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ANALYSIS OF TECHNOLOGICALLY LOADED TERRITORIES IN THE POLTAVA REGION BASED ON REMOTE SENSING DATA

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Abstract. *In the Poltava region, over the past decades, natural complexes have undergone significant transformations as a result of intensive economic activity. This has led to the formation of potentially hazardous areas where exogenous geomorphological processes are becoming more active and environmental risks to the region are increasing. Systematic monitoring of changes in agricultural landscapes under the influence of technogenic transforming factors makes it possible to promptly identify problem areas, assess the scale of degradation processes, and take timely measures for their stabilization and restoration.*

The article presents an analysis of technogenically loaded areas of the Poltava region, in particular the Poltava and Bilanivka mining and processing plants, tailings storage facilities, the evaporation pond of the Kremenchuk Oil Refinery, the dam of the Kremenchuk Hydroelectric Power Plant, the Makukhivka and Diivka landfills, as well as sites of fires in nature reserves. The tools of remote sensing monitoring used to assess the impact of technogenic transforming factors on the environment are characterized, including band synthesis technologies and InSAR interferometry, the determination of the Modified Normalized Difference Water Index (MNDWI), as well as data processing using Google Earth Pro, Surfer, and QGIS software. The study used data from the Sentinel-1, Landsat-7, and Sentinel-5P satellite missions obtained from the Copernicus Open Access Hub platform, as well as Sentinel-2 radar images downloaded via the Vertex web interface.

Remote sensing methods have demonstrated high effectiveness in detecting and analyzing environmental changes under the influence of technogenic transforming factors. Satellite observations make it possible to assess in detail a wide range of parameters, including surface deformations, vegetation indices, temperature anomalies, moisture changes, as well as the characteristics of soils and water bodies. The geomatics approach is a key element in integrating these data. It enables the combination of heterogeneous satellite and ground-based data within a unified analytical environment, the performance of spatial and temporal analyses, the creation of interactive maps and 3D/4D models, the visualization of change dynamics, and the development of predictive models of technogenically driven phenomena.

Keywords: *analysis of territories, technogenic transforming factors, technogenic-loaded territories, remote sensing methods, satellite observations, geomatics.*

Introduction. The spatial organization of the Poltava region has been formed under the influence of interactions between natural conditions, economic activity, demographic processes, and socio-economic transformations. The region's landscape is characterized by a predominantly flat relief, a well-developed hydrographic network, the presence of numerous rivers and lakes, as well as extensive areas of agricultural land. However, over recent decades, as a result of intensive economic activity, natural complexes have undergone significant transformations, leading to the formation of potentially hazardous areas with active exogenous processes that pose an environmental threat to the region. Systematic monitoring of changes in agricultural landscapes makes it possible to timely identify problematic areas and implement the necessary measures for their stabilization and restoration.

Problem statement. Mapping changes in agricultural landscapes under the influence of technogenically transforming factors is an important tool for rational nature management, environmental protection, assessment and forecasting of the development of natural and anthropogenic processes, as well as for preventing their negative consequences.

Remote Sensing of the Earth (RSE) provides the capability for continuous monitoring of changes in land cover, vegetation condition, hydrological processes, temperature and atmospheric fluctuations, as well as for recording natural disasters over large territories. Owing to multispectral satellite imagery, it is possible to obtain highly accurate information about objects and phenomena on the Earth's surface. To identify change dynamics, modern software enables the analysis of metadata from satellite observations acquired over different time periods. The integration of remote sensing methods with geographic information systems (GIS) makes it possible to promptly acquire, process, and visualize spatial information on the state of the environment, assess natural resources, identify potentially hazardous areas (fires, landslides, unauthorized landfills, etc.), and forecast environmental risks.

The purpose of the article is to analyze territories affected by technogenically transforming factors using Earth remote sensing data.

Materials and methods of scientific research. In the study of technogenically loaded territories of the Poltava region, a comprehensive set of Earth remote sensing methods and geoinformation technologies was applied. Satellite data from the Sentinel-1, Sentinel-2, Sentinel-5P, and Landsat-7 missions were used, obtained from the Copernicus Open Access Hub and Vertex platforms. To ensure spatial and temporal analysis of data processing, the software products Google Earth Pro and Surfer were employed. The main tools included InSAR interferometry, band synthesis, and calculation of the Modified Normalized Difference Water Index (MNDWI). Satellite image classification was performed in Dzetsaka (a QGIS plugin) using the Random Forest algorithm, with prior creation of Regions of Interest (ROI) polygons.

This integrated approach made it possible to comprehensively assess land surface deformations, changes in moisture, temperature anomalies, and the characteristics of soils, forest, and water bodies, which is crucial for timely monitoring and stabilization of agricultural landscapes.

Analysis of recent research and publications.

Technogenically transforming factors are those associated with human activity, primarily industrial production and the use of technological processes, which affect the environment by causing transformations of natural and socio-economic systems. In order to protect the natural environment and ensure the constitutional rights of citizens in the course of potentially harmful activities, a number of regulatory legal acts have been adopted in Ukraine. General regulation of relations in the field of protection, use, and reproduction of natural resources, as well as prevention of the negative impact of human activity, is carried out in accordance with the Law of Ukraine "On Environmental Protection" [1]; control of industrial emissions is regulated by the Law of Ukraine "On Integrated Prevention and Control of Industrial Pollution" [2] and the Methodology for Calculating the Amount of Compensation for Damage Caused to the State as a Result of Excessive Emissions of Pollutants into the Atmospheric Air [3]. Radiation safety is regulated by the State Sanitary Rules "Basic Sanitary Rules for Ensuring Radiation Safety in Ukraine" [4] and the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" [5]. Issues of waste prevention and management are regulated by the Law of Ukraine "On Waste Management" [6].

Scientific studies [7–9] confirm that technogenically loaded territories require special attention from society. In particular, quarrying activities and the operation of facilities of the metallurgical, machine-building, and oil-refining industries cause soil erosion, territorial pollution, disruption of hydrological regimes, and deterioration of water quality. These processes are accompanied by significant deforestation, a reduction in fertile land areas, and, consequently, threats to the ecological sustainability of regions. Elevated levels of dust, noise, and gas pollution pose hazards to living organisms and public health. Ukrainian scientists study the impact of technogenic factors on soil and vegetation conditions, including D. O. Semenov, A. I. Fateiev, K. V. Smirnova, A. M. Shemet, and O. A. Lykova [10]; the analysis of impurity content in atmospheric air is conducted by O. V. Yehorova, V. S. Bakharev, O. A. Mysliuk, and O. M. Khomenko [11]; research on environmental protection technologies and waste management is carried out by O. E. Illiash and Yu. S. Holik [12]. In addition, researchers of the National University "Lviv Polytechnic," under the leadership of K. R. Tretiak, conduct geodetic monitoring of energy facilities, including hydraulic engineering structures [13].

Presentation of the main material.

The assessment of territories affected by technogenic transformative factors was carried out on the basis of an analysis of satellite imagery. Data from the Sentinel-1, Landsat-7, and Sentinel-5P missions were obtained from the Copernicus Open Access Hub platform, while Sentinel-1 radar images were downloaded via the web interface of the Vertex Archive of the ASF DAAC (Alaska Satellite Facility Distributed Active Archive Center).

The simplest way to monitor territorial changes over a long period is to use the Google Earth Pro service. In this way, the impact of agrolandscape transformation on the spatial organization of the territories of the Horishni Plavni, Pryshyb, and Novohaleshchyna territorial communities of Kremenchuk District was assessed, where the mining industry of Poltava Oblast is concentrated.

From 1985 to the present, significant spatial changes have occurred in these territories. A comparison of satellite images from 1985 and 2025 makes it possible to visually identify an expansion of the areas occupied by the Poltava Mining and Processing Plant by approximately 60%, about 30% of which is associated with the development of the Yerystivske deposit, which began in 2006 (Figs. 1–2).

Until recently, the villages of Ostaptsi, Vasylenky, and Bondari existed in the territory of Kremenchuk District; however, due to the development of the Bilanivskyi Mining and Processing Plant, they were completely destroyed and their residents resettled. According to the territorial organization plan for the construction of the Bilanivskyi MPP, the resettlement of fourteen settlements is envisaged (Fig. 3). As of today, the area of mining excavations is about 70 ha, whereas in 2011 it did not exceed 5 ha.

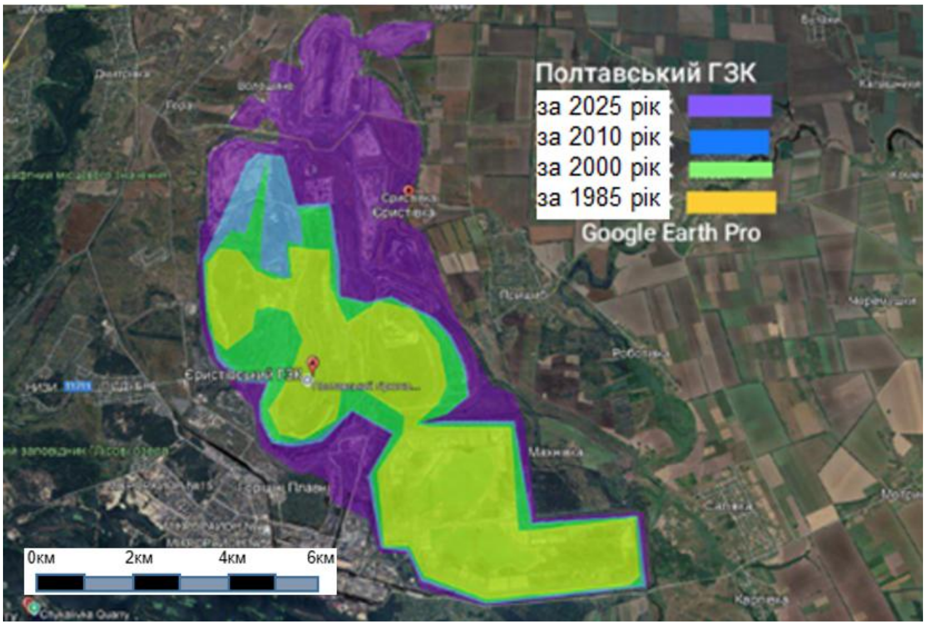

Fig. 1. Dynamics of changes in the area of the Poltava Mining and Processing Plant in 1985–2025 (based on Google Earth Pro data).

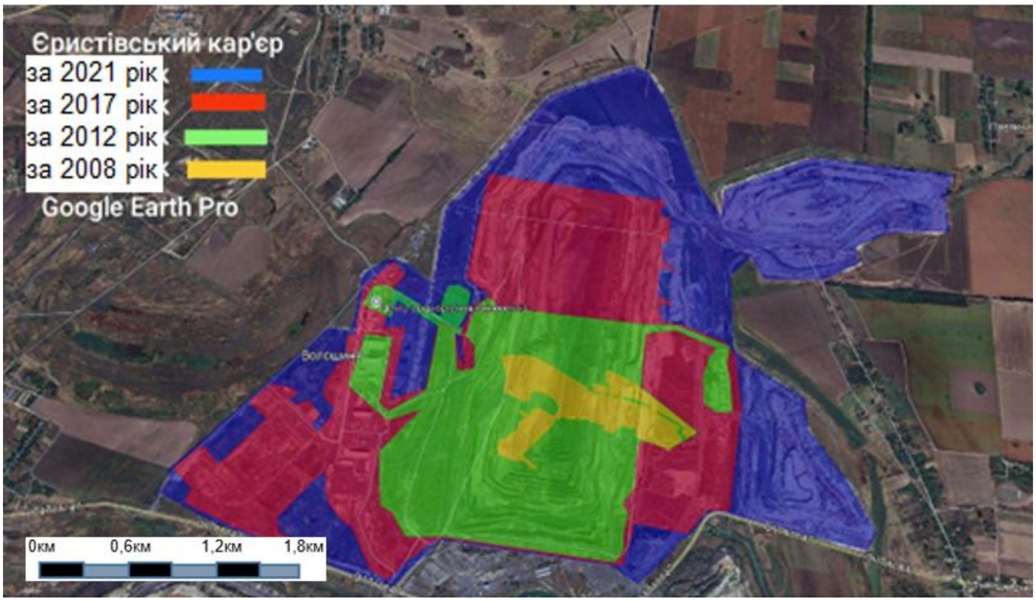

Fig. 2. Dynamics of the expansion of the Yerystivskyi open pit in 2008–2021 (based on Google Earth Pro data).

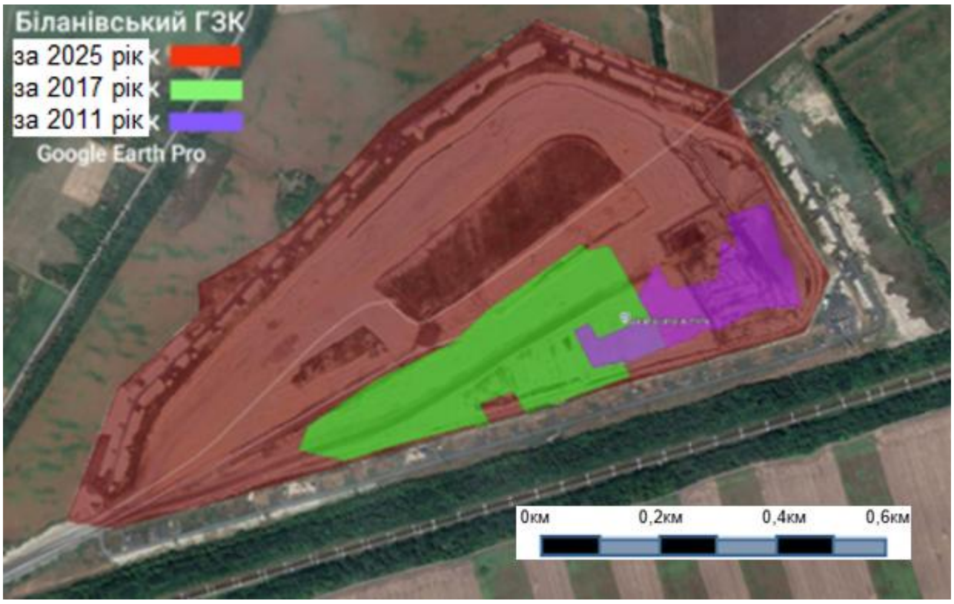

Fig. 3. Change in the area of the Bilanivskyi Mining and Processing Plant during 1990–2020. Source: Google Earth Pro.

However, this problem concerns not only the residents of settlements planned for resettlement. The mining industry also poses a significant threat to adjacent territories. The population of villages bordering the open pits has noticeably decreased. The reasons for this include not only the expansion of mining areas but also the deterioration of the environmental condition, in particular air and water pollution. In areas of open-pit mining, deforestation and disturbance of natural vegetation are observed as a result of stripping operations and the storage of overburden rocks on the soil surface. Large areas of fertile land suitable for agricultural use are withdrawn from circulation. The Bilanivskyi open pit is the deepest in Poltava Oblast; therefore, during its operation a significant amount of rock is brought to the surface, and the areas occupied by waste dumps exceed the area of the pit itself several times. As a result, not only the fertile soil layers within the excavations are disturbed, but also the territories allocated for dumps. Such transformation processes are clearly visible on Sentinel-2 optical satellite images, where the mining area is easily recognizable even to the naked eye (Fig. 4).

Fig. 4. Comparison of territorial changes of the Bilanivskyi MPP during 2011–2021 based on Sentinel-2 satellite images (a – 04.06.2017; b – 07.06.2025).

Mining activities cause intensive inflow of mine and pit waters containing significant concentrations of pollutants—chlorides, sulfates, sulfuric acid, soluble compounds of iron, manganese, copper, etc. Disturbance of the land surface leads to deterioration of its biological, erosion, and aesthetic properties. Open-pit mining has the most pronounced geotoxicological impact of mining production on humans and the environment.

Tailings storage facilities—artificial accumulators of waste from mining and processing industries—are no less dangerous. Their impact is complex and long-term: they cause contamination of soils, surface and groundwater with heavy metals, toxic elements, and acids; create the risk of aerosol pollution due to wind erosion of dried tailings surfaces; and increase the danger of embankment failures and dam breaches, which may result in the release of toxic slurries into water bodies and soils. The persistent nature of such pollution directly affects the quality of life in adjacent communities.

An object of monitoring that poses an environmental risk due to chemical loading is an artificial technogenic water body—the settling pond of the Kremenchuk Oil Refinery on the Rudka River near the village of Bondari. This industrial evaporation pond is used for the accumulation of wastewater, including that containing petroleum product residues. Part of the water evaporates, forming a dust chloride–sulfate mixture that can be transported by air currents over long distances and affect large areas.

To determine the scale of the hazard, remote sensing methods were used to study changes in the hydrological regime of the Kremenchuk Oil Refinery settling pond over the past seven years. For this purpose, a synthesis of bands 3 and 11 was performed using Sentinel-2A satellite images dated April 10, 2018, and April 18, 2025. Moisture maps (Fig. 5) were constructed based on the calculation of the Modified Normalized Difference Water Index (MNDWI), which was determined using the formula [14]:

$$MNDWI = (Band\ 3 - Band\ 11) / (Band\ 3 + Band\ 11).$$

On the thematic maps, open water is displayed in dark blue, moist areas in light blue, while other surface types are shown in light gray. Visual analysis indicates significant drying of the evaporation pond, which suggests an increased environmental risk of hazardous processes and, therefore, requires immediate intervention by environmental authorities to mitigate the situation.

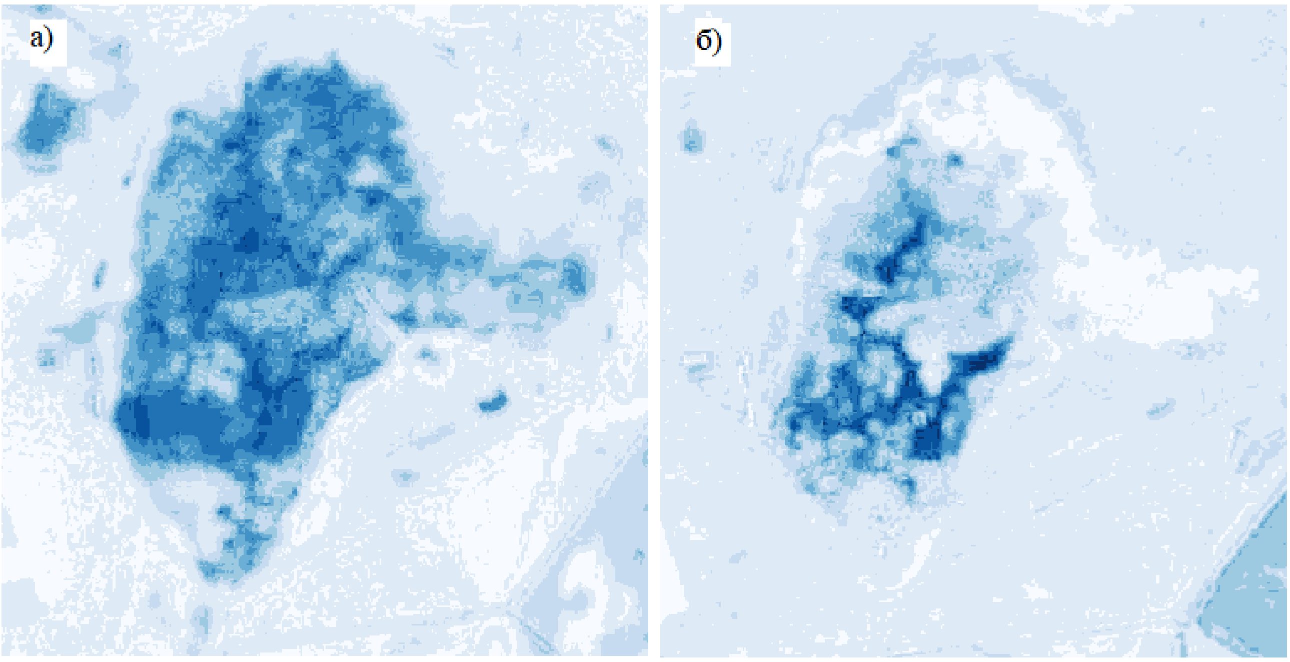

Fig. 5. Comparison of the moisture level of the evaporation pond of the Kremenchuk Oil Refinery on 10 April 2018 (a) and 18 April 2025 (b)

The assessment of territories, buildings, and engineering structures affected by technogenic transformation factors can also be carried out using interferometric InSAR methods. The accuracy of radar observations depends on the selected InSAR technique and can reach up to 1 mm. The use of Differential Interferometric Synthetic Aperture Radar (DInSAR) enables pixel-by-pixel determination of vertical surface deformations. Based on the obtained data, a vertical displacement map is generated in the SNAP software environment [15]. The application of the radar technology PSInSAR, which is based on the analysis of persistent scatterers—points that retain stable radar backscattering characteristics over long periods of time [16]—allows the determination of deformations at individual points using satellite SAR imagery. The derived parameters make it possible to analyze the spatial dynamics of movement across the entire study area.

For modeling a map of isolines of average annual vertical displacement velocities, the dam of the Kremenchuk Hydroelectric Power Plant was selected. As a result of processing satellite imagery using the PSInSAR method for the period from 08 January 2024 to 02 January 2025, a dataset of digitized points containing vertical displacement data was obtained. Further modeling was performed in the specialized geoinformation and cartographic modeling software Surfer (Fig. 6), which enables the creation of three-dimensional surfaces, isoline maps, contour maps, terrain modeling, and spatial data analysis. As a result of radar data analysis, isolines of average annual vertical displacement velocities were obtained, where the maximum value on the concrete part of the dam reaches 5 mm/year, and on the embankment section up to 1 cm/year. This indicates a high level of structural stability of the hydraulic structure. However, to obtain more reliable results and identify long-term deformation trends of the dam, it is necessary to conduct studies over a period of at least three years.

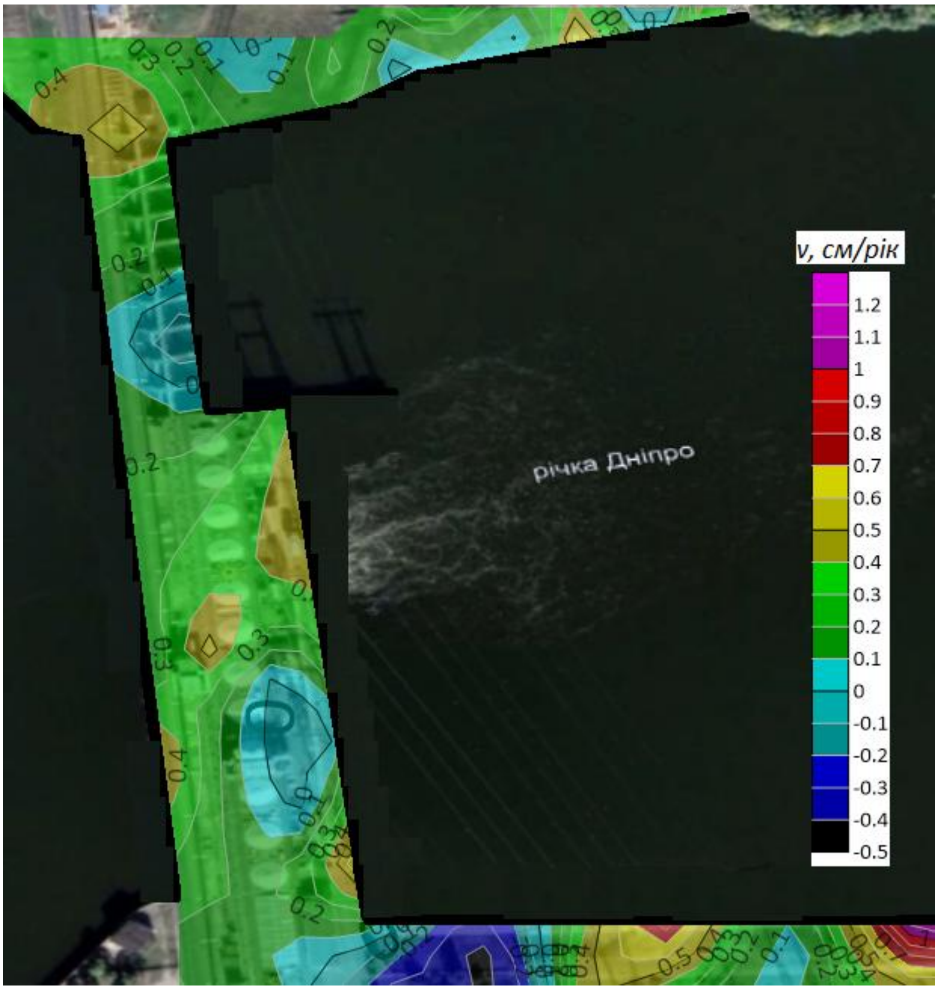

Fig. 6. Isoline map of average annual vertical displacement velocities of the Kremenchuk Hydroelectric Power Plant dam for 2024

Landfills represent a serious environmental and anthropogenic hazard, as they are sources of soil, groundwater, surface water, and air pollution, and also negatively affect landscapes and biodiversity. Most Ukrainian landfills do not meet environmental standards and are overloaded, which increases the risks of the spread of infectious diseases, water contamination, landfill gas formation, and spontaneous combustion of waste. The situation is further aggravated by the war, which has significantly increased the volume of construction and other types of waste. According to the Department of Ecology and Natural Resources of the Poltava Regional Military Administration, there are 334 landfills in the Poltava region [17].

One of the largest landfills in the region is the Makukhivka landfill, located 1.5 km east of the city of Poltava and approximately 600 m from the village of Makukhivka in Poltava Oblast. Currently, the landfill covers an area of 17.34 ha, and the monthly volume of waste received reaches approximately 12,000 tons [18]. The Makukhivka landfill poses significant environmental and technogenic risks to the region; therefore, continuous monitoring of the development of processes within the landfill area is required prior to addressing its reclamation. Emissions of hazardous substances into the atmosphere, including dioxins, furans, methane, and other toxic gases, pose a serious threat to public health. Methane, which is formed as a result of anaerobic decomposition of organic waste [19], accumulates within the waste mass and may break through to the surface, causing explosions and fires. Equally dangerous is soil and groundwater contamination, which negatively affects local ecosystems and agriculture. This occurs due to the formation of leachate—a liquid that percolates through layers of waste and concentrates toxic substances [19]. In the absence of proper protective systems, such as impermeable liners or treatment facilities, leachate penetrates the soil and groundwater and may also enter the Kolomak and Vorskla rivers.

Near the city of Kremenchuk in Poltava Oblast, there is also a landfill located on Deiiva Hill, which has been in operation for more than 50 years—since the 1960s (Fig. 7).

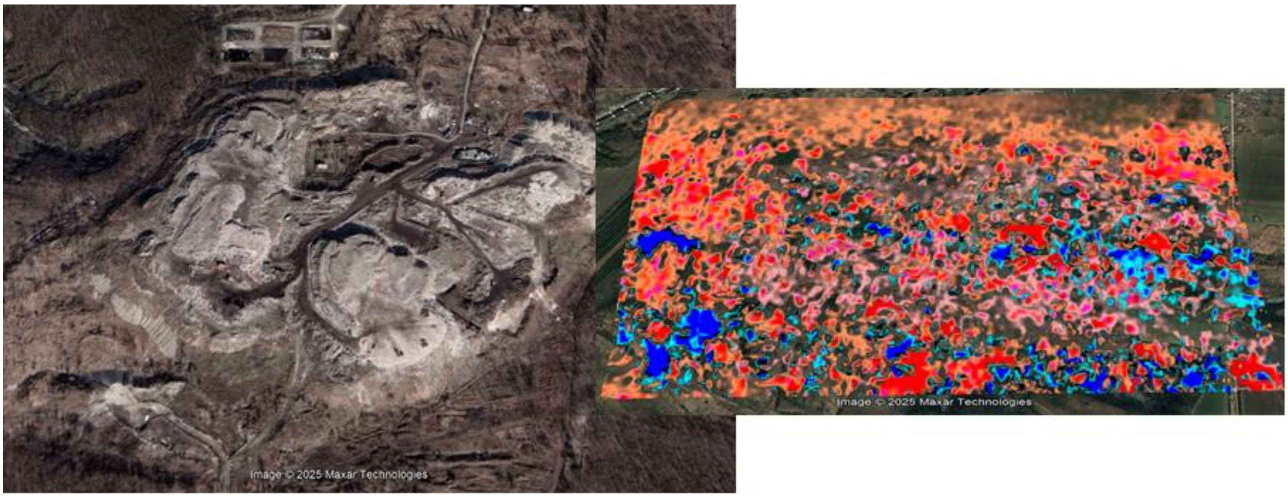

Fig. 7. Landfill on Deiiva Hill near the city of Kremenchuk, Poltava Oblast, and a map of vertical deformations of the landfill for 2019–2021 (visualized using Google Earth Pro)

The area of the landfill exceeds 28 ha, of which approximately 18 ha have already been filled with waste (as of November 2024), accounting for about 60% of the total landfill area. On average, the landfill receives approximately 260 tons of waste per day. Due to the significant load, there are well-founded concerns regarding its further operational longevity.

To assess the condition of the landfill, satellite imagery from Sentinel-1 acquired in SLC IW mode for the period 2016–2019 was used. The resulting map of vertical surface deformations was transferred to the Google Earth Pro software environment. The image (Fig. 7) demonstrates a complex deformation structure across the landfill area. Uplift processes predominate (indicated in red), which is likely caused by active biogas accumulation. At the same time, the presence of localized subsidence zones (shown in blue) indicates the heterogeneity of processes occurring within the landfill body.

Remote sensing methods represent a powerful tool for assessing the environmental impact of landfills. Satellite and aerial data enable the acquisition of detailed imagery over large areas without the need for direct field measurements. Using remote sensing, key parameters of technogenic load can be determined, including the size and configuration of landfills, the dynamics of their temporal changes, ground deformations, levels of soil and water pollution, atmospheric contamination, and impacts on vegetation cover. In addition, remote sensing methods make it possible to detect zones of spontaneous combustion, which is an extremely relevant task, as landfill fires occur almost annually in many regions.

Satellite observations also enable the detection of forest fires, which are a widespread phenomenon globally, including in Ukraine. In the Poltava region, the number of forest fires has increased compared to previous years. One of the most recent fires began on 15 September 2024 near the village of Mala Pereshchepyna and, according to official data, affected approximately 700 ha. As a result of the fire, nature reserves of both local and national significance were damaged.

Satellite data made it possible to conduct environmental monitoring of the affected area. Using Landsat 8–9 imagery and a custom script with a 7-5-3 band combination, fire spread pathways were identified. A comparison of visible-spectrum imagery with the Thermal band revealed a sharp increase in land surface temperature during the fire event (Fig. 8). In addition, satellite data detected elevated concentrations of nitrogen dioxide, which were transported toward the city of Cherkasy, polluting the atmosphere along their path.

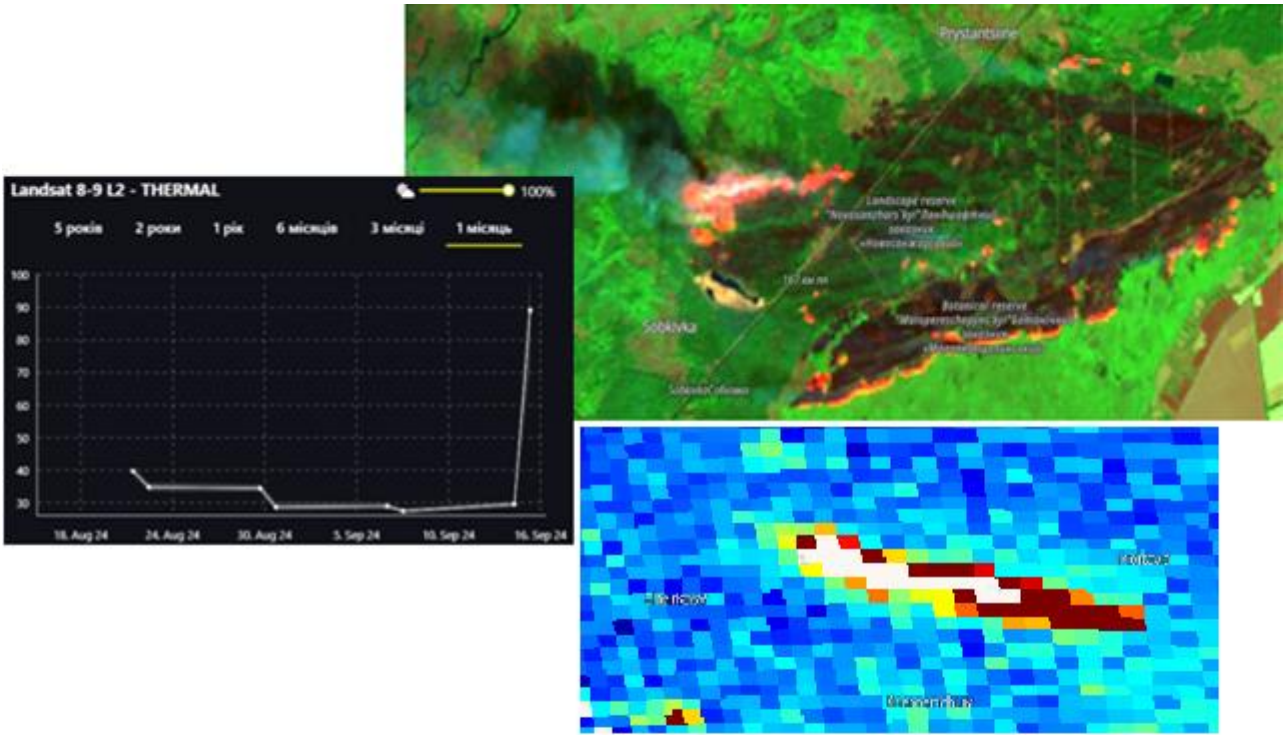

Fig. 8. Forest fire in the Poltava region on a Landsat 8–9 satellite image

Satellite imagery enables detailed analysis of damaged areas. In the QGIS geographic information system, object classification was performed using the Dzetsaka plugin, resulting in a color raster with clearly delineated zones: burned areas (red), damaged coniferous forest (dark red), undisturbed forest (green), and other land cover classes (purple and yellow) (Fig. 9). Based on the classification results, it was determined that 694.28 ha of territory were burned or partially damaged. The affected sites include the nationally significant botanical reserve Malopereshchepynske Swamp, the Novosanzharskyi landscape reserve, as well as the settlements of Sobkivka, Balivka, and Prystantsiine.

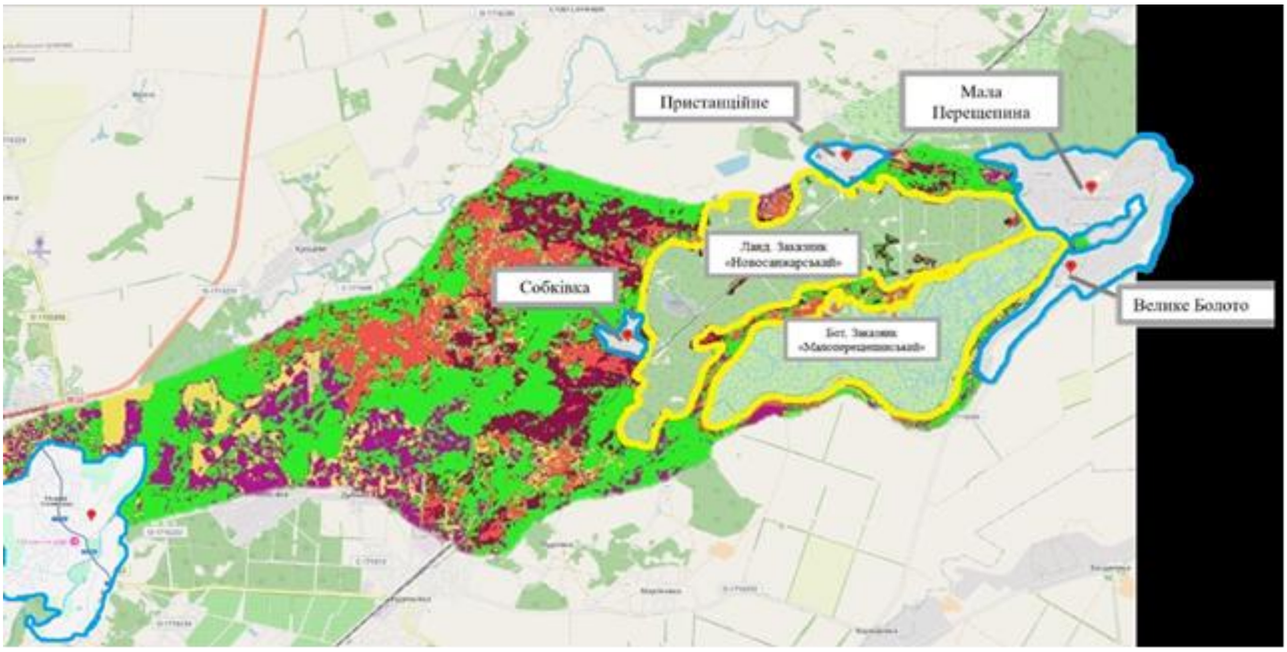

Fig. 9. Analysis of the territory affected by a natural disaster using remote sensing monitoring methods

Conclusions and Recommendations. As a result of the conducted study using Earth observation (remote sensing) data, a number of important conclusions were obtained regarding the analysis of the impact of technogenically transformed factors on the territory of the Poltava region It was established that the activities of mining enterprises cause significant and progressive degradation of the natural environment. Among the most substantial negative consequences are: the allocation of large land areas for waste rock dumps, tailings storage facilities, and reservoirs for highly mineralized mine and quarry waters; alteration of terrain due to blasting operations, accompanied by rock fracturing, deforestation, and surface deformations; disturbance of hydrogeological conditions; contamination of surface and groundwater, including the transport of toxic elements and salts; air pollution by dust and gas emissions; changes in the composition and physicochemical properties of the atmosphere and hydrosphere (acidification and salinization); soil degradation; and increased noise and vibration loads.

Remote sensing methods have demonstrated high efficiency in detecting and analyzing changes caused by landfill activities, as well as in assessing the consequences of forest fires. Radar interferometry (InSAR) enables modeling of surface deformation processes, which is crucial for assessing territorial stability, forecasting landslides, and identifying other hazardous geological phenomena. In addition, satellite observations provide opportunities for detailed environmental assessment, including soil pollution evaluation, water quality monitoring, vegetation monitoring, detection of atmospheric anomalies, and identification of changes in natural ecosystems.

To obtain the most reliable information, it is advisable to combine different Earth remote sensing methods and, where possible, compare them with ground-based observation techniques.

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АНАЛІЗ ТЕХНОГЕННО-НАВАНТАЖЕНИХ ТЕРИТОРІЙ НА ПОЛТАВЩИНІ ЗА ДАНИМИ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ

Анотація. *У Полтавській області протягом останніх десятиліть унаслідок інтенсивної господарської діяльності природні комплекси зазнали суттєвих трансформацій. Це призвело до формування потенційно небезпечних територій, де активізуються екзогенні геоморфологічні процеси та зростає екологічна небезпека для регіону. Систематичний моніторинг змін в агроландшафтах під впливом техногенно-трансформуючих чинників дає змогу своєчасно виявляти проблемні ділянки, оцінювати масштаби деградаційних процесів та оперативно вживати заходів для їх стабілізації й відновлення.*

У статті проведено аналіз техногенно-навантажених територій Полтавської області, зокрема Полтавського та Біланівського гірничо-збагачувальних комбінатів, хвостосховищ, ставка-випарника Кременчуцького нафтопереробного заводу, греблі Кременчуцької ГЕС, Макухівського та Деївського сміттєзвалищ, а також місць пожеж у заказниках. Охарактеризовано інструменти дистанційного моніторингу для оцінки впливу техногенно-трансформуючих чинників на довкілля, зокрема технології синтезу каналів та інтерферометрію InSAR, визначення модифікованого нормованого диференційованого індексу вологості (MNDWI), а також обробку даних у програмних продуктах Google Earth Pro, Surfer та QGIS. Для досліджень використано дані супутникових місій Sentinel-1, Landsat-7 та Sentinel-5P, отримані з платформи Copernicus Open Access Hub, а також радарні знімки Sentinel-2, вивантажені через вебінтерфейс Vertex.

Методи дистанційного зондування Землі продемонстрували високу ефективність у виявленні та аналізі змін довкілля під впливом техногенно-трансформуючих чинників. Супутникові спостереження дають змогу детально оцінювати широкий спектр параметрів: деформації земної поверхні, вегетаційні індекси, температурні аномалії, зміни вологості, а також характеристики ґрунтів і водних об'єктів. Геоматичний підхід є ключовим елементом інтеграції цих даних. Він дозволяє поєднувати різнорідні супутникові та наземні дані в єдиному аналітичному середовищі, виконувати просторовий *та часовий аналіз процесів, візуалізувати динаміку розвитку техногенно зумовлених явищ.*

Ключові слова: *аналіз територій, техногенно-трансформуючі чинники, техногенно-навантажені території, методи ДЗЗ, супутникові спостереження, геоматика.*