

TECHNICAL SCIENCES

SYSTEMATIZATION OF TECHNOGENIC OBJECTS IN THE MINING REGION AS A BASIS FOR SUBSTANTIATING AN INTEGRATED APPROACH TO REDUCING TECHNOGENIC-ECOLOGICAL HAZARDS

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Ukraine is one of the leading countries in terms of reserves of mineral resources, with over 20 thousand deposits identified in its subsoil, of which more than 8.9 thousand are of industrial significance. The most developed deposits are iron ore, coal, manganese ore, titanium-zirconium ore and deposits of construction raw materials [1, p. 6]. In addition to the vital importance of mineral resources for economic development, the processes involved in their mining and processing create a significant technogenic load on the environment. Today, Ukraine is among the top 20 countries in the world in terms of land area occupied by mining facilities. Thus, according to the national report on the state of the environment [2, p. 512], over 52.7 thousand hectares of land area are used for mining mineral resources, with the Dnipropetrovsk, Donetsk and Zhytomyr Oblasts being the most affected.

Among all the mining sectors of Ukraine, the iron ore industry stands out in terms of its economic and environmental impact; in 2021, it provided the country with \$4 billion in foreign exchange earnings from exports of raw materials and products. Today, 75% of iron ore production comes from the large Kryvyi Rih Iron-ore Basin, which accounts for 48.6% of total reserves [3, p. 86].

Intensive iron ore mining, which has been ongoing for over 120 years, has led to a severe technogenic-ecological situation: numerous forms of the earth's surface disturbances have formed, including failure zones (50-200 m deep), unfilled underground cavities of closed mines, mined-out spaces of closed quarries and significant waste accumulations from the mining-metallurgical complex. Failure zones and unfilled cavities create uncontrolled technogenic risks, pose a threat to the safety of the population, infrastructure and fertile soils,

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and complicate underground mining operations, particularly ventilation and mine drainage. Closed quarries where the earth's surface has not been restored lead to the loss of the industrial and economic potential of territories. The environmental situation has deteriorated significantly due to the accumulation of large volumes of industrial waste, the vast majority of which comes from the mining-metallurgical complex, accounting for 92% of the total volume in the Dnipropetrovsk Oblast and 65.5% of the total in Ukraine, thereby creating a significant technogenic load.

Based on a comprehensive analysis of the morphology and spatial structure of the earth's surface disturbances, four main types of technogenic objects have been identified [4, p. 130-131; 5, p. 147; 6, p. 13]: mine failure zones, zones of gradual subsidence, quarry cavities and dumps, as well as industrial waste tailings dams. It has been found that the total area of disturbed land reaches about 50% of the area of the city of Kryvyi Rih, with waste accumulation facilities accounting for over 65%.

The revealed wide range of technogenic objects differs significantly in terms of their origin, spatial location, form of manifestation, degree of controllability and pattern of development over time. These include mine failure zones, unfilled underground cavities, closed quarries and surface waste accumulations, each of which is characterized by a specific formation mechanism and particular impact on the natural and technical environment. This diversity of technogenic objects necessitates their classification according to a set of common and distinctive features, thereby enabling a shift from a local description of individual disturbances to a comprehensive scientific examination of them as interrelated elements of a mining region. However, these objects differ not only in morphological and genetic characteristics, but also in the scale and direction of technogenic-ecological impact. Some of them are the dominant sources of geomechanical hazards due to the risk of deformation, caving and instability of the rock mass, while others form long-term environmental pressure on the atmosphere, hydrosphere, soil and vegetation cover, and biota. In addition, some of them result in significant social-economic consequences in the form of a threat to the population, infrastructure, and the loss of the economic potential of the territories. Under such conditions, scientifically based classification and systematization of technogenic objects is a prerequisite for a comparative assessment of their level of hazard, the prioritization of environmental protection measures, and the development of comprehensive solutions to reduce the technogenic load in the Kryvyi Rih Basin.

For the purpose to systematically generalize and scientifically substantiate the level of technogenic-ecological hazard of objects of the earth's surface and subsoil disturbances, formed under conditions of long-term intensive iron ore mining, a comprehensive, multi-factor systematization of their main

characteristics and hazard factors has been performed. The differentiation was based on the identification features of objects and a set of geomechanical, ecological and social-economic criteria for hazard assessment, which made it possible not only to objectively compare the scale of existing threats, but also to identify the interrelationship between these disturbances as elements of a single natural-technogenic system of the mining region (Table 1).

Based on the systematization performed, it has been found that technogenic disturbances resulting from underground and open-pit mining, as well as the accumulation of waste from the mining-metallurgical complex, are characterized by varying, but interrelated levels of geomechanical, ecological and social-economic hazards. It has been determined that the priority hazard is posed by technogenic cavities formed by underground mining, which are the main factor causing disturbances in the stress-strain state of the rock mass and initiating the development of deformation processes and associated changes in the natural-technogenic balance. Closed quarries, in this context, serve as additional spatial elements of a technogenically disturbed environment, influencing the overall stability of the territories. Waste from the mining-metallurgical complex, forming the main source of long-term technogenic pollution, is at the same time considered as a resource basis for the development of environmentally friendly technologies aimed at reducing technogenic risk, rational use of natural resources and ensuring the environmental safety of mining regions.

The proven interconnected nature of the development of geomechanical processes and environmental consequences indicates that technogenic objects in mining regions function as a single interdependent system. Under such conditions, considering them in isolation does not allow for an objective assessment of the overall impact on the rock mass, on the Earth's surface and the environment, leading to the adoption of local, ineffective decisions. In this regard, the expediency of applying an integrated approach to managing the environmental safety of technogenic objects is substantiated, which provides for a coordinated consideration of geomechanical processes, sources of technogenic pollution, and the potential for their environmentally safe transformation.

The results obtained form the basis for developing a concept for the complex liquidation of technogenic cavities, according to which various types of disturbances of the earth's surface and subsoil are regarded as interconnected objects within a single natural-technogenic system, requiring coordinated engineering intervention. The implementation of this concept involves the use of paste backfilling technology based on tailings selected from maps of drained tailings dams, with their subsequent transportation to the backfill complex, preparation of backfill mixtures, and their delivery through backfill pipelines to specific groups of technogenic cavities. The concept provides the possibility of

simultaneous stabilization of the geomechanical state of the mass, reduction in the environmental impact and environmentally safe utilization of waste from the mining-metallurgical complex.

Table 1

Systematization of technogenic objects in mining regions by classification criteria, groups and levels of technogenic-ecological hazard

Criteria group	Characteristic/ Indicator	Types of technogenic objects				
		Mine failure zones	Underground cavities	Closed quarries	MMC waste	
Classification criteria for objects	Source of origin	UMO	UMO	OPM	UMO/OPM	
	Spatial location	Deep	Deep	Deep	High altitude	
	Nature of manifestation	Explicit	Hidden	Explicit	Explicit	
	Degree of controllability	Uncontrolled	Uncontrolled	Controlled	Controlled	
	Nature of formation	Sudden	Gradual	Gradual	Gradual	
Groups and levels of technogenic-ecological hazard	Geomechanical & technological	Sudden caving/shear	High	Ultra-high	Low	Low
		Extent of deformation	Ultra-high	High	Low	Low
		Disturbance of the mass	Ultra-high	High	Low	No
		Hydrological changes	Ultra-high	High	Medium	Low
		Mining decline	High	Medium	Low	No
	Ecological	Soil and vegetation cover degradation	Ultra-high	High	Medium	Ultra-high
		Air pollution	Low	No	Low	Ultra-high
		Hydrosphere pollution	Low	Low	Low	Ultra-high
		Loss of biodiversity	Ultra-high	Low	Medium	Ultra-high
	Social-economic	Threat to the population	Ultra-high	Ultra-high	Low	Medium
		Threat to infrastructure	Ultra-high	Ultra-high	Low	Low
		Economic losses	High	High	Low	Medium
		Loss of economic potential of territories	Medium	Medium	Ultra-high	High

Note: UMO – underground mining operations; OPM – open-pit mining; MMC – mining-metallurgical complex

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