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Application of geographic information systems in monitoring the fertility of agricultural lands

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Abstract. This article presents the structure and functionality of GIS Agroecologist Online, a geographic information system designed for environmental monitoring of soils. The system was developed to store and automatically process environmental monitoring data. New algorithms were implemented, including calculating soil cultivation indices, constructing agro-ecological group cartograms, and calculating statistical characteristics for soil survey data. Additional modules were added for preparing technical specifications for design and estimate documentation, calculating fertilizer doses, and providing soil protection recommendations. The system was used in the Belgorod region, resulting in the development of 111 sets of design and estimate documentation, the liming of 123,000 hectares of acidic soils, and the calculation and optimization of 50.79 million tons of organic fertilizers. The system also supported the development of adaptive landscape systems on 685,000 hectares, leading to significant improvements in the main agroecological characteristics of arable soils in the region.

1 Introduction

Protection and rational use of soils are the most important components of the strategy for ensuring environmental safety in Russia. To control the condition of soils, state environmental monitoring is carried out, the basis of which is periodically repeated agrochemical, ecological-toxicological and soil surveys over the entire area of agricultural land, carried out by the agrochemical service [1-6]. One of the main tasks of monitoring activities is the creation of an information database on the ecological state of soils at the federal level, based on the analysis of which management decisions should be made with subsequent assessment of their consequences [7-11].

However, it is worth noting that today the problem of using a universal software product adapted to the tasks of agrochemical monitoring and specific agricultural producers has not been solved [12-14]. Widely used geographic information systems (GIS) from foreign manufacturers cannot currently be used for these purposes due to the implementation of Decree of the President of the Russian Federation No. 166 of March 30, 2022 “On measures to ensure technological independence and security of critical information infrastructure of the Russian Federation” [15]. Domestic software developments do not always fully satisfy the specific needs of the Russian agrochemical service. Consequently, the main task in the

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context of this issue is the development and implementation of domestically produced GIS that fully meets the requirements of environmental monitoring and soil protection.

The main goal of the project was to develop and implement a domestic geographic information system for storing and automatically processing environmental monitoring data, which will improve the quality of management decisions and help ensure control over the effective implementation of soil conservation measures and the formation of sustainable agricultural landscapes.

2 Materials and methods

The research method is based on the analysis of data from agrochemical and soil erosion surveys and determination of the dynamics of qualitative indicators of the state of soils in the Belgorod region using the GIS Agroecologist Online software tools.

The process of processing the results of agroecological monitoring was carried out in the GIS Agroecologist Online environment and MS Excel tools. The production of cartographic material, as well as spatial-territorial analysis, was carried out using the appropriate tools "GIS Agroecologist Online" and ArcGIS Desktop 10.5. The program code was written using high-level programming languages JavaScript, C# and standardized hypertext markup language for viewing web pages in an HTML browser.

The basis of the GIS is a database in SQL format containing monitoring information on soil fertility indicators for each individual plot of arable land. The spatial basis of the system is the plans for on-farm land management, vectorized by employees of the Federal State Budgetary Institution "CAS "Belgorod" and refined with the help of satellite images [16].

3 Results and discussion

A number of developed GIS tools have scientific novelty. Thus, for the first time, it was possible to develop and implement a geographic information system that allows for a comprehensive analysis of data from agrochemical, ecological-toxicological, soil-erosion surveys, and on this basis, automatically generate field passports, build agrochemical and soil maps, design adaptive landscape systems of agriculture and conservation soils (ALSACS) [18]. For the first time, the function of automatically constructing maps of the agro-ecological grouping of lands has been implemented. An electronic field history book has been developed, which accumulates agro-ecological monitoring data, information on the implementation of technological regulations for the cultivation of agricultural crops and environmental measures, allowing for monitoring the implementation of ALSACS projects. For the first time, based on a complex modern algorithm that takes into account specific indicators of the agrochemical state of soils and the needs of agricultural crops, a module for calculating doses of fertilizers has been developed, which allows optimizing the cycle of basic plant nutrients in agroecosystems.

Based on the results of the work, 6 certificates of state registration of databases were obtained. The main results are presented in 37 scientific works, of which: 1 is a monograph, 12 are included in the Scopus citation database, 14 are included in the Russian Science Citation Index, 10 are in the proceedings of all-Russian and international conferences.

The introduction of the domestic "GIS Agroecologist Online" into the work of the agrochemical service made it possible to automate the process of entering and processing data from agroecological soil monitoring, which significantly accelerated and improved the quality of management decision-making aimed at the formation of environmentally sustainable, highly productive agroecosystems. Representatives of regional management bodies of the agro-industrial complex and agricultural producers have remote access to the electronic resources of the agrochemical service, which is necessary for effective work to ensure environmental safety in the agro-industrial complex and increase agricultural productivity.

This GIS is developed on a modular basis based on distributed database technology (Figure 1). The database structure contains tools for input, storage and output of data, as well as their pre-processing and transfer to GIS for further work.

The database contains about 325 tables with data and reference information, more than 330 queries, 30 functions and more than 480 stored procedures [17]. Access for authorized users to GIS Agroecologist Online is provided through the website http://www.agrochim31.ru.

The agrochemical data block contains information on the main indicators of soil fertility, which are determined during agrochemical examination: degree of acidity, content of organic matter, mobile forms of phosphorus and potassium, microelements, etc. [20] Based on these data, thematic cartograms, statistical diagrams, and reporting forms with tabular data are automatically constructed, which facilitates their detailed visualization (Fig. 2, 3).

For the first time, a GIS has implemented an algorithm for calculating the index of the degree of soil cultivation based on the information available in the database on acidity, the content of organic matter, mobile forms of phosphorus and potassium in soils. An example of automatic construction of a cartogram for this indicator is presented.

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For the first time, a complex algorithm for constructing cartograms of agro-ecological groups of lands has been implemented in GIS. Cartograms are constructed based on an analysis of the results obtained as a result of a soil survey. Based on cartograms of agro-ecological groups of lands, a system of anti-erosion measures is designed, including differentiated placement of crop rotations of different specializations depending on the steepness of the slopes and actual soil erosion, placement of forest belts (beams, ravines, water regulation), soil conservation treatments, placement of watercourses, etc. [19]

For the first time, an algorithm for calculating variation-statistical characteristics for soil survey data and local agro-ecological monitoring has been implemented in GIS. The use of this functionality significantly accelerated and simplified the work of agrochemical service specialists when processing large amounts of soil monitoring data.

For the first time, a module has been developed for this GIS, allowing land users to draw up technical specifications through the website http://www.agrochim31.ru, and specialists of the agrochemical service to automatically develop design and estimate documentation (DED) for liming acidic soils. In the Belgorod region, using this module, 111 sets of design documentation were developed for land users, according to which liming of acidic soils was carried out on an area of 123 thousand hectares.

In GIS, for the first time, a module has been developed for calculating annual doses of fertilizers (organic and mineral) for the planned yield of agricultural crops, taking into account important agro-ecological parameters of soils and the characteristics of previous crops.

Using this module, the use of 50.79 million tons of organic fertilizers was calculated and optimized in the Belgorod region. The implementation of this function will make it possible to solve the most pressing environmental problem of modern agriculture - the formation of a balanced cycle of plant nutrients in agroecosystems.

For the first time, a module has been developed in GIS that significantly simplifies the process of developing ALSACS projects. Recommendations for soil protection and the formation of environmentally sustainable and highly productive agricultural landscapes are concentrated in this document. Using this module, 375 ALSACS projects were prepared and implemented on an area of 685 thousand hectares.

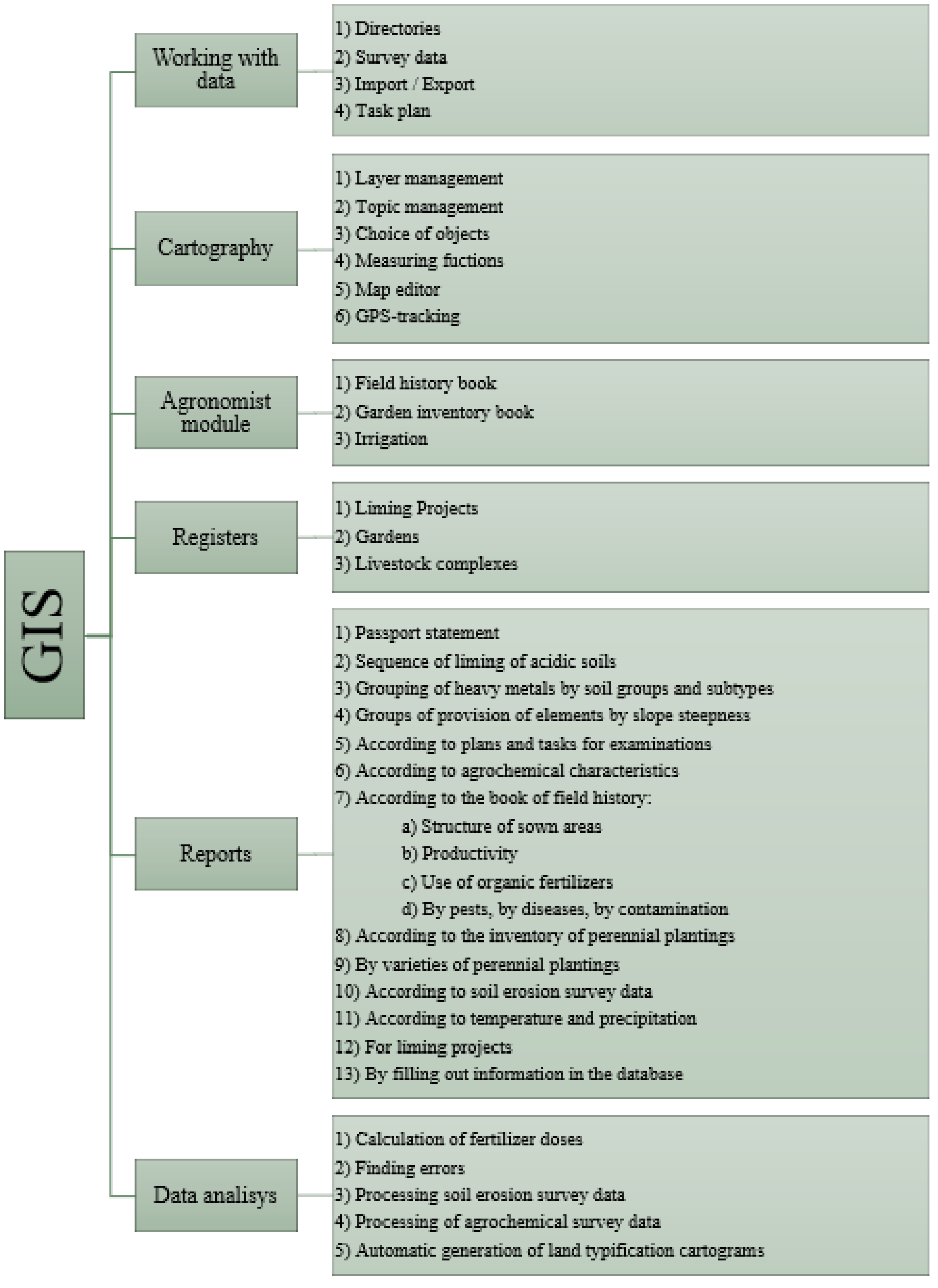

Fig. 1. Modular structure of "GIS Agroecologist Online".

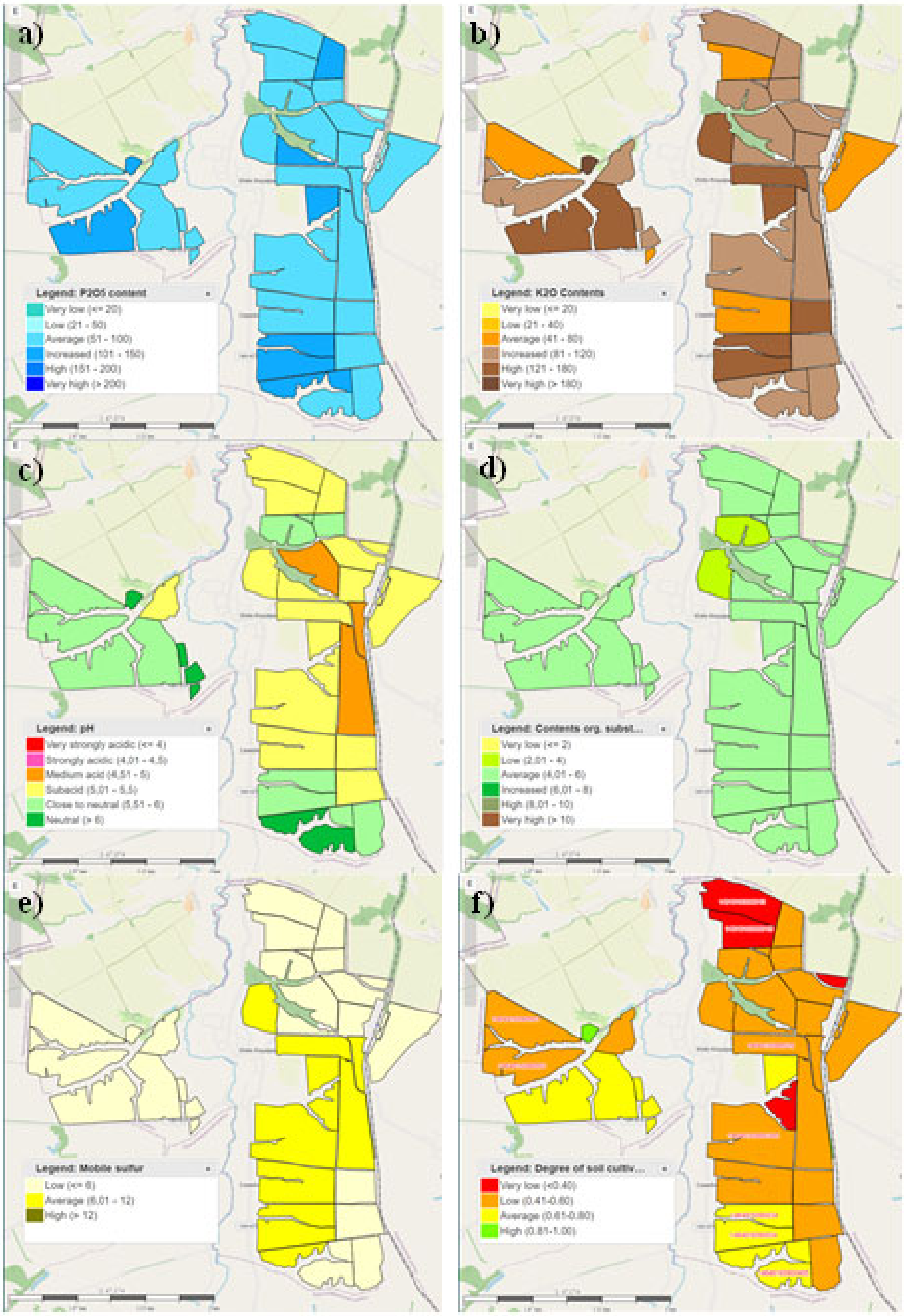

Fig. 2. Cartograms of the main indicators of fertility: a) – content of mobile forms of phosphorus, b) – content of mobile forms of potassium, c) – degree of acidity, d) – content of organic matter, e) – content of mobile sulfur, f) – degree of cultivation.

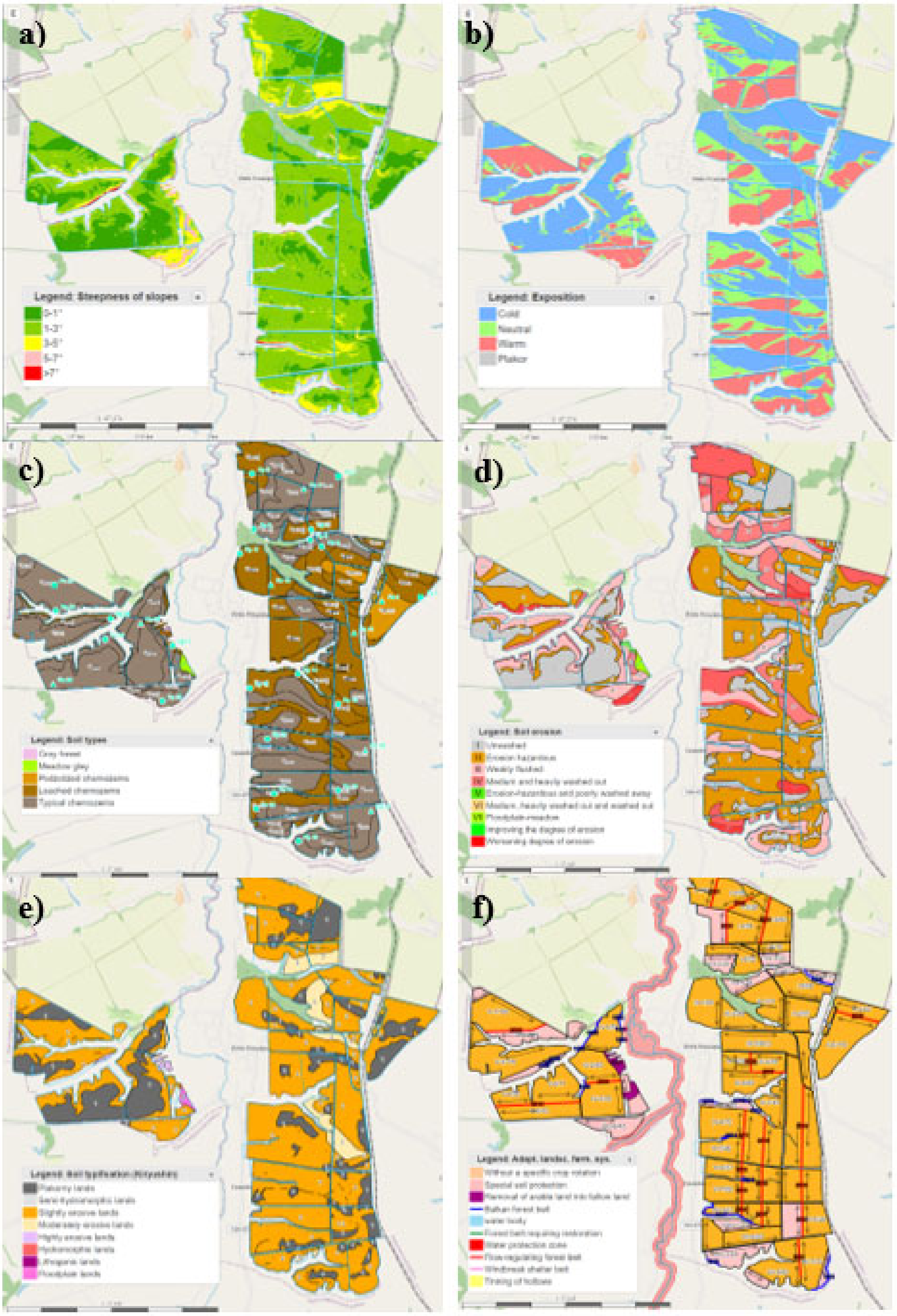

Fig. 3. Cartograms of soil-erosion survey: a) – slope steepness, b) – slope exposure, c) – soil, d) – soil erosion, e) – agro-ecological groups of lands, f) – environmental protection measures of the ALSACS project.

4 Conclusion

During the period of development of ALSACS projects developed using GIS Agroecologist Online, the main agroecological characteristics of arable soils in the Belgorod region have significantly improved: the share of acidic soils has decreased by 12.3%, the content of organic matter has increased by 0.3%, mobile forms of phosphorus have increased by 25 mg/kg, potassium – by 35 mg/kg. At the same time, the grain yield of corn increased by 2.06 times, winter wheat by 1.59 times, spring barley by 1.44 times, sunflower by 1.75 times, and soybeans by 2.16 times.

Unlike most domestic software products, GIS Agroecologist Online is fully adapted to the tasks facing the agrochemical service when conducting environmental monitoring of soils. This GIS allows not only the collection and storage of monitoring data, but also their automatic processing for making specific management decisions on soil protection. The effectiveness of GIS Agroecologist Online is evidenced by the large scale of its implementation in the agrochemical service of Russia and among land users. Thus, registration data was issued to 1,893 users, which included 99 centers of the agrochemical service of Russia, agricultural management bodies, and land users. As of January 1, 2024, information on the ecological state of soils on an area of 24.85 million hectares was loaded into the GIS. In the Belgorod region, land users on an area of 1.44 million hectares gained access to GIS. Data in the electronic field history book was entered on an area of 0.84 million hectares.

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