND

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The main problems in the effective use of land resources as an important factor of the country’s development and population’s food security are considered. The study was conducted in the northern region of the Republic of Kazakhstan. The object of the study was grain-growing farms in the Akmola region.

The study concluded that satellite imagery and unmanned aerial vehicles should be used to monitor crops and assess yields in the Akmola region. These technologies allow for more efficient land management, prompt response to problems and informed decision-making. The experience of GIS application in the United States consists in the formation of database systems for all soil types that are of economic importance. There are 4 national soil databases, as well as several automated soil databases containing data on more than 13,400 soil varieties. The country’s Soil Conservation Service has created soil geographic databases, including a geographic database on soil surveys, state soil associations, and major land resource areas.

The economic efficiency of land conservation measures will be determined by the amount of net income, taking into account the prevented environmental damage in value form, using the efficiency coefficient of environmental costs relative to the total production and environmental costs. The acreage area in the Akmola region on average for 2018–2023 amounted to 26,264.32 thousand hectares, the average actual crop yield was 12.5 centner/ha. Based on the given system of formulas, the estimated crop yield on non-eroded soils (Yn) is 13.5 centner/ha, and the crop shortfall (V) due to land erosion is 871.88 thousand centners of grain, which is 69,750 thousand tenge at an average grain price of 80,000 tenge/t

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1. Introduction

Sustainable land management has not only and not so much an economic basis, but aims to take into account and use natural factors. Land cannot be used rationally in economic activity without paying attention to the landscape and soil features, geographical location and climate on the land plot in question. On the other hand, considering all these circumstances not only provides an economic result of land use, but also ensures its long-term sustainability due to the physical and environmental safety of land and its characteristics.

Agricultural land is the most important, irreplaceable, fundamental means of production, distinguishing agriculture from other sectors of the national economy [1].

To substantiate the relevance of scientific topics related to assessing the effectiveness of geoinformation system methods in agricultural land management, the following arguments can be given:

– the population continues to grow, leading to increased food demand. Of course, this requires more efficient use of agricultural land to ensure the population’s food security;

– geoinformation systems allow optimizing farming processes, which helps increase yields and reduce losses;

– geoinformation systems provide tools for monitoring and management of water, soil and other resources, contributing to sustainable agricultural development;

– the introduction of new technologies, such as geoinformation systems, is a key factor in increasing the competitiveness of agriculture.

Accurate data provided by geoinformation systems allows farmers to optimize resource use by reducing fertilizer, pesticide and water costs. This leads to growing profits and increasing economic sustainability of agricultural enterprises.

Geoinformation systems help predict and manage risks associated with natural disasters such as droughts and floods.

Thus, research on the development and efficiency evaluation of geoinformation system methods in agricultural land use is relevant. Such research contributes to solving modern problems of food security, sustainable development, increasing economic efficiency and risk management in agriculture.

2. Literature review and problem statement

The paper [2] presents the results of research showing that Landsat satellite image data and Quantum GIS tools allow the analysis and visualization of spatial data for various agricultural lands. But there are unresolved issues related to data accuracy and resolution. Currently, Landsat satellite images have limited spatial resolution, which may be insufficient for detailed analysis of small-scale objects. These difficulties can be caused by objective limitations associated with technological and economic factors, as well as fundamental challenges in the development and application of new data processing methods. To overcome these problems, more accessible and high-resolution data from new satellite systems can be used. This suggests the need to conduct a study on evaluating the effectiveness of geoinformation system methods in agricultural land use, taking into account modern technologies and methods of data analysis.

The paper [3] provides the results of research showing that the use of GIS technologies helps effectively determine the infestation degree of crops in the Akmola region. This study shows the potential of geoinformation systems in monitoring and managing weed infestation, providing accurate data for decision-making in agriculture. However, there are unresolved issues with data persistence and reliability. These include ensuring continuous monitoring and updating of data, which requires significant resources and infrastructure, the need to integrate data from other sources to improve the accuracy and completeness of information.

An option to overcome these difficulties may be to use more accessible technologies and open data, as well as to develop cooperative approaches for combining the resources of various farms to share geoinformation systems. All this suggests the need to conduct a study on evaluating the effectiveness of geoinformation system methods in agricultural land use, taking into account modern technologies and methods of data analysis. This will help improve monitoring and management of weed infestation, increase productivity and sustainability of agricultural production, as well as reduce costs and increase economic efficiency in the agro-industrial sector.

Statistical analysis of objects was performed, and the minimum, maximum, average and standard deviations in the indicators of the studied acreage in the Akmola region were revealed.

The paper [4] presents the research on a statistical yield model, accounting for weather conditions to predict wheat production. The advantages of this model are the use of open, verified weather and yield data, as well as proven low computational complexity. However, the accuracy of the model is about 95 %. Given that forecasting results affect agribusiness management and profitability, or they are planned to be used by government agencies, the accuracy of such a result should be improved.

In [5], the points are given that determine in the plans an economically feasible production structure, ensuring the highest output with the lowest costs and income necessary for the development of the economy and meeting the material and social needs of its members. Effective use of agricultural land is determined by a scientifically based structure of acreage developed in each division of agricultural production according to its specialization and contractual obligations of agricultural buyers.

The paper [6] shows the efficiency of using neural networks in agriculture. It is demonstrated that the application of artificial neural networks can significantly improve the accuracy of crop forecasting, which is important for optimizing agrotechnical measures and increasing the productivity of agricultural land.

At the same time, there are unresolved issues related to implementing these technologies in practice. This may be caused by objective difficulties associated with high requirements for computing resources and qualifications of specialists, the need for significant financial investments in the development and support of artificial intelligence systems, making relevant research impractical for some agricultural enterprises.

In [7], both general scientific and special research methods are presented. Logical-historical methods, as well as dialectical logic principles, made it possible to consider all phenomena in development and interrelation. When studying the research problem, a monographic method was applied. Using statistical methods, as well as graphical analysis, the initial data were analyzed, factors and conditions of land management were evaluated.

The database of typical objects was created with the help of geoinformation system technologies. Using geoinformation systems, a set of specialized maps was compiled for on-farm and inter-farm land management projects for objects (rural districts, villages, agricultural enterprises) of the Akmola region.

The paper [8] shows the primary importance of introducing innovative territory planning projects, improving the agricultural soil protection system, implementing anti-erosion and other environmental measures in improving agricultural land use.

The paper [9, 10] shows the application of geoinformation systems, which is a modern land policy of the country aimed at creating a rational balance between the sustainable development of the agro-industrial complex and preserving natural potential in order to improve living conditions in rural areas. Geoinformation systems contribute to the growing profitability of agricultural enterprises and optimization of their costs. Digital cartographic products are increasingly used by intensively developing farms.

In the modern agricultural sector, innovative technologies are becoming important for agricultural enterprises to improve production efficiency and increase yields. One such technology is geoinformation systems (GIS), which allow the collection, storage, analysis and visualization of spatial data on agricultural land.

However, the implementation of GIS in the agricultural sector is not always efficient and easy. The main problems with GIS faced by agricultural enterprises include: the lack of qualified personnel, high cost of equipment and software, difficult integration with other systems, the need for constant data updating, data privacy and security issues.

Solving these problems will allow agricultural enterprises to use GIS more effectively to optimize production processes, improve resource management and increase the overall efficiency of agricultural production.

3. The aim and objectives of the study

The aim of the study is to identify the features of application of geoinformation systems (GIS) in agriculture in order to increase the efficiency of agricultural land use.

To achieve the aim, the following objectives were set:

– to evaluate the experience of GIS application in agriculture to improve the efficiency and sustainability of agricultural land;

– to assess the effectiveness of GIS application for degraded agricultural land.

4. Materials and methods

The object of the study is the process of GIS application to improve the efficiency of agricultural land.

The hypothesis of the study is the possibility of using geoinformation systems (GIS) to increase the efficiency of agricultural land use for increasing yields in the agro-industrial complex.

The paper applies GIS methods to improve the efficiency of agricultural land, taking into account system analysis, monographic, statistical and economic methods. Based on a system analysis of the rapid development of modern innovative technologies, the need to create conditions in agricultural production for the widespread use of geoinformation systems was proved.

The data of the Committee on Statistics of the Republic of Kazakhstan, Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan [11–15] on crop yields for 2018–2023 were analyzed.

5. Results of the study on the effectiveness of using geoinformation system methods in agriculture

5. 1. Evaluation of the experience of GIS application in agriculture to improve the efficiency and sustainability of agricultural land

One of the main tasks in ensuring the country's food security is the preservation and reproduction of natural resources used in agricultural production. The solution of this problem is directly related to modern land monitoring. The factors that hinder the country's food security:

1. Lack of long-term strategic planning for land conservation and reproduction. First of all, this is reflected in the reduction of farmland areas, their degradation and infestation with perennial weeds.

2. Vulnerability of land as the main means of production in the agro-industrial complex. The Northern Kazakhstan and Akmola regions are conditionally suitable for agricultural production. Favorable climatic conditions allow obtaining moderate yields. Unfortunately, the vulnerability of these territories is many times higher. This is manifested in low or no yields.

3. Outdated data on soil indicators. The adaptive landscape approach based on the compilation of agroecological maps, elaborated and successfully applied in many developed countries, has proven effective in individually selecting the direction of agricultural production depending on the agroecological type of soil.

The above problems can lead to crisis situations in agricultural production. These issues can be solved by developing and implementing modern production systems using geoinformation technologies. Reliable spatial data on farmland areas, soil composition, agroecological soil types, and climatic indicators will help develop optimal land use patterns, increasing the profitability of agricultural production.

There are several benefits of GIS application:

– land monitoring and management: GIS allow agricultural enterprises to monitor land condition in real time. Soil maps, satellite images and remote sensing data help to identify soil types, composition and structure for the optimal selection of crops and cultivation methods;

– resource optimization: GIS technologies allow more efficient use of resources such as water, fertilizers and pesticides. These include soil moisture maps and topographic data that help design and manage irrigation systems, ensuring optimal water supply and preventing over-wetting or drought;

– accurate soil fertility maps help to optimally distribute fertilizers, which reduces costs and minimizes negative environmental impacts;

– GIS can also be used to predict yields and manage risks related to weather conditions and other factors;

– risk maps, such as the likelihood of droughts or floods, help farmers develop strategies to minimize losses;

– geographic information allows accurate planning of the timing and scope of work, which helps increase productivity.

For further substantiation, a study on the Akmola region was conducted. As a key agricultural region in the Republic of Kazakhstan, it is important for the country's economy. Analysis of agricultural land condition for 2018–2023 allows us to assess the industry dynamics and identify the main trends.

From 2018 to 2023, the area of agricultural land in the region remained stable at about 10,524.0 thousand hectares, the acreage is 4,158,502.8 thousand hectares:

– the volume of agricultural products in the region for the considered period showed moderate growth due to implementing modern technologies and improved infrastructure;

– the main crops grown in the region are wheat, barley, oats, rapeseed, and corn. There is an increase in the area for sunflower and soybean cultivation;

– stable development of animal husbandry in the region, including the production of meat, milk and eggs. Product quality improvement and modernization of production processes contributed to the growth of production;

– state support and investments in the agricultural sector contribute to agricultural development in the region. The implementation of subsidy and modernization programs has improved the economic performance of the industry;

– despite positive dynamics, there are still unresolved problems in the agriculture of the Akmola region, such as lack of qualified personnel, low resource efficiency and instability of market prices for agricultural products.

Arable land is the most valuable type of agricultural land. Arable land accounts for 26.3 million hectares or 11.9 % of the total area of agricultural land. The largest arable land areas are concentrated in the Kostanay (6.2 million hectares), Akmola (6.0 million hectares) and North Kazakhstan (5.0 million hectares) regions, which makes 65.6 % of the republic's arable land. There is a steady trend towards developing previously rested good-quality soils into arable land. All these changes in the distribution of arable land area in the region by year and their dynamics are shown in Table 1.

The analysis of arable land dynamics in the Akmola region shows that arable land areas grow mainly in major grain-growing regions of the republic [12–16]. Also, all these changes in arable land in dynamics are shown in Fig. 1.

Table 1

Dynamics of arable land area in the Akmola region for 2018–2022 (thousand hectares)

Region	2018	2019	2020	2021	2022	Changes (+,–)
Akmola	5,957.4	6,035.8	6,040.4	6,125.4	6,151.8	–231.4
Total (area)	25,354.1	26,011.1	26,324.5	26,660.5	26,971.4	–8,441.5

Note: Bureau of National Statistics of ASPR RK [16]

By the results of a social survey, enterprises engaged in crop production and implementation of navigation systems were identified. The data are shown in comparative form in Fig. 2, 3.

A more evident representation of successful GIS application in agriculture in the Akmola region is shown in Table 2.

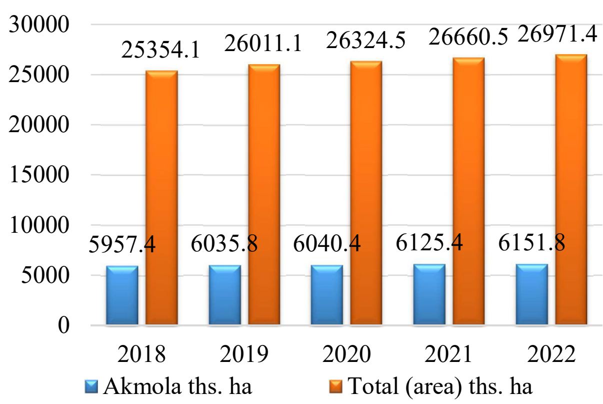

Fig. 1. Dynamics of changes in arable land areas in the Akmola region for 2018–2022

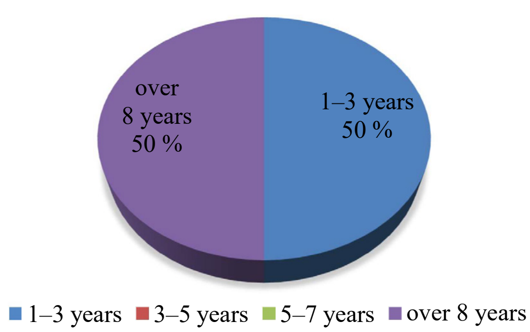

Fig. 2. Period of crop production

Note: Compiled by the author

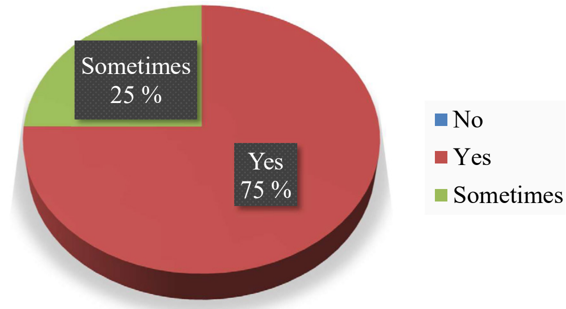

Fig. 3. Implementation of navigation systems at agricultural enterprises

Note: Compiled by the author

The analysis of data on Uryupinsky & K LLP in the Akmola region for 2021–2023 shows sustainable development and stability in production indicators. The total area is 15,000 hectares for all three years, indicating stability in the size of agricultural land.

The area of cultivated land increased from 12,800 hectares in 2021 to 13,500 hectares in 2023, indicating an expansion of acreage. Yields remain stable at 10 centner/ha each year. This may indicate the constant quality of agrotechnical measures and stable climatic conditions.

Table 2

Comparative data on Uryupinsky & K LLC in the Akmola region for 2021–2023

Name	Uryupinsky & K LLC		
	2021	2022	2023
Total area	15,000	15,000	15,000
Number of farms in the group	1	1	1
Area (ha)	12,800	13,000	13,500
Yield (centner/ha)	10	10	10
Crops (tenge)	787,000,000	82,000,000	877,000,000
Labor resources per 100 ha of agricultural land	15	15	15
Expenses	146,100,000	159,100,000	167,100,000
Seeds (tenge)	85,800,000	90,700,000	10,800,000
Fertilizers (tenge)	110,750,000	118,750,000	129,750,000
Wages	3,200,000	3,800,000	4,050,000
Fuels and lubricants (tenge)	19,800,000	20,000,000	22,500,000
Crop rotations	Wheat, barley, oats, sunflower	Wheat, barley, oats, sunflower	Wheat, barley, oats, sunflower
Subsidy	35,000,000	37,200,000	40,600,000
Net profit	609,900,000	689,900,000	709,900,000

For the study, a section of the electronic map in the ArcGIS "Base Map" program was taken. Fig. 4 shows the areas of Uryupinsky & K LLP.

In general, the data analysis shows a positive trend when using GIS technologies at Uryupinsky & K LLP, which is reflected in increased income from grain crops and acreage expansion, despite the increase in costs. Table 3 shows the monitoring of crops and yields on farms.

Using satellite imagery and unmanned aerial vehicles to monitor crops and assess yields in the Akmola region demonstrates significant benefits. These technologies allow farms to manage land more effectively, respond quickly to problems and make informed decisions, which ultimately led to increased yields and agricultural sustainability in the region. Next, an analysis of fertilizer optimization was carried out. Table 4 shows the optimization of fertilizer use in farms.

The analysis allows us to conclude that the agriculture of the Akmola region is developing. However, to achieve better results, attention should be paid to solving the remaining issues of GIS application to identify and predict crisis situations.

In solving the problem of ensuring the country's food security, foreign experience is interesting, in particular, the example of the United States. Land monitoring consists in the formation of database systems for all soil types that are of economic importance. It is carried out by the United States Soil Conservation Service. Currently, there are 4 national soil databases in the United States, as well as several automated soil databases containing information on more than 13,400 soil varieties. The country's Soil Conservation Service has created soil geographic databases, including a geographic database on soil surveys, state soil associations, and major land resource areas.

Table 3

Monitoring of crops and yields on farms in the Akmola region for the last 2018–2022

Parameter	Description
Technology used	Satellite imagery, unmanned aerial vehicles
Task	Crop health monitoring and yield assessment
Result	Farms receive real-time information about field condition, allowing them to quickly respond to problems and take measures to improve yields

Table 4

Optimization of fertilizer use in farms of the Akmola region for 2018–2022

Parameter	Description
Technology used	GIS for creating detailed soil maps
Task	Fertilization planning
Result	Optimization of fertilizer use, cost reduction and minimization of negative environmental impact

Another element of geoinformation support for early forecasting of crisis situations in agricultural production is thematic digital mapping. Accurate soil maps have been created that display the current land condition.

Thus, the experience of GIS application in agriculture shows that geoinformation support should include elements for predicting crisis situations. Food security is a very vulnerable element, showing the development of modern society and requires high-tech solutions to ensure it.

5. 2. Efficiency of GIS application for degraded agricultural land

The use of geoinformation systems to assess degraded agricultural lands has several key points.

Data collection and monitoring: GIS allows collecting data from various sources, including satellite imagery, aerial photography and data from unmanned aerial vehicles; continuous land monitoring helps track changes in real time and identify early signs of degradation.

The most important basis for effective agricultural production is the preservation and improvement of soil fertility. The country's agricultural lands are subject to the development and spread of negative processes, which are one of the main reasons for the loss of the resource potential of soils and, as a result, decreasing yield of crops growing on them.

Among the many factors having a negative impact on land resources, we can highlight the erosion of arable land (water erosion and deflation (wind erosion). These processes are the most significant and harmful factors of soil degradation and are characterized by large-scale, deep and irreversible changes in soil cover.

When studying the problem, an analysis of data on the distribution of negative processes in the Republic of Kazakhstan was made (Table 5).

The main areas of agricultural land affected by wind erosion are in the Almaty region – about 2 million hectares, Zhetysu region – 2.9 million hectares, Atyrau and Turkestan – 3.1 million hectares each, Kyzylorda – 2.8 million hectares, Zhambyl and Aktobe – more than 2.0 million hectares each.

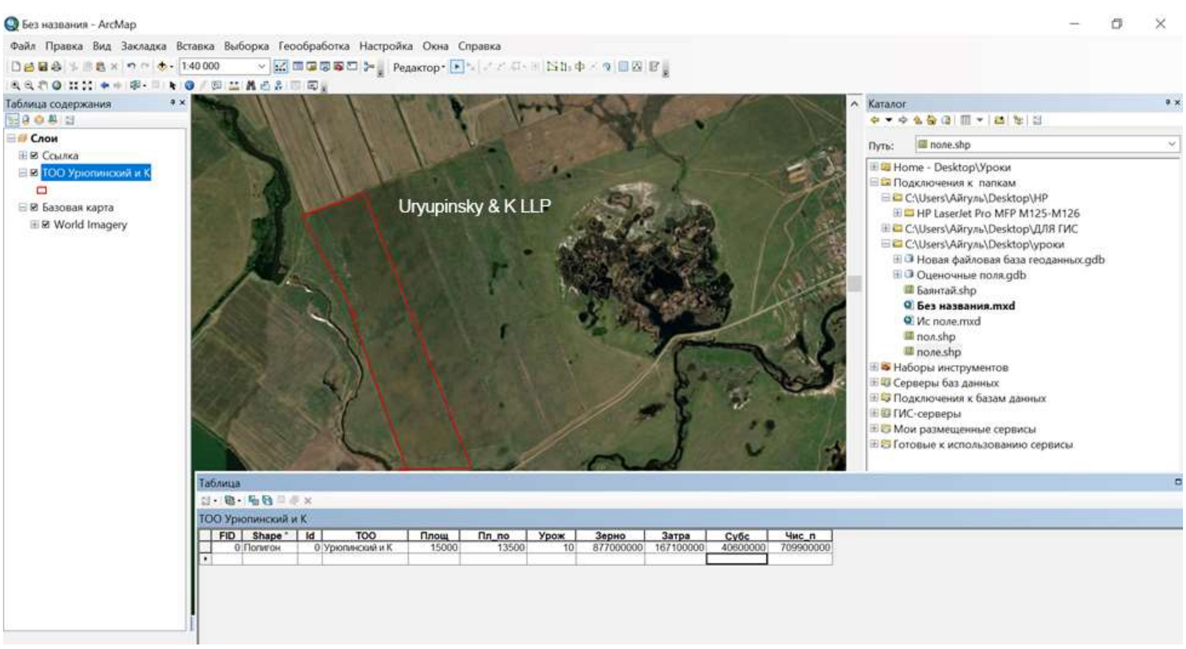

Fig. 4. Land plot of Uryupinsky & K LLP

Table 5

Distribution of negative processes in the territory of the Republic of Kazakhstan

Region	Total eroded arable land/Erosion degree of arable land moderate and strong									
	2018		2019		2020		2021		2022	
Abay	–	–	–	–	–	–	–	–	58.1	0.7
Akmola	352.2	34.3	352.2	34.3	352.2	34.3	352.2	34.3	352.2	34.3
Aktobe	34.2	0.8	34.2	0.8	34.2	0.8	34.2	0.8	34.2	0.8
Almaty	98.2	12.4	98.2	12.4	98.2	12.4	98.2	12.4	44.2	12.4
Atyrau	–	–	–	–	–	–	–	–	–	–
E-Kazakhstan	247.9	13.3	247.9	13.3	247.9	13.3	247.9	13.3	189.2	11.5
Zhetysu	–	–	–	–	–	–	–	–	54	–
Zhambyl	54.3	1.5	54.3	1.5	54.3	1.5	54.3	1.5	54.3	1.5
W-Kazakhstan	172.6	27.3	172.6	27.3	172.6	27.3	172.6	27.3	172.6	27.3
Karaganda	111.3	15.6	111.3	15.6	111.3	15.6	111.3	15.6	111.3	15.6
Kyzylorda	–	–	–	–	–	–	–	–	–	–
Kostanay	93.5	16.0	93.5	16.0	93.5	16.0	93.5	16.0	93.5	16
Mangystau	–	–	–	–	–	–	–	–	–	–
Pavlodar	334.3	110.6	334.3	110.6	334.3	110.6	334.3	110.6	334.3	110.6
N-Kazakhstan	28.0	4.3	28.0	4.3	28.0	4.3	28.0	4.3	28	4.3
Turkestan	232.5	17.6	232.5	17.6	232.5	17.6	232.5	17.6	232.5	17.6
Total	1 768.0	253.7	1 768.0	253.7	1 768.0	253.7	1 768.0	253.7	1758.4	252.6

Note: Bureau of National Statistics of ASPR RK [16].

The largest share of eroded agricultural lands (more than 30 % of their total area) is in the Almaty, Zhetysu, Atyrau and Turkestan regions. The smallest share of eroded agricultural lands (up to 5 %) is in the Akmola, Karaganda, Kostanay and North Kazakhstan regions.

The areas affected by water erosion (washed-out) of the total area of eroded lands occupy 4.9 million hectares or 2.3 % of agricultural land.

Water erosion of soils is observed in all regions of the republic and its severity depends on the nature of the relief (steepness and length of the slope, size and shape of the drainage basin), the amount and intensity of precipitation, type and mechanical composition of soils, carbonate content, salinity, turfness, depth of groundwater and erosion base level, water permeability and nature of land use. Water erosion is a process of interaction between flowing streams and soil, depending on the nature of the runoff and its transporting capabilities. It is closely related to water content, morphological conditions of the surface and bedrock properties. The largest areas of washed-out soils of agricultural land are in the Turkestan (0.9 million hectares), Mangystau (0.8 million hectares), Akmola and Almaty (0.6 million hectares) regions.

Fig. 5 below shows a plot in the Akmola region affected by degradation.

Agricultural lands around various industrial facilities may contain toxic elements in quantities exceeding the maximum permissible concentrations by tens or hundreds of times. If there are degraded lands within the boundaries of land use, the output volumes and the amount of income received decrease. The extent of damage depends on the type of degradation, which can be divided into several directions:

– nutrient depletion, dehumidification on agricultural land;
– erosion on arable land;
– salinization on irrigated lands and rock dusting;
– desertification of territories;
– waterlogging and swamping;
– loss of valuable land due to road laying, construction of industrial facilities;
– heavy metal pollution.

Identification of degraded lands is performed during large-scale soil surveys, which are not carried out often, when significant changes in soils and soil cover are detected. Annual land monitoring is made only in especially dangerous erosive areas. The most effective and promising method for assessing the degradation of agricultural land is remote sensing. The positive aspects of the method are objectivity, efficiency, uniformity, visibility, reliability and timeliness. Due to the wide coverage of the territory, this method helps to minimize time and material costs when monitoring agricultural land. That is why remote sensing allows prompt detection and prevention of land degradation. Examples of identifying soil degradation using remote sensing data are shown in Fig. 6.

Remote sensing cannot work without specialized software for processing satellite images or materials from unmanned aerial vehicles such as: Photomod, ScanMagic, TNTmips, MultiSpec, Ilwis, Msphinx and geoinformation analysis (ArcGIS, Mapinfo, etc.).

Fig. 5. Land plot in the Akmola region

Fig. 6. Land plot of Uryupinsky & K LLP affected by degradation

Geoinformation systems (GIS) play an important role in the remote sensing system, since they are a means of collecting, processing, storing, systematizing, analyzing and presenting information obtained during monitoring.

As a result of monitoring degraded lands, measures for agricultural land conservation are proposed.

The economic efficiency of land conservation measures will be determined by the amount of net income (profit), taking into account the prevented environmental damage in value form, using the efficiency coefficient of environmental costs relative to the total production and environmental costs:

$$E_{me\ tot} = \frac{Ir - (Denv - K * Cr)}{Cr}, \quad (1)$$

where the numerator is the economic effect of land restoration measures;

Ir is the net income received on restored lands, thousand tenge;

Cr is the cost of degraded land restoration, which provided an increase in net income, thousand tenge;

Denv is the damage caused by degradation, thousand tenge.

The yield on non-eroded soils was calculated by the formula:

$$Yn = \frac{YaAt}{K1Aw + K2Am + K3Ah + An}, \quad (2)$$

where *Ya* is the average actual yield, centner/ha;

At is the total area occupied by the crop, ha;

*K*1, *K*2, *K*3 are the coefficients of yield reduction on weakly, moderately and heavily eroded lands, respectively;

An is the area of non-eroded land, ha.

The coefficient of crop yield reduction is calculated by the formula:

$$K = 1 - \frac{P}{100}, \quad (3)$$

where *P* is the percentage of yield reduction according to research institutions.

To simplify calculations, the entire acreage should be expressed in terms of cereal crops. The acreage area in the Akmola region on average for 2018–2023 amounted to 26,264.32 thousand hectares, the average actual crop yield was 12.5 centner/ha. Based on the given system of formulas, the estimated crop yield on non-eroded soils (*Yn*) is 13.5 centner/ha, and the crop shortfall (*V*) due to land erosion is 871.88 thousand centners of grain, which is 69,750 thousand tenge at an average grain price of 80,000 tenge/t.

Analysis to identify degraded agricultural lands on the example of the Akmola region showed crop yields on non-eroded soils and crop shortfall due to land erosion. Identification of soil degradation degree using GIS technologies will ensure full and rational land use, increase fertility, prevent erosion processes and, on this basis, increase production and yield, ensuring high efficiency of capital costs associated with the implementation of planned activities.

6. Discussion of the results of using geoinformation systems to increase the yield of agricultural land

The basis of efficient agricultural production is the preservation and improvement of soil fertility. Currently, the country's agricultural lands are subject to the development and spread of negative processes, which are one of the main reasons for the loss of the resource potential of soils and, as a result, decreasing yield of crops growing on them. Analysis of soil characteristics and cultivation practices makes it possible to predict crop yields. These results are explained by the GIS's ability to integrate disparate data and create accurate models reflecting real conditions in fields. Satellite imagery and unmanned aerial vehicles provide farmers with real-time information on field condition, which allows them to quickly respond to problems and take measures to improve yields (Table 3).

Optimization of irrigation systems using GIS takes into account various factors such as topography, climatic conditions and soil types. This allows developing efficient irrigation schemes, as confirmed by the data in Table 4. The obtained results are explained by the GIS's ability to integrate data on soils, relief and climate, which allows creating models that optimize water distribution [17].

Table 5 contains an analysis of data on the spread of negative processes in the Republic of Kazakhstan. The main areas of agricultural land affected by wind erosion are in the Almaty region – about 2 million hectares, Zhetysu region – 2.9 million hectares, Atyrau and Turkestan – 3.1 million hectares each, Kyzylorda – 2.8 million hectares, Zhambyl and Aktobe – more than 2.0 million hectares each.

The largest share of eroded agricultural lands (more than 30 % of the total area) is in the Almaty, Zhetysu, Atyrau and Turkestan regions. The smallest share of eroded agricultural lands (up to 5 %) is in the Akmola, Karaganda, Kostanay and North Kazakhstan regions.

The areas affected by water erosion (washed-out) of the total area of eroded lands occupy 4.9 million hectares or 2.3 % of agricultural land.

With the help of Earth remote sensing satellites, areas affected by degradation were identified. It is Earth remote sensing that allows for timely and prompt detection and prevention of land degradation. Examples of identifying soil degradation using remote sensing data are shown in Fig. 5, 6. As a result of monitoring degraded lands, measures for agricultural land conservation are proposed. The economic efficiency of land conservation measures will be determined by the amount of net income (profit), taking into account the prevented environmental damage in value form, using the efficiency coefficient of environmental costs relative to the total production and environmental costs.

Despite the results obtained, the study has certain limitations. The main ones are related to the high cost of GIS hardware and software, as well as the need for constant data updating and qualified specialists to work with GIS. These limitations may hinder the large-scale implementation of GIS in agriculture, especially in small farms.

One of the disadvantages of the study is the limited amount of data for the analysis, which may affect the generalizability of the results. It is also worth noting the need to integrate data from various sources to improve the accuracy and completeness of the analysis.

The development of this study may be wider application of GIS to analyze various aspects of agriculture, such as land management, fertilizer optimization and soil monitoring. This will allow a more comprehensive approach to the management of agricultural lands and increase their efficiency and sustainability.

The application of GIS in agriculture in the Akmola region has demonstrated significant benefits in crop forecasting, irrigation optimization and risk management. These technologies allow for more accurate and timely data collection, which contributes to increased efficiency and sustainability.

7. Conclusions

1. The experience of GIS application in agriculture shows that technologies significantly increase the efficiency and sustainability of agricultural land. They contribute to optimal resource use, improve crop management and reduce environmental risks. With global climate change and growing food needs, the introduction of GIS is becoming not only a technological advantage, but also a necessity to ensure food security and sustainable agricultural development.

2. The effectiveness of GIS application for degraded agricultural land shows that these technologies significantly increase the efficiency of restoration and further use of such areas. One of the main recommendations in agriculture is the zoning of territories and their phased use. Each of the zones should have its own specific time of use, and also not exceed the permissible load on it. GIS allows for accurate identification and analysis of degradation factors, resource optimization and constant land monitoring. This provides significant improvements in the productivity and sustainability of agricultural land.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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