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GEOMATIC MONITORING OF ENVIRONMENTAL HAZARDS IN TECHNOGENIC-LOADED TERRITORIES

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It was noted that the territory of Eastern Ukraine is saturated with potentially dangerous industrial facilities and areas with geodynamic processes that require constant control and monitoring to detect deformations. Geomatic methods and tools were proposed for a comprehensive assessment of deformations, indicators of environmental threats in technogenically loaded territories. The choice of the geomatic monitoring system depends on the type of environment and the direction of research. Visualization of the content of chemical substances, gas concentration, temperature, humidity, precipitation can be carried out through the interfaces of the Giovanni platform. Landsat, Sentinel-2, MODIS space images are processed to classify land cover objects, change their boundaries, monitor vegetation cover, analyze the geological structure, identify the dynamics of water and wetland objects, the scale of floods and inundation; SIR - C/X - SAR radar images are processed to *determine the location of urban areas and individual buildings, to emphasize the relief of mountainous areas, to control the pollution of water bodies' surfaces; SRTM digital terrain models are processed to determine terrain characteristics. Observation of the deformation of the Earth's surfaces and construction of displacement maps is performed by the InSAR satellite radar method, which is based on the use of space images from the Sentinel-1 spacecraft. To clarify the identified problem areas, it is necessary to jointly use the ground-based geodetic methods of monitoring the deformations of technogenically loaded territories. Processing of the received data is carried out in various geoinformation systems ArcGIS, QGIS, Google Earth, Digital; the land subsidence estimation using Sentinel-1 Data in SNAP, the landslides detection using Sentinel-1.*

It was proposed to consider methods of geomatic monitoring of territories as a system that includes ground-based geodetic methods, remote sensing of the Earth and geographic information systems (GIS). This approach will make it possible to study territories, in particular the state of the Earth's surface, depending on the conditions of its functioning.

The article states that geomatics monitoring is carried out to neutralize threats, to restore natural resource potential, to ensure geopolitical, ecological, security and military stability.

Key words: *deformation of the Earth's surface, geoinformation systems, geomatics, monitoring, satellite radar, technogenic-loaded territories.*

Introduction. Military aggression in Ukraine and military actions led to numerous technogenically loaded and ecological disasters in a third of the territory. Buildings and structures of various purposes were damaged, partially or completely destroyed, including roads, railways, water and sewage systems, oil and gas pipelines, etc. There are constant technogenically loaded threats to critical and military infrastructure, including energy facilities and hydraulic structures. This requires monitoring with modern geomatics tools and methods, reassessment of forecasts and warnings of environmental disasters and deterioration, increasing the stability of objects and reducing their vulnerability.

Definition of unsolved aspects of the problem. The article provides a geomatic analysis of the current situation, proposes measures and technologies for monitoring, forecasting and further development of the security environment in Ukraine that is resistant to external threats and military and other geopolitical challenges. The war requires a rethinking of state geodetic work, internal monitoring, environmental and economic policies and the adoption of a strict system of regulation in the field of geodetic monitoring, rational use of territories, spatial development and construction.

The purpose of the article is to conduct geomatic monitoring of technogenically loaded territories of Central and Eastern Ukraine to identify potential threats and ways to improve their stability, predict safety and reliability.

Analysis of the latest scientific research and publications. According to scientists, geomatic methods can be considered as an effective tool for providing specific engineering solutions for monitoring the surrounding area. These methods play a crucial role in the assessment and management of risk through the occurrence of natural events (earthquake, displacement, etc.), or for the monitoring of anthropogenic activities [1].

Scientists pay attention to the methods of constructing an automated system for monitoring polluted and disturbed lands as the result of military and industrial use and their subsequent conversion [2]. Scientific studies have identified more destructive geohazards in terms of environmental monitoring, covering the current state of the use of geospatial technologies [3]. In scientific papers, the experience of using geographic information systems (GIS) to ensure the design, creation and functioning of nature conservation areas in Ukraine was considered [4]. Attention is primarily paid to the characteristics, opportunities and limitations of monitoring and evaluation. Three types of monitoring and evaluation are considered: - environmental audit; state of the environment reports; geomatics, or geographic information system (GIS), monitoring and evaluation [5]. On the example of the city of Kyiv, new possibilities for deciphering, identifying and interpreting Earth remote sensing data and operational geospatial models of the ecological observation infrastructure network were presented and reproduced [6]. Based on the analysis of spatio-temporal series of data from space surveys of the thermal range and digital elevation models, the development of areas of flooding and flooding in certain areas of Kyiv is predicted. The main cause of flooding is the relief of the city and the violation of the natural filtration of storm water as the result of urban development [7]. Landscape monitoring during climate change is an extremely important issue. With the help of remote sensing, based on the thresholds for the difference in estimates in time intervals covering a 20-year period of time, an assessment was made of the sensitivity to land degradation of the Mediterranean region, which is one of the main global candidates for the development of desertification phenomena [8]. The analysis was carried out on the basis of the MEDALUS (MEditerrean Desertification and Land Use) model, developed as part of a special European project. The model parameters were implemented and then processed using a GIS-based approach to estimate the soil quality, climate, management and vegetation factors required as inputs for the ESA assessment [9]. [10] presented the aquifer vulnerability methodology for the theory and application of flow accumulation, land use, and hydraulic conductivity; the aquifer vulnerability was assessed using the F-hydra model. [11] carried out coastal vulnerability modeling in South India: a multi-parameter approach using remote sensing and GIS.

The significant contribution to the development of theoretical and practical issues of studying geodynamic processes, organizing geodetic monitoring, introducing the latest technologies, optimizing observation schemes and methods, processing and analyzing results, and predicting deformations were made by K. Tretiak, I. Trevoho, K. Burak, P. Cherniaha, S. Voitenko, A. Moroz, A. Ostrovskyi, A. Maznytskyi, V. Starovierov, O. Heunecke, F. Sanso, A. Ferretti, A. Mouratidis, F. Costantini, X. Chen, G. Tessari, M. Fabris, V. Achilli, A. Hooper, E. Brockmann [12-22], etc. The problems of scientific and practical confirmation of the possibility of safe work execution and the use of technogenically loaded territories were raised in the works [23], where the main conclusion was the need to accurately predict the further geodynamic development of such territories.

Basic material and results. On February 24, 2022, Ukraine entered a new stage of global history, attracting the attention of the world community and becoming one of the leading subjects of world politics. Ukraine's status as a candidate for EU membership requires the country to increase its institutional efforts, introduce measures and tools to preserve environmental, economic and military stability, relying not only on external assistance, but also strengthening its own in the field of infrastructure development and placement, settlement systems and industrial sustainability and civil engineering. Given the geopolitical challenges, Ukraine must strengthen national security and create a safe environment for the population.

As a result of climate change, anthropogenic impact and military operations, there is a negative impact on the environment. There is a development of dangerous geological actions (underflooding and flooding); pollution of territories, including nature protection ones; land degradation leading to desertification phenomena; pollution of water resources; deformation of the Earth's surface.

With the beginning of the full-scale invasion of the aggressors on the territory of our state, technogenically loaded territories, especially Central and Eastern Ukraine, were in the danger zone. Territories that have a significant anthropogenic impact on the environment are considered technogenically loaded. The impact is always associated with changes in the natural landscape with subsequent negative consequences, such as the contamination of territories with various emissions, the occurrence of technogenically loaded environmental crisis phenomena, accidents and catastrophes. To neutralize threats, a monitoring system is needed, which is a component of the national information infrastructure, created for observation, collection, processing, transmission, storage and analysis of information about the state of the environment, forecasting its changes and developing scientifically based recommendations for preventing negative changes in the state of the environment and complying with requirements security [24]. The development of information technologies constantly changes trends in the organization and methods of monitoring.

Geomatics is defined as a systematic, comprehensive approach to the selection of tools and appropriate methods for the collection, storage, accounting, modeling, analysis, on-demand retrieval, transformation, display and dissemination of spatially bound data from various sources with defined characteristics of accuracy, continuity and in digital format. Geospatial technologies, including geographic information systems, remote sensing - Earth observation, as well as related spatial data analysis tools, models, databases, today make a significant contribution to the prediction, prevention, research, solution, rehabilitation and management of these phenomena and their consequences [25]. Geomatic monitoring is difficult to imagine without the use of remote sensing data, as well as GIS processing. Since the object of research can be studied in dynamics, over the past few years this has led not only to visibility, but also to the possibility of obtaining new information as a result of data analysis [26]. Satellite images can be used to perform various thematic tasks, such as the study of natural resources, the implementation of balanced management of these resources, the detection of environmental and environmental violations, and for geodetic purposes, the satellite radar method can be used to monitor the displacements of the Earth’s surface [20, 27].

The use of technogenically loaded territories requires an individual approach to the issues of geomatic monitoring, in particular, deformations of the Earth's surface and the state of disturbed lands. In conditions of war, access to such territories becomes more difficult. There is a need to use modern approaches to conducting geomatic monitoring of technogenically loaded territories, in particular, remote determination of displacements of the Earth's surface, for their further assessment and determination of the state of lands under critical infrastructure.

According to the authors, the existing research methods, in particular, ground-based geodetic methods, remote sensing of the Earth and geoinformation systems, should be considered as components of a system of methods for geomatic monitoring of technogenically loaded territories. This approach will allow us to study the state of the Earth's surface depending on the conditions of its functioning.

Technogenically loaded territories are all Dnipro hydroelectric nodes [28], which in case of destruction can cause both local and geo-scale technogenic risks and threats for Central and Eastern Ukraine.

There are more than fifty reservoirs in Ukraine, the largest of which are cascade reservoirs on the Dnipro River. These are six reservoirs: Dnipro (water surface area 410 km2), Kamyanske (567 km2), Kaniv (582 km2), Kyiv (922 km2), Kakhovka (2155 km2) and Kremenchuk (2250 km2), which were created during 30 - 70s of the XX century [29]. The breach of the Kakhovka HPP dam on June 6, 2023 led to serious consequences: the flooding of about 80 settlements on the Left Bank of the Dnieper, the death of people and animals, a mass plague of fish, a change in the course of the river, and the destruction of biosphere reserves in the Kherson region. The agrarian sector of the Kherson region, where crops were harvested twice a year, was also affected. Many irrigation canals, from which irrigated areas were cultivated, were destroyed. The area of cultivated land will decrease and the yield will decrease, and this is a huge threat for the whole of Ukraine, because the Kherson region had the largest amount of arable land before the war. There will be waterlogging of the drained lands below the Dnieper, soil degradation, part of the woody vegetation will die, which restrained the phenomenon of coastal erosion and the spread of ravines and ravines. Enterprises in Nikopol and Marhanka of the Dnipropetrovsk region were threatened with shutdown. Water poisoning will occur as a result of the decomposition of fish, the washing of a large amount of fertilizers from fields, pesticides, landfills in flooded settlements, industries and factories. The waters of the Dnieper in the lower reaches, as well as parts of the Southern Buh and Inhulets, will become unsuitable for drinking and use in agriculture [30].

With the help of GIS technologies, the technologist and writer Lars Wildereng presented the simulation of worst-case scenarios in the event of the destruction of the Kakhovka hydraulic unit [31]. If the locks are blown up, i.e. 200 m long out of the total 3,500 m, another 400–1,800 m will be demolished. A wave with a height of 4–5 m will reach the Antoniv bridge east of the city of Kherson in 19 hours, after which the Inhulets River will begin to flood. and after 4–5 days - the overflow of the Bug River to the city of Mykolaiv. The following simulation of the worst-case scenario of a dam breach was carried out by the Swedish hydrological engineering company Dämningsverket. Modeling was performed using the US Army Corps of Engineers (USACE) HEC-RAS 6.3 software. Terrain data were obtained as part of NASA's Shuttle Radar Topography Mission (SRTM) program and are available on the USGS website [31]. It was assumed that the level of the dam would be 13 m above the level of the lower reaches of the Dnieper and that the breach of the dam would expand to a width of about 200 m within an hour. The simulated peak flow will reach 14,000 m3/s of water, which is comparable to the average Niagara Falls flow of 2,400 m3/s and the Dnieper average flow of 1,670 m3/s. On the left bank of the Dnieper, the flood will be much stronger.

We are following a similar disaster in the Kyiv region on the Irpin River, where the villages of Demydiv, Kozarovychi, Huta-Mezhyhirska, Chervone, Moshchun, Horenka, and the village of Hostomel were flooded as a result of the explosion of the Irpin hydroelectric plant [32]. Since the Irpin River is 6 m below the level of the Kyiv Reservoir, this caused a large-scale spill of water up to 1 km from the administrative border of the city of Kyiv. Part of the flooded territories consisted of plowed and treated with fertilizers that dissolved in water, agricultural lands, part of the flooded territories consisted of unauthorized and authorized landfills of solid household and industrial waste, part of them consisted of construction sites and warehouses of building materials located in the floodplain of the Irpin River. After identifying the flooded objects in the QGIS software, according to the processed space images it was revealed that the total flooded area (Fig. 1) is 2165 hectares, not taking into account the territories of settlements and adjacent territories where the soil became saturated with water, there was a significant rise of the soil and upper aquifers horizons.

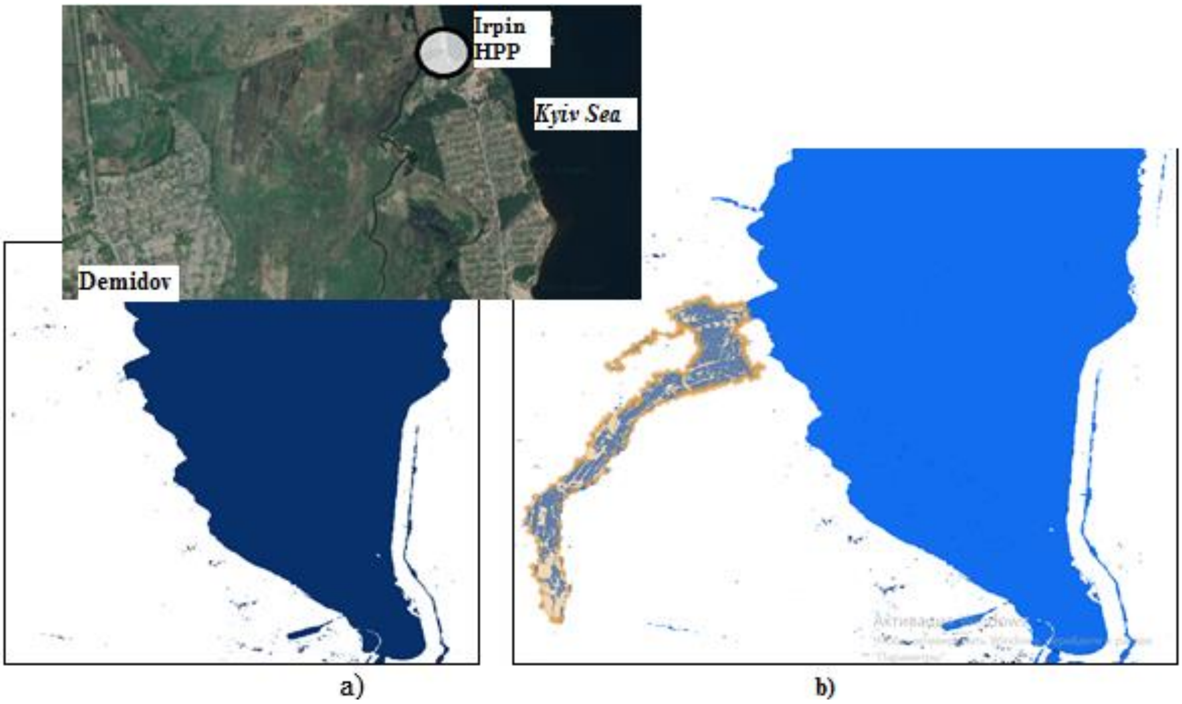

Figure 1 – Processed space images of the Kyiv Reservoir:
a) November 1, 2021; b) March 21, 2022

On September 14, 2022, enemy missiles hit the hydraulic facilities of the Karachun Reservoir in Kryvyi Rih. There was a threat of spilling 290–300 million m3 of water, but thanks to the partial damage of the dam, only more than 8 million m3 of water spilled and only the private sector of the city was flooded [33].

According to the conducted geomatic monitoring, the area of territories of possible flooding by the reservoirs of the Dnipro, in addition to 702 thousand hectares of the surface of the reservoirs themselves, reaches from 350 to 500 thousand hectares. Military actions can de-energize the existing 27 operating pumping stations that constantly pump water from rivers and streams, filtered water into the Dnipro.

The problem is particularly acute in the area of the Obolon dam (Kryva Ruda River) and the city of Kremenchuk in the Poltava region. In case of shutdown of pumping stations, up to 120,000 hectares will be flooded or completely flooded only in the Poltava region.

Violations and the need for constant monitoring of retaining walls and collapses at sludge storage facilities, the height of which reaches more than 10 meters (at the Poltava mining and processing plant) and in case of flooding or undermining, the sludge will flow into the Dnipro River, which will cause an ecological accident and turn into an ecological disaster, pose a high threat.

Despite the negative processes in the reservoirs themselves, according to the data of remote studies, it was revealed that the reservoirs carry out cyclic and constant support of groundwater, surface water, which contributes to the rise of the Earth's surface in the zone of influence of the reservoirs. This is especially observed in the Cherkasy region on the Right-bank Ukraine, where the elevation of the upper layers of the soil can be 5-15 cm. At that time, the Left-bank Ukraine can have subsidence of up to 5 cm (Fig. 2).

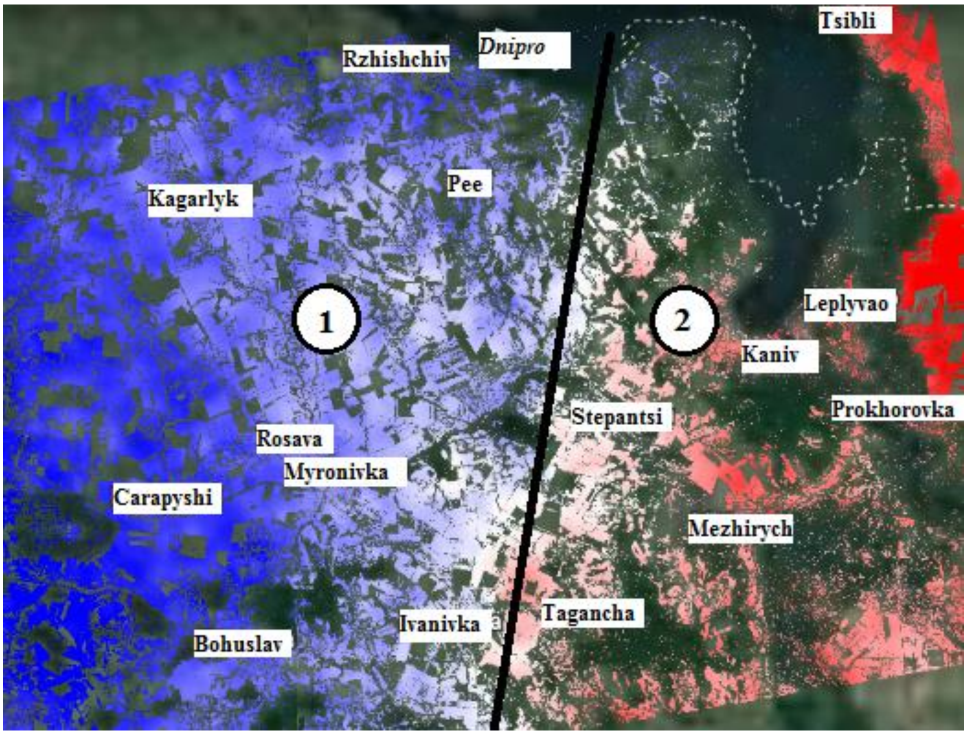

Figure 2 – Cartogram of vertical displacements of the Earth's surface on the territory of the Cherkasy region (between two snapshots from 11/02/2020 and 11/14/2020): 1 – raising of the upper layers of the soil, 2 – their lowering

Geomatic monitoring of the territory around the Kaniv Reservoir is performed on the basis of Sentinel-1 data processing in the SNAP (Sentinel Application Platform) software. Interferometric processing of data and construction of displacement maps using satellite radar can be carried out by various methods and tools. For work, radar images uploaded to the Copernicus Open Access Hub web platform, which was developed by the European Space Agency under the Copernicus program, are most often used. SNAP software can also process snapshots uploaded to the Vertex ASF Data Portal and SSARA.

Satellite monitoring of the territory of Ukraine revealed numerous ups and downs of land, both seasonal and permanent. These movements not only worsen the natural fertility of lands, the quality of drinking water in aquifers, but also negatively affect built-up areas, buildings and structures.

On the territory of the Donetsk region, in the area where a significant number of mines are located, there is a slow subsidence of entire soil massifs. According to Fig. 3 annual subsidence of parts of the Earth's surface is up to 5 cm/year (highlighted area).

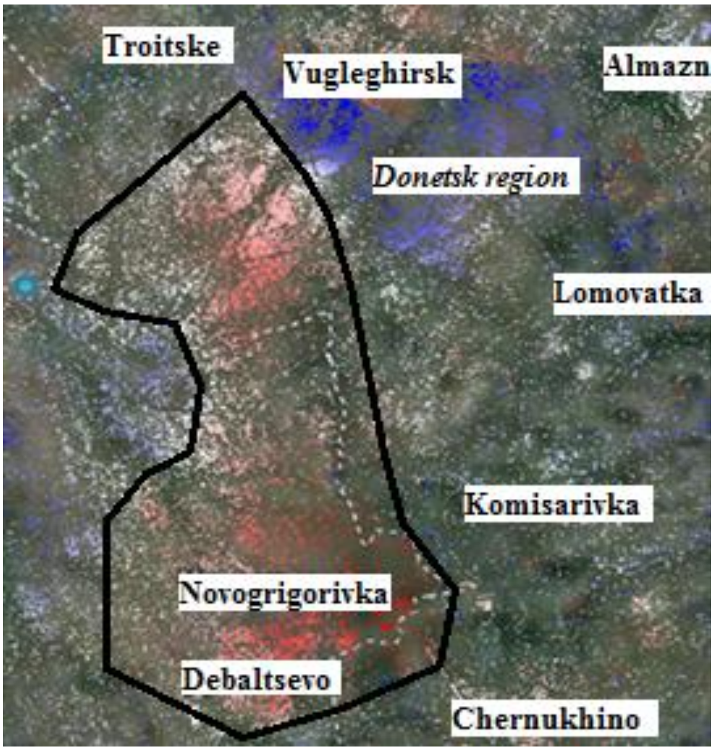

Figure 3 – Cartogram of vertical deformations of part of the Donbas territory

The cartogram of vertical deformations is presented for the period 20.08.2021 - 27.08.2022. According to previously conducted research [34], the Earth's surface should be subject to slow annual fluctuations. In the first half of the year, the soil is raised, and in the next half year, the soil is lowered, that is, in a year, the surface points must return to their original position.

The geodynamics of the Earth's surface in towns and cities in the zones of active activity of the extractive industry indicates significant subsidence of individual territories, micro-faults, violation of the integrity of sedimentary rocks, leaching of salt domes, loss of huge reserves of underground fresh water that have accumulated since the Ice Age and are a particularly valuable national resource.

Increasing requirements for the accuracy of determining geodynamic parameters, continuous improvement of models cause the need for a comparative analysis of different strategies for processing observations. Since each of the measuring technologies has its own characteristics and advantages when determining various parameters, an optimal combination of various tools of observation is necessary. The most reliable results are obtained during joint processing of various types of observations. In order to determine the deformations of the Earth's surface in such technogenically loaded territories, the combined development of radar and ground geodetic methods is necessary.

Terrestrial geodetic methods include traditional geometric and trigonometric leveling, construction and determination of elements of spatial linear-angular networks of triangulation and trilateration; processing of the results of GNSS networks, terrestrial laser scanning and terrestrial photogrammetry [13, 16, 17, 21, 26, 34, 35]. Office processing of measurements can be carried out on the basis of various software products: Delta/Digitals («Geosystem»), Leica Infinity, Cyclone, CloudWorx (Leica Geosystems); Dipsos, RealWorks Survey (Trimble); VoidWorks, I-Site Studio (I-Site Pty Ltd.); Focus Inspection, Focus reverse engineering (Metris); CREDO 3D Scan (Credo); PolyWorks/Modeller, PolyWorks/Inspector (InnovMetric Software); RapidForm2006, RapidFormXO (INUS Technology); Scene Vision 3D (3rdTech); 3D-Extractor (Callidus Precision Systems); Faro Scene (Faro Technologies Company); RiSCAN PRO (Riegl Laser Measurement Systems); Z+F LFM Modeller (Zoller+Froehlich GmbH); Reconstructor (Topotek Survey Technologies); PointCLoud (KUBIT GmbH); Studio (RainDrop Geomagic) and etc.

All the listed methods of geodetic research can complement each other. Satellite radar is effective over large areas, when a general trend of displacement can be observed. Further, having identified dangerous areas, having in the arsenal the most available technologies and tools for determining the deformations of the Earth's surface, it is possible to obtain fairly accurate geodetic results for individual points. Satellite radar is convenient to use, especially for surveys of dangerous areas, in particular combat zones, since with the help of remote monitoring, without leaving the area, it is possible to detect terrain shifts of various kinds and types. For example, by remotely "scanning" an area near the town of Popasna, Donetsk region, one can see a large number of disturbed lands, so-called explosive «funnels», which reach a depth of 5-8 meters and a diameter of up to 50 meters (Fig. 4).

In the zone of the military actions there is physical destruction of the surface fertile layer not only due to explosions, but also through the construction of defensive structures. Disturbed lands occupy hundreds of square kilometers, and losses of agricultural production as a result of the impossibility of technical reclamation and restoration of the fertile layer to the previous state reach billions of hryvnias [36]. The composition of the soil is worsened by both metal and non-metal fragments, objects that, without the removal of large residues and inclusions, do not allow to cultivate the fields.

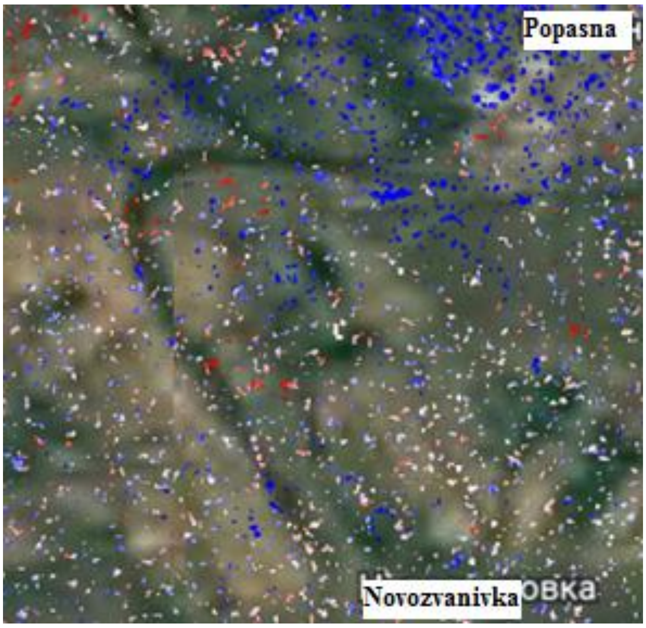

Figure 4 – Detection of landslides in the zone of active military actions (processing of space images in the SNAP software)

It also worsens soil composition and loss of biota as a result of combustion and high temperatures and abnormal pressures, sawing and destruction of soil structure and compaction. The mixing of continental rocks with the upper fertile layer is a complete fact, and it will significantly worsen the natural background of fertility disturbed lands in places of the military actions. Thus, in Fig. 5 shows a map of the density of fires on the territory of Ukraine for the summer period of 2022 based on MODIS satellite data from the FIRMS (Fire Information for Resource Management System). According to the cartogram, there is a shift of the ellipse of the location of fire points from the southeast closer to the center of our state. The research results were obtained with the help of the geographic information system «ArcGIS».

The soil is worsened by numerous vegetation fires and flooding with the ingress of fuel and lubricants, chemicals, the removal of salts to the surface, etc.

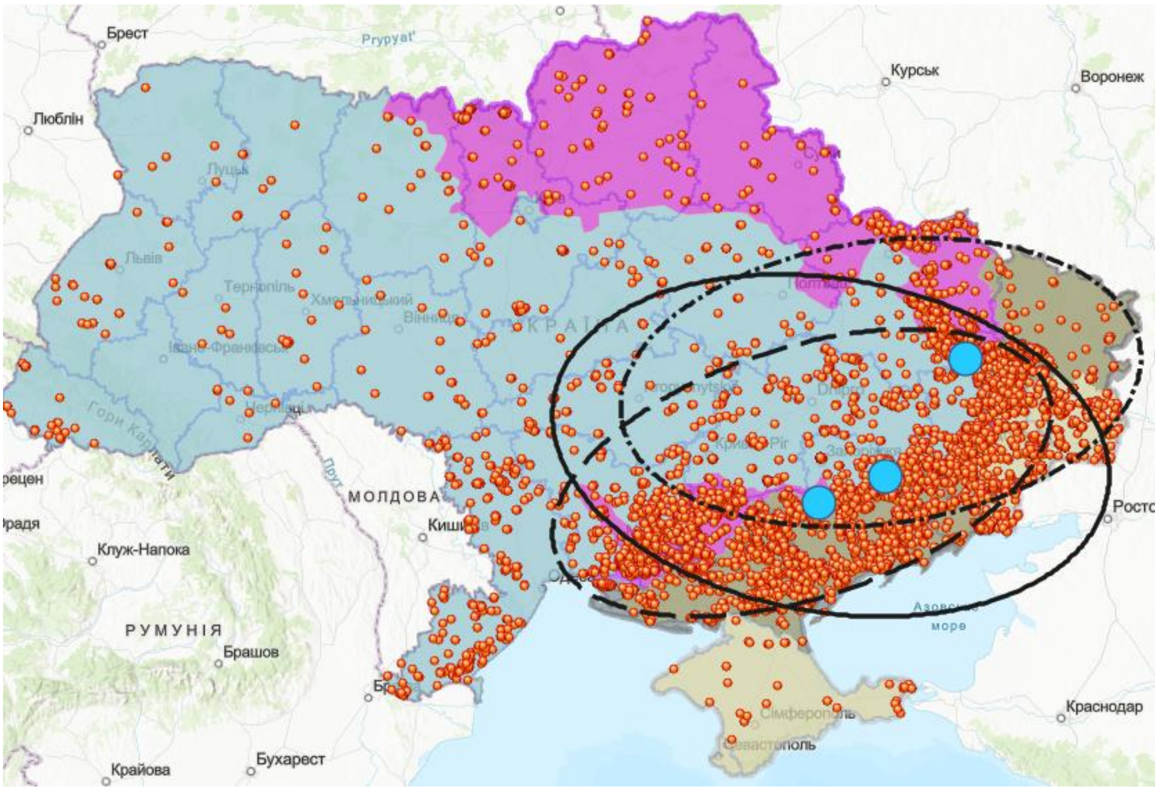

Figure 5 – Localization of firing points on the territory of Ukraine for the summer period in 2022

Military aggression creates an ecological catastrophe not only in Ukraine, but also an ecological catastrophe of a geopolitical scale in Europe and the world. Nuclear energy facilities are especially at risk. After the closure of the Chornobyl NPP, 4 nuclear power plants with PWR-type reactors remained in operation in Ukraine: Zaporizhzhia, Rivne, Khmelnytskyi, and Pivdennoukrayinsk, which operate 15 power plants, 9 of which are located in the South-Eastern part of Ukraine, practically in the war zone [37]. In Fig. 6 shows the zone affected by radioactive substances in the area around nuclear power plants, in the event of an accident of only one power unit (by analogy with the accident that occurred at the Chornobyl NPP). In a diameter of approximately 70 km around each station (without taking into account wind pressure) in the territories there will be an emission of radiation >1000 rads, a dose of 700 rads is considered fatal.

Chemical substances released during the reaction of explosives, combustion of vegetation, fuel, fuel and lubricant materials form stable chemical clouds of dust and substances that, settling on the surface, pollute territories, form soil toxicosis and toxic water horizons, spreading toxins over thousands of kilometers. Fertile chernozem lands are especially affected. In Fig. 7, using the Giovanni platform, the concentration of nitrogen dioxide on the territory of Ukraine is visualized.

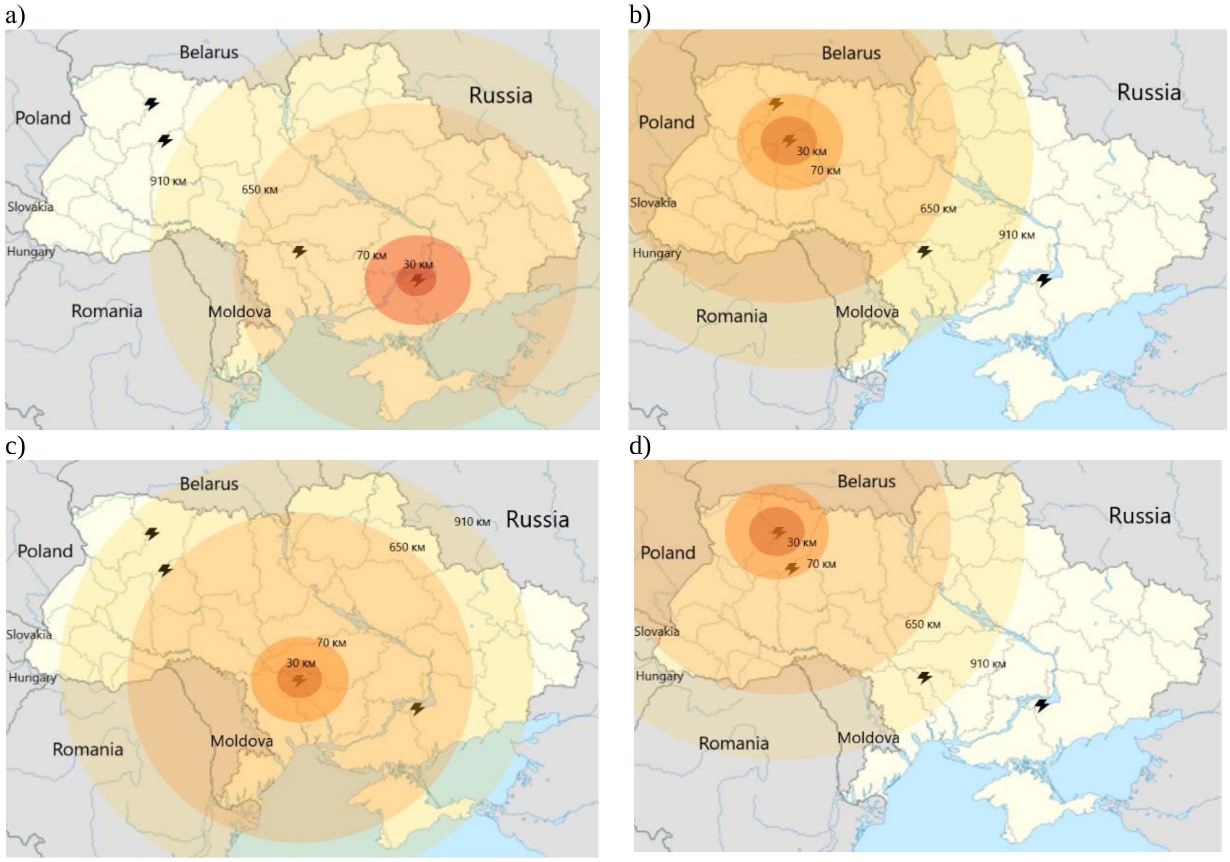

Figure 6 – The predicted zone of damage by radioactive substances to the territory around nuclear power plants in the event of an accident of one power plant: a – Zaporizhzhia NPP; b – Khmelnytskyi NPP; c – Pivdennoukrayinsk NPP; d – Rivne NPP

There are most darkened areas (0.25 mg/m^3) in the Central-Eastern part, on the territory active hostilities. Nitrogen dioxide affects the respiratory system, dryness and irritation in the throat is felt, this can lead to inflammation of the respiratory tract. Nitrogen dioxide weakens night vision, which is the ability of the eye to adapt to darkness, this effect is already observed at a concentration of 0.14 mg/m3, which is below the detection threshold (0.23 mg/m3) [38].

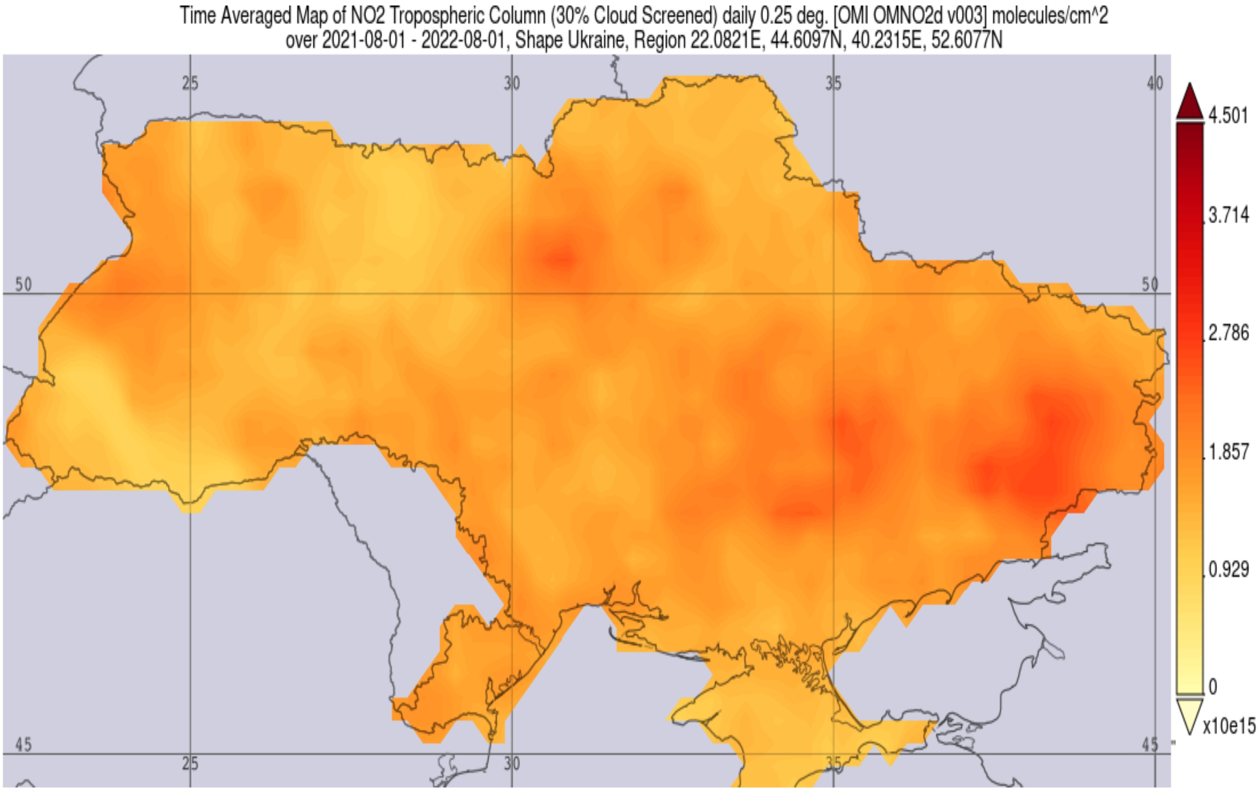

Figure 7 – The average concentration of nitrogen dioxide in the troposphere for the territory of Ukraine from August 1, 2021 to August 1, 2022 [Giovanni platform]

As a result of hostilities, the areas of disturbed industrial sites «greenfields» and "brownfields" reach tens of thousands of hectares, especially where the remains of industrial enterprises that need to be completely rebuilt or land that needs to be rehabilitated are located. Also, large areas are made up of former farmyards of agricultural enterprises and the remains of rural settlements destroyed by the war.

In addition to the geomatic methods listed above, to improve land productivity and design a soil condition monitoring system, it is envisaged to prepare and provide relevant information using the QGIS geoinformation system. This geoinformation analysis should take into account the specifics of the natural conditions of the farm. The use of GIS technologies will allow you to visualize numerical data, perform statistical analysis, transform data to find derived information, build electronic surfaces of the distribution of indicators (Fig. 8).

This, in turn, indicates that ecologically and economically justified agricultural use of land contributes to effective management of land resources, preservation of fertility and natural resource potential.

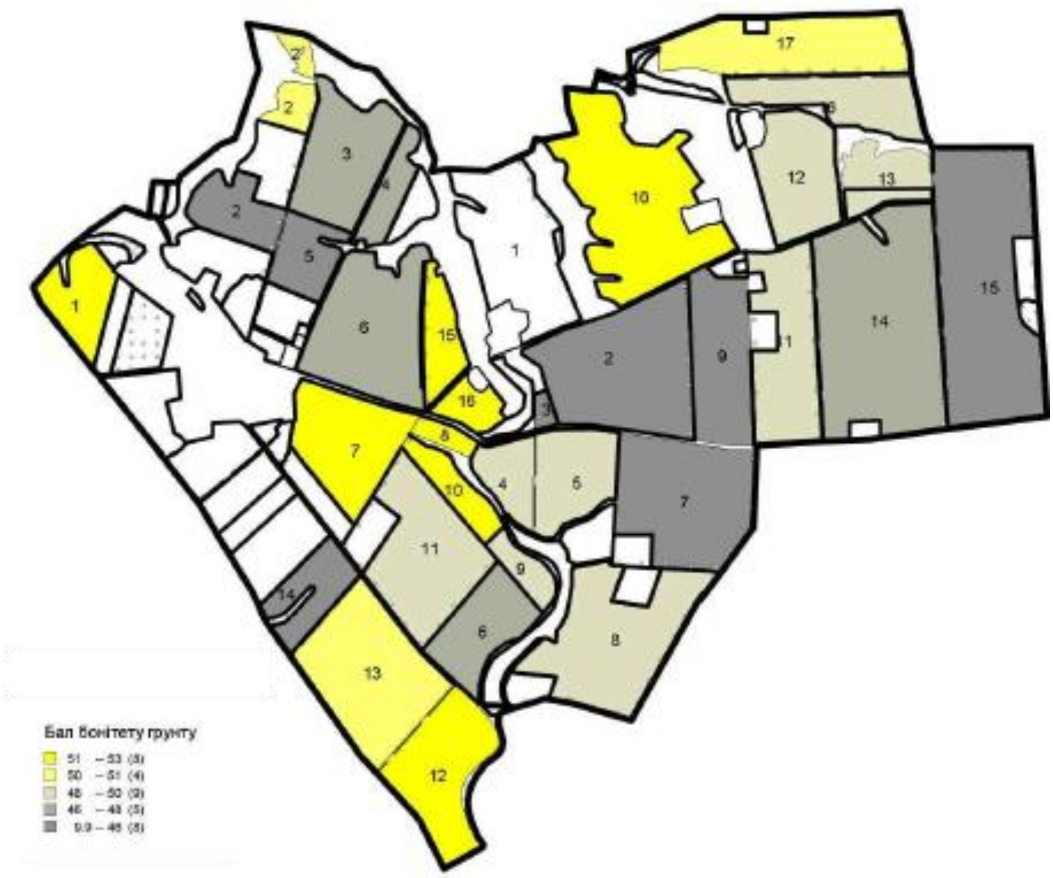

Figure 8 – Map diagram of the agrochemical characteristics of soils of the «Agroecology» PE of the «Mykhaylyky» department of the Shishatskyi district of the Poltava region.

Disturbed meliorative systems and hydrotechnical structures require special attention. Thus, in the Poltava region, satellite monitoring in conjunction with QGIS revealed more than 320 ponds that are not filled with water.

Systemic security measures of the regulatory policy of the state, changing construction standards and building rules, structural restructuring of industry, transfer of military infrastructure to safe territories, resettlement of settlements, restructuring of logistics will have a positive effect on the security of the country.

Summary. As a result of industrialization and the implementation of state megaprojects in Central and Eastern Ukraine, anthropogenically overloaded territories were formed, where a critically negative ecologically dangerous situation is forming. Dangerous geodynamic processes must be subject to constant monitoring for a high-quality forecast of the spatial movement of the Earth's surface.

Proposed geomatic methods and tools for comprehensive assessment of deformations of technogenically loaded territories. The choice of a geomatic monitoring system depends on the type of environment and the direction of research.

Visualization of the content of chemical substances, gas concentration, temperature, humidity, precipitation can be carried out through the interfaces of the Giovanni platform. Landsat, Sentinel-2, MODIS space images are processed to classify land cover objects, change their boundaries, monitor vegetation cover, analyze the geological structure, identify the dynamics of water and wetland objects, the scale of floods and inundation; SIR - C/X - SAR radar images are used to determine the locations of urban areas and individual buildings, to emphasize the relief of mountainous areas, and to control the pollution of water bodies' surfaces; to determine terrain characteristics, there are SRTM digital terrain models. Observation of the deformation of the Earth's surfaces and construction of displacement maps is performed by the InSAR satellite radar method, which is based on the use of space images from the Sentinel-1 spacecraft. In order to clarify the identified problem areas, it is necessary to jointly use ground geodetic methods of monitoring the deformations of technogenically loaded territories. Processing of the received data is carried out in various geoinformation systems ArcGIS, QGIS, Google Earth, Digital; for estimating land subsidence - Estimating Subsidence using Sentinel-1 Data in SNAP, Landslides detection Sentinel-1.

It was proposed to consider the methods of geomatic monitoring as a system, the components of which include ground geodetic methods, remote sensing of the

Earth, and geoinformation systems. This approach will make it possible to study the state of the Earth's surface depending on the conditions of its functioning.

Geomatic monitoring should be carried out to neutralize threats of various kinds, to restore natural resource potential, to ensure geopolitical, ecological, and military stability of individual agglomerations and regions, as well as Ukraine as a whole.

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ГЕОМАТИЧНИЙ МОНІТОРИНГ ЕКОЛОГІЧНИХ ЗАГРОЗ НА ТЕХНОГЕННО-НАВАНТАЖЕНИХ ТЕРИТОРІЯХ

Відмічено, що територія Східної України насичена потенційно небезпечними промисловими об'єктами та ділянками з геодинамічними процесами, за якими необхідний постійний контроль і моніторинг для виявлення деформацій. Запропоновані геоматичні методи і засоби для комплексної оцінки деформацій, показників екологічних загроз на техногенно-навантажених територіях. Вибір геоматичної системи моніторингу залежить від виду середовища і напрямку досліджень. Візуалізацію вмісту хімічних речовин, концентрації газів, температури, вологості, опадів можна здійснити через інтерфейси платформи Giovanni. Для класифікації об'єктів наземного покриву, зміни їх меж, моніторингу рослинного покриву, аналізу геологічної структури, виявлення динаміки водних та водно-болотних об'єктів, масштабів паводків і затоплення опрацьовують космічні знімки Landsat, Sentinel–2, MODIS; для визначення місць розташування міських територій і окремих будівель, для увиразнення рельєфу гірських територій, для контролю за забрудненням поверхонь водойм – радіолокаційні знімки SIR – C/X – SAR; для визначення характеристик рельєфу – цифрові моделі рельєфу SRTM.

Спостереження за деформацією земних поверхонь і побудова карт зміщень виконується методом супутникової радіолокації InSAR, що базується на використанні космічних знімків з КА Sentinel-1. Для уточнення виявлених проблемних ділянок необхідно сумісно використовувати наземні геодезичні методи моніторингу деформацій техногенно-навантажених територій. Опрацювання отриманих даних здійснюється в різних геоінформаційних системах ArcGIS, QGIS, Google Earth, Digital; для оцінки просідань ґрунтів – Estimating Subsidence using Sentinel-1 Data in SNAP, Landslides detection Sentinel-1.

Запропоновано розглядати методи геоматичного моніторингу як систему, до компонентів якої входять наземні геодезичні методи, дистанційне зондування Землі та ГІС-технології. Такий підхід дасть можливість досліджувати стан земної поверхні залежно від умов її функціонування.

В статті зазначено, що геоматичний моніторинг здійснюється для нейтралізації загроз, для відновлення природо-ресурсного потенціалу, забезпечення геополітичної, еколого-безпечної та військової стійкості.

Ключові слова: *деформація земної поверхні, геоінформаційні системи, геоматика, моніторинг, супутникова радіолокація, техногенно-навантажені території.*