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ORIGINAL PAPER
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APPLICATION OF GIS IN LAND MANAGEMENT ON THE EXAMPLE OF UKRAINE

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ABSTRACT

Motives: Full-scale hostilities that occurred in Ukraine in 2022 have led to significant losses in agriculture and rural areas. These losses pose a serious threat to the country's food security and may lead to crises on international food markets. Also, to justify information needs and requirements in accordance with legal regulations relating to land use, food security in Ukraine should be considered through continuous monitoring and analysis of the available land resources, and the existing and projected structure of cultivated areas.
Aim: The aim of the study is to provide a theoretical and methodological basis for formulating practical recommendations regarding information and analytical support for the management of land resources through the use of GIS, in particular Earth remote sensing systems, in land management.
Results: To improve the institutional environment for regulating land relations in Ukraine under new conditions of management, the following stakeholders should be considered in the process of managing land resources: 1) government, 2) local authorities, 3) agricultural enterprises, and 4) land owners. The study revealed problems with access to information and analytical support for managing land resources at the level of the central government, territorial self-governments, and agricultural enterprises. Digital transformation has a significant impact on agribusiness because it enables agricultural producers to interact with other stakeholders, compare their performance with competitors, and optimize production processes.

Keywords: digitalization, territorial communities, land resources, monitoring

INTRODUCTION

The domestic system of land use developed in recent years is characterized by a number of environmental and economic problems caused by the insufficient level of effectiveness of land resources management. At the same time in the process of management decision-making an important role is played by information support, in particular the updating of information about land resources, ensuring its availability and increasing the usefulness. That is formation of management system of land

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resources should be based on constantly updated information base about objects of land relations that causes necessity of increase of efficiency of use of information and resource potential and also creation of information system that will allow to provide the organization of the balanced land use. However, today land information systems function separately, based on analytical, statistical and technical systems, which leads to a significant number of errors in the process of planning, regulation, control and organization of land use. In this connection scientific substantiation of the main directions of information-analytical support of land management becomes especially urgent. Also, the regulation of land relations under martial law should be systematic, as it creates many simplifications to ensure the functioning of the agrarian sector of the economy and the rapid restoration of infrastructure of Ukraine (Kuryltsiv & Kryshenyk, 2022).

In connection with the significant deterioration of conditions for statistical and operational accounting of actual land use, remote sensing of the Earth based on artificial intelligence and geoinformation technologies is of great importance as a tool for data collection and analysis. Therefore, the relevance of the need to form information requirements for management decisions in land use increases, which includes in this study:

- definition and clarification of land management functions, which determine the requirements for information and analytical support of management decisions;
- substantiation of methodological foundations for the collection and processing of geospatial data in land management and land policy, including, in addition to statistical reporting and available data from the State Land Cadastre, other information flows and methods such as remote sensing, agroscouting, surveys, monitoring of open registers and information platforms, cross validation of data collected and their subsequent analysis in the Big Data and Data Mining;
- creation and continuous updating of an appropriate information model of data, including the structure, composition of geodata, new information flows, ways of their creation, processing, analysis, delivery, visualization, interactive support for users in convenient forms;
- development of modern methodological approaches to modeling and forecasting of agricultural land use, which should provide support for management decision-making through modeling scenarios of long-term processes caused by internal and external social, economic, environmental, political internal and external factors.

Information and analytical support of land management for the purposes of their effective use should serve as the basis for further reforms, sustainable development of rural areas.

It's important to note that the full-scale hostilities that occurred in Ukraine in 2022 resulted in significant losses in agriculture and rural areas (Ibatullin et al., 2022). These losses pose a serious threat to the country's food security and may lead to crises in international food markets. More than 30% of the country's territory has been impacted by the effects of hostilities and at the end of 2022 is under occupation or remains dangerous for agricultural activities (KSE, 2023). Therefore, to manage land resources at different levels and make effective management decisions, it is necessary to have timely and reliable analytical information and GIS as well as remote sensing tools can be used for these purposes.

LITERATURE REVIEW

Now there is an increasing demand for timely and reliable information about the current state of land use. Solving the problem of inefficient informational support of land resources management is one of the main tasks on the way to rational use, protection of lands and taking decisive measures that would stop these negative processes. To keep the existing state of land resources is possible only through the development of information support of land management, namely the creation of a unified land-information system, which will contribute to the formation of a complete and reliable information database (Semenchuk & Yuzyk, 2018).

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Joireman and Tchatchoua-Djomo (2023) tackled the discrepancy between customary tenure rights and international policy regarding property restitution after conflicts. Additionally, they aimed to determine the paths taken by customary tenure systems in post-conflict situations. These two concerns are inherently connected. There is an implicit and undefined assumption that individuals can always revert to rural agricultural livelihoods when they are forced to leave customary land. This assumption holds true only if customary land systems continue to operate as they did prior to the occurrence of violence.

Xu et al. (2022) categorized the tenure systems associated with rural homesteads in China, starting from 1949, using a systematic retrospective analysis. Three models were identified: the single entitlement system, the bipartite entitlement system, and the tripartite entitlement system. Under the single entitlement system (1949–1961), rural collective ownership solely served the economic utility function. In the bipartite entitlement system (1962–2018), collective ownership and the right to use were separated.

To an inexperienced observer or someone with an interest in history, the cadastral map may appear to be a mere relic of the past or an intriguing artifact. However, from a historical perspective, it served as a significant instrument of state policy, providing support for control and authority. The underlying motivation behind the creation of cadastral maps was rooted in economic, social, and political power. By providing crucial information, the map granted power to those in control, enabling them to effectively manage and tax land resources (Bacior, 2023).

Various indicators have been employed to assess and compare cadastral systems across different countries. The outcomes of these analyses play a crucial role in enhancing our comprehension of the intricate interplay between cadastral systems, land administration systems, and National Spatial Data Infrastructure (SDI) initiatives. Moreover, this enables a global assessment of cadastral systems, laying the groundwork for identifying best practices and offering a means to enhance national cadastral systems (Rajabifard et al., 2007).

Guzhva (2001) noticed in his work that there are problems of information systems and information resources of the organization. He proposed modern approaches to the development of automated information systems at enterprises. Believes that software products will help automate the processes of business planning of investment projects and strategic business evaluation in enterprises.

The adoption of the GeoPackage standard in mobile applications designed for land administration purposes enhances the practicality and effectiveness of field data collection. By utilizing various sensors such as fingerprint readers, cameras, and accurate GNSS sensors, along with seamless connectivity to cadastral databases through the KKP services, the mobile app significantly improves the efficiency of data capture. This app can be considered a facilitator for more streamlined and productive collaboration in the collection and validation of data for initial titling and forensic titling processes. Its performance has been tested in a village in Denpasar for boundary mapping and in two villages in the Bangli district of Bali Province for forensic titling purposes (Aditya et al., 2021).

According to Ponomarenko et al. (2011) information systems play a large role in the business management process. Information resource is one of the components of company economy. He proposed a process approach to the development of automated information systems and showed their classification for business management.

Pavlenko et al. (2013) highlighted the basics of modern information technologies and production systems in theory and practice. In their opinion, the functionality of information systems is of great importance in creating databases. They note the means of data processing: operational analytical and intellectual analysis.

According to Dyshlyk et al. (2018) the creation of national geospatial data infrastructure is aimed at developing the geospatial world in order to develop economy, provide vital services, maintain sustainable

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development, improving the lives of people around the world based on several things commonly accepted in the world. When forming the ideology of national geospatial data infrastructure and the relevant legal framework in Ukraine it is necessary to take into account the World development trends in this area. The system principles of creation of research institutes and the list of measures and actions to return the process of construction on an innovative way are offered.

The system approach is no less important in the management of land resources. Lyashenko (2019) believes that any system (object) is considered as a set of interrelated elements, has input, output, connection with the external environment and feedback. System approach to management assumes management of the organization as a single system, where any managerial influence on one part of the system affects its other parts, which means that it is necessary to manage the organization as a whole. As a way of management, the system approach is based on understanding the object of management as a whole, on revealing the diversity of its internal and external relations; a set of related, coordinated methods and means of managing the economy, industry, enterprise, subdivision, etc. At least any system management is based on two main system principles: providing a given purpose of functioning and creation of conditions for stability of existence in the changing world and protection against unauthorized external action.

MATERIALS AND METHODS

A number of general scientific and special research methods at the empirical and theoretical levels, in particular, system (structural and functional analysis), abstraction, analysis and synthesis, deduction and induction were used to achieve the objectives. The use of these methods made it possible to substantiate the information and analytical support land management, determine the content and tasks of institutional transformations in agriculture and agrarian policy.

Comparative and statistical analysis of the process of researching the quantitative composition of agricultural land of state institutions, the areas of land with or without title documents, the amount of land registered in the State Land Cadastre; abstract-logical method – when making theoretical generalizations and forming conclusions.

An important direction of information-analytical support of agricultural land use management at any level is the use of remote sensing. This method makes it possible to promptly assess the state of land over vast areas, timely identify and analyze threatening phenomena such as waterlogging, landslides, and land cover deterioration.

Spatial analysis use as the basic approach to identify the real state of land resources. Creating a system of integrated accumulation, processing, updating and storage of data, containing structured information about the current state of land, algorithms for analyzing the suitability of soils for the main types of land use, quantitative and qualitative indicators and normative monetary evaluation of land plots.

RESULTS

Land monitoring is one of the functions of land resource management. In accordance with the legislation, monitoring is a system of observing the state of land for the purpose of timely detection of changes, their assessment, prevention and elimination of the consequences of negative processes. At the local and regional level, land monitoring is carried out by territorial bodies of the State Geocadastre, at the national level by the State Geocadastre (Verkhovna Rada of Ukraine, 1993). In connection with the war, losses of crops, fires, as well as physical destruction of fields, there was a need to implement a new task, namely, monitoring of damage and loss of land caused by hostilities. Since the lack of proper land accounting creates gaps, we recommend filling this gap with methods such as remote sensing of the Earth and the use of geographic information systems. This choice of tools is justified by the fact that GIS allows for monitoring relatively quickly and without excessive costs, providing a broad overview of the state of the land. This, in turn, should become a universal

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tool for information support of organizational and management processes, effective management, use of information resources (Dorosh et al., 2020) and will allow competent state bodies at all levels to quickly and effectively make decisions that will contribute to ensuring food security of the country.

Because of the armed aggression the soil cover is destroyed, degradation processes develop, including on chernozems – mechanical destruction, pollution, clogging, etc. According to the data of the Ministry of Agrarian Policy of Ukraine (Minagro, 2023), in the structure of damages the greatest losses are fixed due to destruction or partial damage of agricultural lands and harvesting.

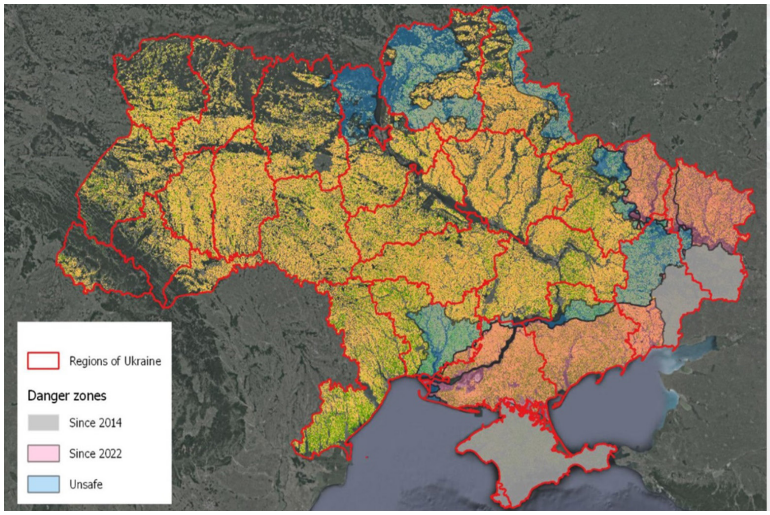
The total area of agricultural land in temporarily occupied, de-occupied and hazardous territories is more than 10 million hectares (Fig. 1) (Copernicus, Sentinel-2, 2022). In the structure of damage, the greatest losses are recorded due to destruction or partial damage of agricultural land and harvesting. Agricultural land suffered two significant types of damage – mine contamination and direct physical damage. In addition to minefields, areas affected by active combat operations are contaminated by unexploded ordnance, which poses a deadly threat to Ukrainian farmers during fieldwork. The second type of damage is physical damage to the fertile soil layer, such as craters from artillery shelling and rocket attacks, damage to the soil by the tracks of tanks or other military equipment (KSE, 2022).

About 19% of all irrigated agricultural land in Ukraine is located in the temporarily occupied Kherson region and another 10% in the partially occupied Zaporizhzhia region. The approximate cost of replacing and repairing the damaged irrigation infrastructure is $225 million (KSE, 2022).

In addition to direct land damage, occupation, military actions and mine contamination limit farmers' access to fields and opportunities for harvesting.

The production of crops has been significantly impacted by Russia's invasion, with losses estimated at astonishing 1 billion UAH or nearly half a quarter of export potential. The most substantial production losses are for croplands, which accounts for 510 million UAH, followed by winter crops at 490 million UAH for spring 2022.

A significant part of the dangerous territories in order to return them to economic use requires measures to eliminate the consequences of military operations: demining, cleaning of fortification structures, restoration of the surface layer, etc., which requires the implementation of national programs and investment projects. After that,



Temporary occupied and de-occupied agricultural lands of Ukraine as of September, 5

- Area: ~ 10 Mha
- Normative value assessment : ~ 33 bln UAH
- Loss of about a quarter of the export potential: up to 15 Mt, or more than $1 bln

Zones	Croplands		Winter crops	
	Mha	%	Mha	%
Occupied since 2014	1,65	5,4%	0,62	7,7%
Occupied since 2022	4,90	16,0%	1,96	24,5%
Unsafe territories	3,33	10,9%	0,74	9,3%
Unoccupied territories	20,78	67,8%	4,69	58,5%
Total	**30,66**	**100,0%**	**8,02**	**100,0%**

Fig. 1. Croplands of Ukraine in Spring 2022 and Occupied Zones
Source: own preparation based on Copernicus, Sentinel-2 (2022).

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significant areas of de-occupied land will most likely require land management, which includes the following: identification of disturbed lands and lands affected by negative processes and implementation of measures for their restoration or conservation, reclamation of disturbed lands, reclamation of low-productive lands, protection of lands from erosion, flooding, waterlogging, secondary salinization, drying, compaction, pollution by industrial waste, radioactive and chemical substances and other types of degradation, conservation of degraded and low-productive lands.

Infrastructure facilities of the agricultural, warehousing, transport, energy and food industries experienced significant disruptions. Seaports were partially blocked, which reduced the export opportunities of the industry. Logistics, transport, storage and other economic chains are disrupted. Agricultural enterprises are experiencing an acute shortage of fuel and lubricants, seeds, fertilizers, plant protection products, and spare parts. Some agricultural equipment is damaged or involved in other humanitarian or military work. Employees of enterprises are enlisted in the armed forces of Ukraine, territorial defense and other non-agricultural activities.

Under these conditions, the implementation of anti-crisis agrarian policy in Ukraine should be based on current reliable information about the sown areas of crops available in the controlled areas, their spatial identification and condition. In this regard, GIS tools can also be used in the development of land management projects that provide environmental and economic justification for crop rotation and land management, developed at the request of landowners or land users in order to organize agricultural production and manage agricultural land within land ownership and land use for efficient agricultural production, rational use and protection of land, creation of a favorable environmental conditions and improvement of natural landscapes. It is necessary to assess the possibility of sowing, harvesting and organization of transport and storage processes. It is also important to determine the available areas of agricultural land for subsequent sowing and harvesting potential in each region, taking into account the structure of crops and local resources and features, in particular military, production and climatic characteristics.

To improve the processes of data collection and processing in land management in terms of soil resources, the following issues in particular need to be addressed:

– conducting a repeat (or correction) of the solid ground survey, since the materials of the preliminary one, conducted more than 50 years ago, are outdated. The new survey should be carried out on new methodological principles, taking into account the consequences of the armed aggression of the Russian Federation against Ukraine;
– organization of land and soil cover monitoring taking into account European experience, improvement of the national system of agrochemical passportization of agricultural lands, operating in the country since the 60s of the last century, with the use of remote sensing tools. Combination of new cartographic-analytical materials obtained as a result of repeated soil survey with the data of agrochemical passportization and monitoring will be the same exemplary world level of information on soils (chernozems) of the country;
– improvement of information provision through formation of soil data bases with extended evaluation, cartographic and prognostic possibilities, activation of Ukrainian Soil Information Center, transfer of information to the State Land Cadastre;
– carrying out appraisal of soils according to improved methodology and determination of objective price of lands (normative value assessment).

In conditions of essential deterioration of conditions for realization of the statistical and operative account among tools of gathering and the analysis of the data of actual land use the remote sensing of the Earth with use of artificial intelligence and geoinformation technologies takes the major place. Yes, we are supposed to carry out with the help of these tools:

– determining the boundaries of arrays of agricultural land and crops;

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– identification of infrastructure facilities and areas under land resources that were damaged during military operations and shelling;
– evaluating the availability of cropping areas to engage them in agricultural production;
– identification of the boundaries and areas of cultivation under specific crops, including a preliminary estimate of yields;
– analysis of the volume and structure of sown areas in the territorial section with forecasts of yields and gross yields of agricultural crops using vegetation indices;
– determination of the state and dynamics of land transformation by types of land.

One of the goals of monitoring as an element of land management is to collect information on damaged land as a result of armed aggression, which can also be done with GIS tools. Damage to land resources as a result of armed aggression was analyzed in particular using the spread of active fires according to NASA Firms and Copernicus Emergency Management Service (Fig. 2).

It has been established that the main land losses due to fires are concentrated in the 30-kilometer buffer zone along the line of contact and are obviously related to combat operations and shelling. The use of satellite imagery should make it possible to carry out preliminary work to identify, assess and zoning the areas of agricultural land affected by the armed

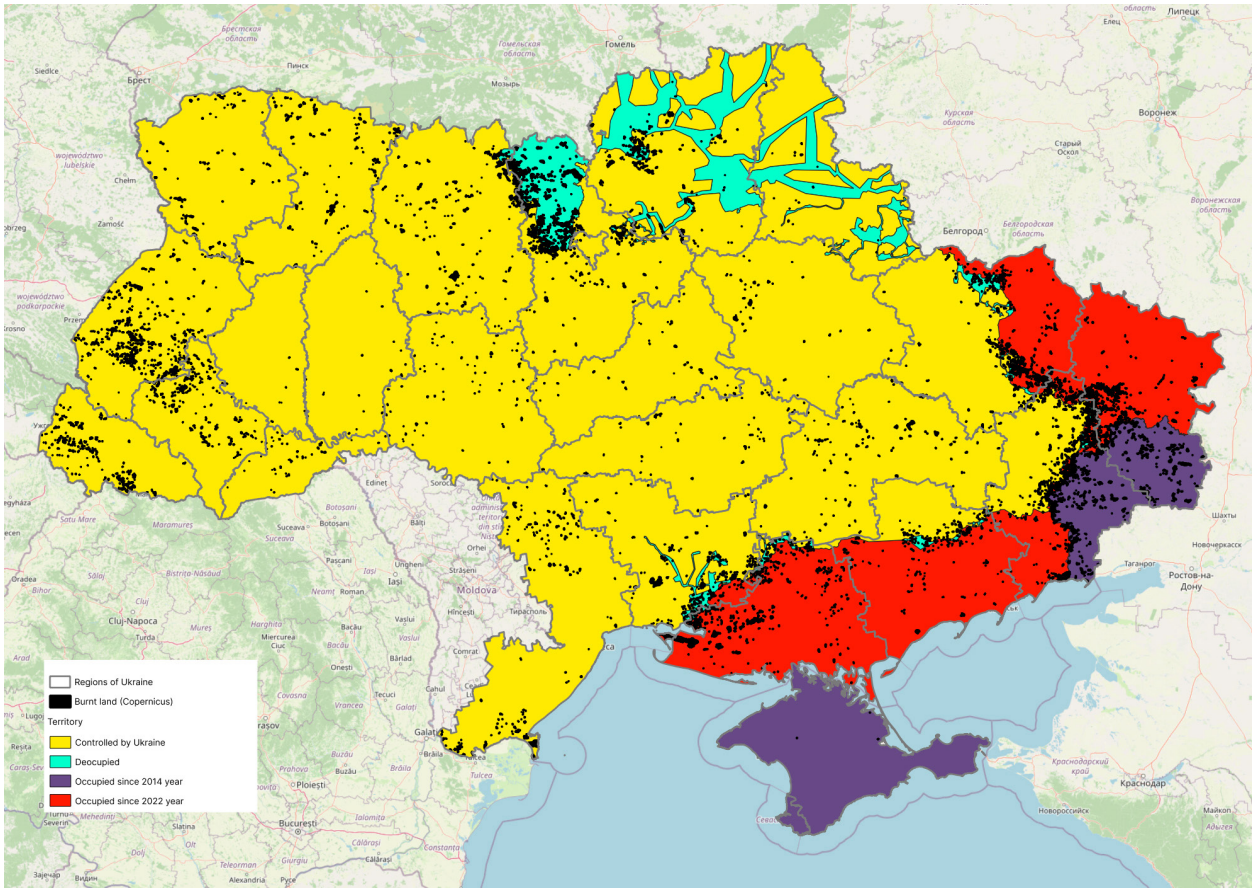

Fig. 2. Location of active agricultural fires region, taking into account the temporarily occupied and de-occupied territories of Ukraine as of September 2022

Source: own preparation based on NASA Firms and Copernicus Emergency Management Service data (2022).

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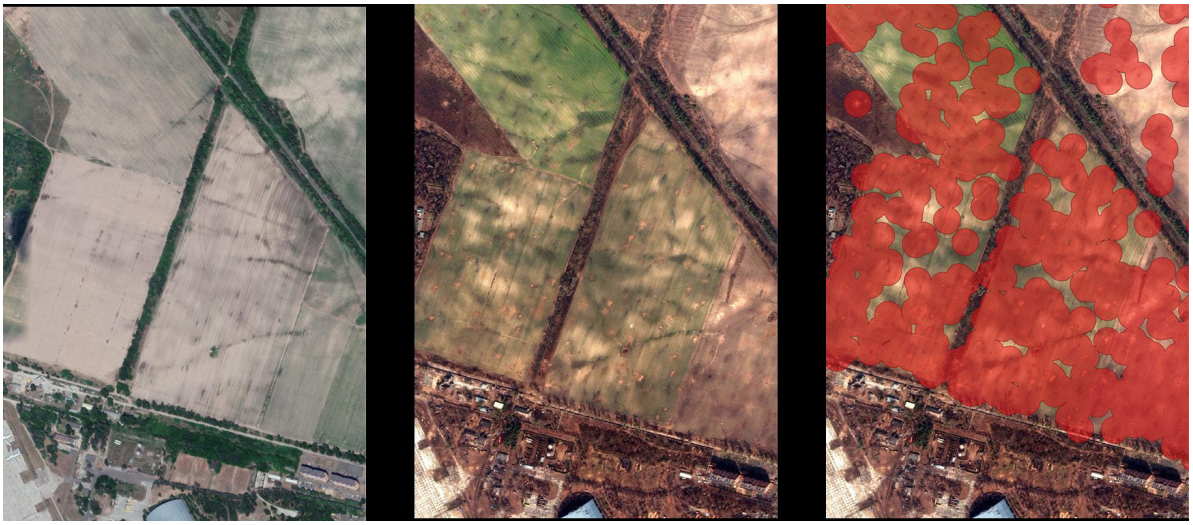

Fig. 3. Analysis of the nature and scale of agricultural land mass lesions using satellite images
Source: own preparation based on satellite images Sentinel-2 (2023).

aggression. Automated detection of munitions explosion craters on satellite images with the installation of 30-meter buffer zones makes it possible to identify the main areas and concentration of such damaged lands (Fig. 3). The process of identifying craters after explosions was carried out using Python programming based on reference pixels selected by specialists.

Therefore, the following stakeholders should use Earth remote sensing information:

1. Public authorities (Ministry of Agrarian Policy and Food, the State Service of Ukraine for Geodesy, Cartography and Cadastre, etc.).
2. Local authorities (new united territorial communities).
3. Agricultural enterprises (agricultural holdings, agro-firms, farms, production cooperatives, etc.).
4. Owners of land lots.

The problems of information and analytical support for land management at the level of landowners can vary, and they often depend on the specific country, region or local conditions. However, some common problems that may arise include the following:

1. Lack of information: landowners may not have sufficient information about their rights and obligations, land law, procedures for registering property rights, etc. This can lead to illegal actions or conflicts.
2. Information registration systems: in some regions, there are outdated or inefficient systems for registering land rights, which can lead to delays in resolving land ownership issues or land transactions.
3. Corruption and unfair practices: owners may face corruption or unfair practices when trying to register land rights, submit documents, or receive information from the authorities.
4. Lack of access to technology: in some cases, owners may not have access to modern technology and the Internet, making it difficult to access information and interact with authorities.

The use of land resources at the level of an agricultural enterprise should combine the interests and goals of specific landowners (land users) and society as a whole, as well as all sides of land relations for their rational use and increase the efficiency of agricultural production.

Current problems of land management at the local level should include:

1. The need to determine the boundaries of actual economic use of land, often not coinciding with the legal boundaries and the legal regime of land.

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2. Necessity of defining the cost of land use from the position of economic efficiency of production and economic activity.
3. Necessity of optimal planning of production use and protection of lands.

At all levels of management, a significant number of problems is expedient to solve by introduction of information technologies on the principles of geospatial data infrastructure. Technological solutions that are reasonable to use when creating information-analytical systems of this level include: web platforms, GIS-technologies, artificial intelligence, machine learning, relational and non-relational databases, OLAP and OLTP, remote sensing of the Earth, etc. Combining modern technologies is an important tool to ensure the competitive advantage of any enterprise, society and state as a whole.

Improving the efficiency of public administration in the development of measures to create an information environment for the use of land resources becomes more relevant in the context of land reform, as well as the planning of its future actions. Therefore, there are some problems of information support that should be solved.

At the level of the state, among the problems of information and analytical support of land resources management we can single out:
– lack of quantitative and qualitative land records;
– imperfection of the methodology of statistical reporting on the state and changes in the land fund;
– imperfection of spatial analysis in information support;
– lack of complex system of monitoring of lands, their legal status and actual use, tracing of soil quality;
– presence of different types of errors in the records of the State Land Cadastre;
– insufficient efficiency and relevance of analytical data, in particular in terms of land protection, etc.

No less important aspect in the information-analytical support is the spatial analysis, because it is the basic approach to identify the real state of land resources. It is necessary to create a system of integrated accumulation, processing, updating and storage of data containing structured information on the current state of land, algorithms for analyzing the suitability of soils for the main types of land use, quantitative and qualitative indicators and normative monetary evaluation of land plots in Ukraine. The following information should be included in this system:
– data from the State Land Cadastre;
– data from statistical reports (6-zem, 6a-zem, 6b-zem, etc.);
– cartographic materials;
– data from other cadastres;
– tax and lease payments;
– cartogram of agro-productive groups of soils;
– digital relief model;
– soil suitability scales;
– limits of administrative-territorial formations;
– indices of tillage and forest cover;
– anthropogenic overload factors;
– indicators of environmental sustainability of the territory;
– degree of soil erosion, etc.

At the level of territorial communities, the following problems arise:
– lack of officially approved community boundaries, which does not allow to establish the boundaries of the rights and powers of local government;
– lack of support for management decisions at the local level on the management of communally owned land;
– informational and analytical support of the local regulatory and legal framework regarding the regulation of land relations;
– problems of inventory of unregistered land, administration and collection of land tax, management of communal real estate, management of investment attractiveness of community land;
– introduction of community participation in community land use and protection planning.

CONCLUSIONS

Economic losses from military aggression pose a serious threat to the stability of the country's food security and may cause a crisis in international

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food markets. When formulating requirements and developing information resources for effective management of agriculture, it is necessary to take into account the importance of ensuring food security of Ukraine through constant monitoring at the local level and analysis of available land resources.

Data from various sources and satellite data were used to evaluate the damage to soil and farmland. Using data from the Ministry of Agrarian Policy and Food of Ukraine (MAPF), the decrease in crop production was estimated.

The application of GIS technology in land management is expected to improve data collection and processing processes for soil resources, which will help to Solving the following issues: updating the obsolete base of maps of agro-productive groups of soils; improvement of national agrochemical passportization system for agricultural lands bagricultural holdings with application of remote sensing tools; improvement of national agrochemical passportization system for agricultural holdings soil appraisal using improved methodology; and identification of objective land prices for appraisal of soils using improved methodology and definition of objective land price (normative monetary appraisal).

The mentioned statements will provide an opportunity for the application of GIS technologies in land management, particularly in the development of a working land management project for the reclamation of damaged lands, removal and relocation of topsoil, conservation of degraded and unproductive farmland, improvement of agricultural and forestry land, protection of land from erosion, flooding, waterlogging, secondary salinization, drying, landslides, compaction, acidification, pollution from industrial and other waste, as well as radioactive and chemical substances.

Land management at the level of agricultural enterprises requires the creation and proper functioning of an information system of data on land use in the context of each specific enterprise separately. Therefore, the use of relevant information is a guarantee of stability in the enterprises, which will lead to the attraction of investors and provide an opportunity to obtain a permanent income due to the rational use of land resources.

At all levels of management, it is advisable to solve a significant number of problems by introducing information technology on the principles of geospatial data infrastructure, which will allow the prompt use of relevant information in making effective management decisions.

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