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CURRENT STATE AND DIRECTIONS OF THE USAGE OF REMOTE TOOLS FOR INVENTORY AUDITING OF IRRIGATION SYSTEMS

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Abstract. *The paper examines modern approaches to conducting an inventory audit of irrigation systems using remote tools. The traditional methods of irrigation systems inventory audit require significant financial and labor costs, which complicates large-scale audit and planning of measures for the reconstruction and modernization of irrigation systems. According to the results of the research, it was found that remote technologies are the most appropriate for inventorying such basic elements of irrigation systems as pumping stations, antechambers, open earth and concrete canals, pipelines, hydrants, water distribution facilities, and other components of engineering infrastructure. Based on the analysis, a list of remote tools that can be used to assess the technical condition of irrigation facilities was determined. It includes satellite remote sensing of the Earth, namely the use of optical, multispectral, and hyperspectral images, aerial photography using unmanned aerial vehicles, geophysical research methods, in particular ground penetrating radar (GPR) and electromagnetic methods for tracing underground communications, as well as geographic information systems for integrating, analyzing, modeling, and visualizing the obtained results.*

Our research has shown that a comprehensive approach that combines modern remote sensing, geophysical, and geoinformation methods creates additional opportunities for conducting an effective inventory audit of irrigation systems in Ukraine, increases the efficiency of surveys, the accuracy of determining the technical condition of facilities, and the objectivity of the obtained results. The results of the performed analytical studies can be used to justify the choice of tools and develop recommendations for conducting an inventory audit of irrigation systems by remote means.

Key words: *inventory audit, irrigation systems, remote sensing, GIS, UAV, satellite data*

Relevance of research. The explosion of the Kakhovka reservoir dam by russian troops for a long time left 94 percent of irrigation systems in the Kherson region, 74 percent in the Zaporizhia region, and 30 percent in the Dnipropetrovsk region without an irrigation water source, and reduced the actual irrigated area to only 136,000 ha [1], which is less than 0.6% of the total area of arable land in the regions controlled by Ukraine.

It is clear that with such areas of actual irrigation, irrigated lands has ceased to serve as an insurance fund against the negative impact of weather conditions on crop production volumes. At the same time, climate changes and the loss of more than 18% of the territory, including more than 6.0 million ha of arable land and almost 75.0% of irrigated area and the lands of actual irrigation, necessitate an accelerated increase in irrigation areas, as provided for in the "Strategy for the Restoration of Irrigation and Drainage in Ukraine by 2030" [2] and the "Long-term Plan for the Restoration of the Irrigation Complex of Ukraine for the Period until 2050" [1]. It is the significant increase in the area of irrigation and water regulation using drainage systems, of which, according to the official statistics, 3,3 million ha have been recorded in Ukraine today, that can become an effective mean not only for compensating the losses due to the temporary occupation of significant arable areas, including irrigated lands, but also in increasing the volume and ensuring the sustainability of crop production, primarily grain and leguminous crops, and, due to this, preserving and further increasing Ukraine's export potential and role in solving the world food problem.

Therefore, both the "Strategy…" and the "Long-term Plan…" determine that the expansion of irrigation and water regulation areas should be carried out by developing and implementing projects for the reconstruction and modernization of existing irrigation and drainage systems, on which irrigation or water regulation is currently not carried out, but whose technical condition allows for the restoration of irrigation and water regulation by carrying out their reconstruction or modernization [1, 2]. As already noted, on the territories controlled by Ukraine, more than 800,000 hectares of irrigated lands are recorded, but irrigation is carried out on only 140,000 hectares, that is, more than 600,000 hectares of land that were once irrigated and had all the engineering infrastructure for irrigation are currently not used for their intended purpose. The actual technical condition of those infrastructure, unfortunately, is also unknown, as the last inventory audit of irrigation systems in Ukraine was conducted in 2013, so its data cannot be used as a starting point for developing both the feasibility studies and the projects for the reconstruction or modernization of existing irrigation systems. On the other hand, not using existing networks to speed up and reduce the cost of expanding irrigation areas is also not justified. Therefore, the "Plan of Actions for the Implementation of the Irrigation and Drainage Strategy in Ukraine for the Period Until 2030" [3], as well as the "Long-term Plan…" [2], provide for an inventory audit of irrigation systems as a basis for establishing their availability and actual technical condition, preparing proposals for the creation of water users organizations (WUO), developing feasibility studies and projects for their reconstruction or modernization.

The approximate scope of work on the inventory audit of inter-farm networks on the territories controlled by Ukraine is indicated by the data presented in Table 1.

1. Composition and main characteristics of the inter-farm irrigation networks and facilities on it on the territories controlled by Ukraine (according to the inventory data of the State Water Agency of Ukraine, 2013)

Region	**Main water intakes from irrigation sources pcs.**	**Permanent irrigation network, km**	**including:**		**Pumping stations, pcs.**	**Water reser-voirs, pcs.**	**Useful storage volume at NRL, million m³**
			canals, km	**pipelines, km**			
Oblast:							
Vinnytsia	16	163,36		163,36	48	1	
Transcarpathian					2		
Zaporizhzhia	18	673,1	478	195,1	213	1	5,7
Kyivska	4	289,881	54,224	235,659	44	10	6,074
Kharkiv	37	426,244	19	407,24	76	14	75,7
Kirovohradska	18	120	1	119	25	6	12,04
Mykolaivska	20	528,72	348	173,92	98	12	62,71
Odesa	23	985,016	515,338	467,2	218	10	33,342
Poltava	4	110,64	19,18	98,88	24	2	13,63
Cherkasy	51	341,1	38,4	302,7	81		
Dnipropetrovsk	42	796,36	209,18	587,18	165		
Kherson	71	844,9	740,6	104,3	228	7	18,5
Total in Ukraine	282	5278,321	2422,922	2827,539	1222	63	227,696

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The data in Table 1 are somewhat overestimated, as they do not take into account the losses of irrigation networks in Kharkiv, Kherson, Zaporizhia, Mykolaiv, and Dnipropetrovsk regions due to temporary occupation and destruction.

The engineering infrastructure of irrigation systems includes the collector and drainage networks, which is built in the zone of influence of irrigation systems and are subject of inventory audit. The intra-farm network, the components of which are usually not recorded, also requires audit.

Therefore, solving the problem of accelerated expansion of irrigation areas, the relevance of which is constantly increasing due to progressive warming because of the climate changes, and the need to compensate for the decrease in crop production due to the temporary occupation of more than 18% of the territory of Ukraine, including more than 20% of arable and more than 75% of irrigated land, requires the earliest possible implementation of works on the inventory audit of irrigation networks available on the territory controlled by Ukraine. The development of remote sensing (RS), unmanned aerial vehicles (UAVs) technologies, and GIS systems opens up new opportunities for rapid and systematic mapping of irrigation infrastructure – canals, pipelines, pumping stations, etc.

In this regard, the issue of developing a scientific justification for the practical application of remote methods for irrigation systems inventory audit becomes particularly relevant, which creates the necessary prerequisites for faster, higher-quality, and less costly implementation of irrigation systems inventory audit works and auditing the use of irrigated lands. This paper is aimed at improving the methodology entitled *“Inventory of Engineering Infrastructure Facilities of Reclamation Systems and Audit of Reclaimed Lands”* (Institute of Water Problems and Land Reclamation of the NAAS, 2022) [4], which was developed in accordance with the current standards and regulatory documents [5–14]. The improvement concerns the content of Stage II of the survey process for engineering infrastructure facilities of irrigation systems, with the purpose of assessing their technical condition using remote-based diagnostic techniques, in accordance with the algorithm presented in Figure 1.

According to the proposed algorithm, Stage II of the irrigation system inventory audit process involves a preliminary assessment using remote diagnostic methods based on the analysis of satellite imagery, remote sensing data, and other remote monitoring tools. The assessment is aimed at identifying problem areas (their location, presence of direct damage, waterlogged zones, etc.) and evaluating the technical condition of system components. This approach is particularly relevant because traditional inventory methods are labor-intensive, costly, and time-consuming due to the need for extensive field surveys. This complicates the planning of system rehabilitation and modernization measures and hinders decision-making processes related to the restoration and further development of irrigation infrastructure. The scientifically justified application of remote sensing technologies for the inventory of irrigation systems will ensure:

– reduction of time and costs for surveys conduction;

– the ability to cover large areas in a short time;

– increasing the accuracy and objectivity during the assessment of the technical condition of systems’ elements.

Analysis of recent research and publications. Analysis of Ukrainian and international experience shows that remote sensing (remote sensing of the Earth, unmanned aerial vehicles (UAVs), GIS systems, etc.) are widely implemented and used both in scientific research and in the practice of using irrigation systems for:

– assessments of the state of water bodies [15, 16, 17, 18];

– assessment of agricultural lands condition [19, 20, 21, 22, 23, 24];

– assessments of agricultural crops moisture supply [21, 22, 25];

– determination and control of compliance with irrigation regimes [19, 20, 26];

– inventory audit of irrigation systems’ components [27-49].

The use of remote tools for the purpose of irrigation systems inventory audit is at the stage of research and testing of the areas of application. Thus, there is a need for additional studies and adaptation of existing approaches to solving inventory audit problems.

The aim of the paper is to analyze the current state and determine the directions of using remote tools and technologies for irrigation systems inventory audit.

Materials and research methods. The methodology of irrigation system inventory audit involves a set of measures to verify the availability and condition of engineering infrastructure, including hydraulic facilities, networks, pumping stations, etc.

The term “irrigation systems inventory audit” is understood as the process of checking the

Stage I Preparation for surveys conduction (preparatory stage)	- familiarization with the object of survey, its design solution, and engineering survey materials; - study and analysis of design and technical documentation; - drawing up a work program based on the technical specifications received from the customer; - development and compilation of large-scale maps of the surface of facilities; - development of survey route schemes.
Stage II preliminary (visual) field surveys/remote diagnostics	- inspection (remote diagnostics, remote sensing of the Earth) of engineering infrastructure facilities of land reclamation systems, detection of defects and damage by external signs with necessary measurements and preliminary assessment of their technical condition; - description, photography, and drawing on scale maps of objects in the conventional designations of identified damage and defects.
Stage III Detailed (instrumental) field surveys/ remote diagnostics	- instrumental determination of defects and damages parameters; - determination of the actual strength characteristics of the materials of the main load-bearing structures and their elements; - determination of actual operational loads and impacts received by the structures under investigation, taking into account the impact of soil deformations; - development of recommendations for ensuring the required values of strength and deformability of structures with a recommended sequence of works execution, if necessary.
Stage IV Assessment of the sustainability of the reclamation system/ operation of the WUO (modeling, economic calculations)	- determining the required minimum service area of the system, which ensures the return of costs for the operation of the reclamation system and ensures profitable farming; - determining the maximum allowable values of the cost of water supply/water disposal services while ensuring a given level of profitability; - development of recommendations to ensure the sustainable operation of reclamation systems and to ensure the self-sufficiency of newly created WUOs.
Stage V Assessment of damages resulting from military aggression (if any)	- loss determination: - direct losses; - lost benefit from the inability to use both systems and land for their intended purpose.

Fig. 1. Algorithm for organizing inspections of engineering infrastructure facilities of irrigation systems to assess their technical condition [4]

actual presence, condition, and compliance of all components of the irrigation system, such as pumps, filters, pipes, canals, etc., with the design and passport technical specifications.

The main components of irrigation systems that require remote inventory include: water source (rivers, lakes, ponds, reservoirs, groundwater, and other available water sources); water intake facility (pumping station); irrigation network consisting of such structural elements as supplying and regulating network (canals, pipelines), temporary irrigation network for distributing irrigation water to the irrigation modules on fields (canals, pipelines), water collecting and discharging network for collecting and regulating storm-water and discharge water, drainage and collector network, to regulate groundwater levels; hydraulic facilities and water shut-off valves that help regulate water flow and speed; water supply, water retention and regulating facilities; the facilities that are intended for environmental protection purposes; access roads for the passage of equipment and carrying out operational activities; technical buildings and facilities, etc.

The used general scientific and special research methods were logical method, generalization, analysis, tabular method, scientific abstraction, deductive and inductive methods.

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The object of the research is the process of organizing the irrigation systems inventory audit using remote means (tools).

The subject of the research is the scientific, methodological, and practical aspects of using remote tools for irrigation systems inventory.

Research results and their discussion. In the process of analytical research, the types and systematization of the existing scientific and methodological approaches, methods, and technical solutions regarding the possible use of remote means for the inventory audit of irrigation systems were determined, their advantages and limitations were assessed, and the main directions and types of works on the inventory audit of irrigation systems were determined. For the implementation these works the following is proposed to be used.

Satellite/aerial imagery (the most widely used satellites: Sentinel, Satellite, Aerial Imagery, Landsat-8/9, PlanetScope, WorldView-3) should be used for large-scale assessment of irrigation systems. This tool allows to identify networks of canals, pipeline routes, irrigation areas, create a map of networks, and assess the overall condition of the irrigation system in terms of its location and the presence of individual components. Retrospective (archival) satellite images and aerial photographs are an important tool for reproducing the state of irrigation infrastructure and analyzing long-term changes within the system.

Based on the results of the analysis of available sources and the practice of using satellite images and aerial photographs, a list of them with possible paths for using available archival satellite images and aerial photographs for the purposes of irrigation systems inventory audit in Ukraine were formed (Table 2).

A methodical approach for the use of satellite images and aerial photographs,

2. The list and the possible paths of use of satellite images and aerial photographs for the purposes of irrigation systems inventory audit

Satellite	Observation period	Spatial resolution	Characteristics	Reference
CORONA (KH series)	1960–1972	≈2–10 m	Panchromatic images with high spatial resolution. Can be used to detect large canals and earthworks; requires geocorrection.	United States Geological Survey (USGS EarthExplorer) [27] US National Archives (CORONA collection) [28]
KH 9 Hexagon	1973–1984	≈5–10 m	Declassified panchromatic images, large coverage, good spatial resolution; used for detailed survey and assessment of local networks.	US National Archives [28] United States Geological Survey (USGS EarthExplorer) [27]
Landsat (Landsat 1–9, MSS/TM)	1972 – till now	≈60 m (MSS) up to ≈30 m (TM)	Multi-spectral image series: MSS (≈60 m), TM (≈30 m). Gives a chronology of vegetation and water surface changes; easy to integrate with modern data.	Earth Resources Observation and Research Center (USGS EROS) [29] United States Geological Survey (USGS EarthExplorer) [27] Google Earth Engine [30]
Aerial photographs (national archives)	≈ 1950 – till now	depends on the source (starting from ≈1 m)	Varying spatial resolution (from ≈0.5–5 m); often the best option for local detailing, if available.	National Archives of Ukraine; State Geocadastre; local cartographic services
Modern satellites (Sentinel 2, VHR)	2015 – till now	10–20 m (multi-spectral)	Sentinel 2 (10–20 m multi-spectral), commercial VHR (up to 0.3–1 m). Used for validation and combination with archives.	Copernicus Open Access Hub [31]

which involves comparing archival images (CORONA, KH-9 Hexagon, early Landsat series, aerial photo archives), allows to track changes in the functioning of irrigation systems, identify hydraulic facilities, track landscape transformations under the influence of irrigation, erosion or urbanization, and solve other tasks of irrigation systems inventory audit and auditing the use of irrigated lands. E.g., Spanish scientists, based on the research conducted by isardSAT and IRTA using remote sensing data, proposed a method for classifying irrigation methods and types: flooding, sprinkling, drip irrigation, and non-irrigated fields [32]. This methodology allowed the creation of maps of irrigation systems in the region of Catalonia (Spain), which provide detailed information about the state and development (modernization) of irrigation methods in the region, which were previously not reflected in existing databases. This study used various machine learning algorithm models, as well as remote sensing data from SMOS/SMAP, Sentinel-2, and Sentinel-3 satellites, related to evapotranspiration and soil moisture (an indirect tool for determining irrigated and non-irrigated areas).

Researchers from the University of Virginia have developed a machine learning system called IGraSS (Iterative Graph-constrained Semantic Segmentation) to identify critical infrastructure networks (irrigation canals and roads, etc.) from satellite images. The system uses RGB imagery along with additional data such as normalized differential water index (NDWI) and digital elevation models (DEM) [33].

In China [34], archival CORONA imagery has been used to locate and map ancient irrigation systems in desert oases, which are not seen on modern imagery due to sand deposits or hydrology changing. Examples of the use of declassified Hexagon images for detecting various objects of irrigation systems are given in the work of Emily Hammer et al. [35]. The use of a methodological approach based on the combination of Landsat series with modern data and creating the prerequisites for tracking long-term chronology of changes made it possible to create an irrigation map for the USA with a resolution of 30 m [36]. The application of this approach to assessing the history of irrigation development in one intensively irrigated valley in India using multi-year Landsat satellite images made it possible to track the expansion of irrigated agricultural areas and determine the time limits of their increasing [37]. A similar approach (Ask Holm Carlsen et al. [38]) has been used to identify and map closed drainage systems, covering a diverse range of imagery, different data collection periods, and detection methods.

In general, a methodological approach that involves the joint use of archival panchromatic images (CORONA, Hexagon), chronological multi-spectral series (Landsat), modern VHR / Sentinel data and GIS analytics methods allows to recreate the history of changes in the functioning of irrigation infrastructure, identify inactive canals, etc.

The disadvantage of this methodological approach (method) when used for irrigation systems inventory audit is the inability to determine the presence of underground pipelines or closed canals due to the low spatial resolution of the images.

The next group (type) of remote tools that are already in use and whose prospects for use in conducting an inventory audit of irrigation systems are constantly and rapidly growing are *drones / unmanned aerial vehicles (UAVs) with multi-spectral / thermal / video cameras* (the most common models: DJI Matrice 350 RTK, DJI Mavic 3 Multispectral, senseFly eBee X, Autel EVOII Dual Rugged BundleV3, Yuneec H850 RTF/RTK T1). The use of drones makes it possible to perform a more detailed inspection of hard-to-reach areas, which allows obtaining highly accurate geospatial data for identifying canals, pipelines, reservoirs, and hydraulic facilities. The use of drones is especially relevant in countries with a developed agricultural sector, as confirmed by the experience of such countries as Spain, Italy, India, and the USA, where national programs for the digitalization of water management are created based on their use [39].

The use of drones is particularly promising given that by adding different types of cameras to them, their capabilities can be significantly expanded [40, 41]. Thus, equipping drones with RGB cameras allows them to be used for high-quality visual surveying for orthophotos, detecting structures, faults, color/structural differences, etc.; equipping with Multi-spectral (MS) cameras allows calculating vegetation indices (NDVI) and other indices that are useful for determining moisture content and the state of vegetation along the canals; thermal cameras are critical for detecting leaks (temperature anomalies) and differentiating wet areas, and LiDAR cameras are used to obtain digital terrain models (DTM/DSM), determine canal profiles, control erosion, and determine the geometry of structures.

An example of using a drone with a LiDAR camera to highlight the main elements of an irrigation network is the results of research by

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Mahor and colleagues [42]. The methodology used in this study includes the use of high-resolution digital terrain models (LiDAR with an accuracy of 1 meter horizontally and 0.25 meters vertically) and geographic information systems (GIS) tools such as ArcGIS and Whitebox Geospatial Analysis Tools (Whitebox GAT). Some studies have also demonstrated the effectiveness of using drones with thermal imaging cameras to identify leak locations in irrigation systems in vineyards in Portugal [36], the effectiveness of an approach that involves integrating UAV data with historical satellite imagery to map underground pipelines in agricultural regions in Greece [44], and UAV video analysis algorithms for automatic detection of pipeline leaks [45].

Based on the analysis of the state of use and taking into account the available additional equipment for UAVs, the following main areas of drones usage are proposed when carrying out works on irrigation systems inventory audit:

1. Orthophoto mapping and vectorization: photogrammetric processing (creation of orthophotomap, digital terrain model – DTM), vectorization of linear objects (canals, dams, riverbeds). Used to detect only surface hydraulic facilities in [43, 44].
2. Thermal leak diagnostics: TIR imaging detects temperature anomalies that indicate pipeline leaks, flooding, or damage of the canal foundation [36].
3. Multi-sensor combination (RGB + NIR + TIR + DTM) increases the probability of detecting non-metallic elements (PE pipes, small underground collectors) by detecting changes in vegetation or temperature above the route. For example, an approach with a combined UAV-NIR and historical orthophotos was used to detect underground irrigation pipes [45].
4. Automatic segmentation and ML: The use of computer vision algorithms (U-Net, DeepLab, Random Forest for pixel classification) allows automated detection of canals and defects on orthophotos and thermal layers. The essence of the method is that first the analysis and modeling are carried out on modern images, then the model is adapted during the flight and scanning of the UAV for local conditions [38].

Therefore, the main advantages of using drones are their high spatial-temporal resolution, which allows to see small objects and local defects; flexibility and efficiency, which ensures quick execution of research after detecting a suspected problem, as well as saving time and resources by reducing the number of field trips by personnel.

Despite all the feasibility and advantages, the use of drones has many disadvantages that arise during such research (work). One of the main problems is the flight restrictions in many countries, especially in areas near populations or critical infrastructure; the need for permits and pilot certification. Weather conditions (wind, fog, and precipitation) reduce the quality of the footage or make flights impossible. TIR anomalies or indices can be caused by various factors (shadow, soil type), which is why field confirmations are needed. The processing of the large volumes of images requires powerful hardware and knowledge of photogrammetry, also the geocalibration and georeferencing are necessary. For very large networks (thousands of km), using drones alone can be quite costly [32].

Therefore, the use of UAVs should be considered as an effective addition to traditional methods of irrigation infrastructure inventory audit. Combining drones with retrospective satellite data creates the basis for comprehensive monitoring, performance evaluation, and sustainable water resources management.

Remote tool Geo-radar (GPR)/underground scanning (the most widespread models: Mala, IDS GeoRadar, Leica DSX, Bosch D-tect) is a geophysical device that operates on the principles of radar. It consists of transmitting and receiving antennas that emit short pulses of high-frequency electromagnetic waves and record reflected signals from the boundaries of various environments. Analysis of return time and signal intensity allows to allocate the pipelines placement [47]. Geo-radar is one of the most effective methods for locating and mapping underground pipelines, especially for objects made of non-metallic and fiber-optic materials. The effectiveness of the use of GPR directly depends on the electrophysical properties of the environment. The high electrical conductivity of the soil causes signal absorption, which reduces its penetration depth. Pipelines filled with water or pipelines in very wet soil are also difficult to detect.

The widespread and effective use of geo-radars in conducting irrigation system inventory audits is facilitated by the rapid development of machine learning algorithms and 3D reconstruction of GPR data. The use of deep neural networks allows for automatic recognition of hyperbolic imprints from pipes and distinguishing them from noise. In addition, combining geo-radars with remote sensing methods and analytical models opens up opportunities for automated mapping of underground pipelines and irrigation networks.

The use of *tracers* (the most widespread models: Radiodetection, C.Scope, SebaKMT, Sonel LKZ-2500, Leica, RIDGID) and *locators / metal detectors* (the most widespread models: Fisher, Garrett) can be quite effective when carrying out works on the inventory audit of irrigation systems. Electromagnetic location is currently the most widespread method of searching and tracing underground engineering networks. Unlike geo-radars (GPR, pulse reflection), the EM method is based on the principle of electromagnetic induction. The essence of the method is to create an alternating electromagnetic field near the soil surface, which induces currents in metal objects – pipes or cables. By measuring these fields, the receiving device determines the position and depth of the object [48]. This method is characterized by its universality and considerable practicality, as it allows determining the position, schemes, and depth of pipelines, as well as determining their clogging or damage using transmitter probes [49].

The results of the analytical research conducted on the possibility of using remote tools for irrigation systems inventory indicate that their use is possible only with the application of an integrated approach that combines modern geophysical, remote sensing and geoinformation methods and tools and requires the development of scientific and practical justification (tools, implementation methodology, etc.).

Conclusions. According to the results of the research, it was determined that remote tools are most appropriate to use at the second stage of the inventory audit to identify and preliminary assess the condition of the following main elements of irrigation systems: pumping stations, antechambers, open (earthen and concrete) canals, pipelines, hydrants, water distribution facilities, etc.

Based on the analysis, it was determined that the following remote tools can be used to detect and assess the condition of irrigation system elements: Earth satellite observation (optical, multi-spectral, hyper-spectral images); aerial photography from unmanned aerial vehicles (UAVs, drones); geophysical instruments, GPR and EM methods in combination with GIS modeling, geographic information systems (GIS) for integration, analysis and visualization of results.

The analysis also revealed that satellite or aerial photography should be used for large-scale assessment of irrigation systems; unmanned aerial vehicles should be used for detailed inspection of hard-to-reach areas, identification of canals, pipelines, reservoirs and hydraulic facilities, conducting high-quality visual surveys for orthophotos, detecting structures, faults, color/structural differences, leaks in pipelines, flooding or damage of canals foundations; geo-radars should be used for locating and mapping underground pipelines, especially those made of non-metallic and fiber-optic materials, and tracers and metal detectors should be used for locating and tracing underground irrigation networks.

The results of the analytical research of the experience of using remote tools to conduct an inventory audit of irrigation systems allow us to assert that the use of remote tools in combination with geoinformation methods creates additional opportunities for conducting an inventory audit of irrigation systems in Ukraine.

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Use of artificial intelligence: the authors confirm that they did not use artificial intelligence technologies during the creation of this work.

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СТАН ТА НАПРЯМИ ВИКОРИСТАННЯ ДИСТАНЦІЙНИХ ЗАСОБІВ ДЛЯ ІНВЕНТАРИЗАЦІЇ ЗРОШУВАЛЬНИХ СИСТЕМ

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Анотація. *У статті розглянуто сучасні підходи до проведення інвентаризації зрошувальних систем із застосуванням дистанційних засобів. Традиційні методи інвентаризації зрошувальних систем потребують значних фінансових і трудових витрат, що ускладнює проведення масштабної інвентаризації та планування заходів з реконструкції й модернізації систем зрошення. За результатами досліджень встановлено, що дистанційні технології є найбільш доцільними для інвентаризації таких основних елементів зрошувальних систем, як насосні станції, аванкамери, відкриті земляні та бетонні канали, трубопроводи, гідранти, водорозподільні споруди та інші складові інженерної інфраструктури. На основі проведеного аналізу визначено перелік дистанційних засобів, які можуть бути використані для оцінки технічного стану об'єктів зрошення. До них належать супутникове дистанційне зондування Землі, а саме використання оптичних, мультиспектральних і гіперспектральних знімків, аерофотозйомка із застосуванням безпілотних літальних апаратів, геофізичні методи дослідження, зокрема георадарне зондування (GPR) та електромагнітні методи трасування підземних комунікацій, а також геоінформаційні системи для інтеграції, аналізу, моделювання та візуалізації отриманих результатів.*

Дослідженнями встановлено, що комплексний підхід, який поєднує сучасні дистанційні, геофізичні та геоінформаційні методи, створює додаткові можливості для проведення ефективної інвентаризації зрошувальних систем України, підвищує оперативність обстежень, точність визначення технічного стану об'єктів та об'єктивність отриманих результатів. Результати виконаних аналітичних досліджень можуть бути використані для обґрунтування вибору інструментарію та розроблення рекомендацій щодо проведення інвентаризації зрошувальних систем дистанційними засобами.

Ключові слова: *інвентаризація, зрошувальні системи, дистанційне зондування, GIS, БПЛА, супутникові дані*

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