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Analytical research of the parameters and characteristics of new "quarry cavities – backfill material" systems: Case study of Ukraine

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Abstract

Purpose. The research is aimed to identify, investigate and study the parameters and characteristics of the "quarry cavities – backfill material" systems on the territory of Ukraine using new comprehensive methodological tools that form the basis for the development of effective methods for restoring the earth's surface with an emphasis on industrial and construction use.

Methods. An integrated approach is used, which includes: analysis of the spatial location of industrial waste heaps on the territory of Ukraine as potential backfill materials and resulting quarry cavities that are not subject to complete earth's surface restoration, as well as determination of the volumes of resulting cavities and backfill materials. Based on a set of factors, the "quarry cavities – backfill material" systems have been ranked according to priority. Tools used are: information data from the State Informational Geological Fund of Ukraine, registers of industrial waste accumulation sites in region, the Google Earth satellite program, an online topographic map (OpenStreetMap) and Blender program for constructing 3D models.

Findings. A new concept and theoretical representation of "quarry cavities – backfill material" has been formulated. The characteristics of a number of important conditions for the harmonious existence and effective implementation of promising "quarry cavities – backfill material" systems are provided. A new information-analytical map of the spatial location of potential backfill materials and resulting quarry cavities has been created. Thirteen promising systems and their parameters have been identified, within which it is appropriate to consider backfill technologies for the complete earth's surface restoration. The existing balance of cavities and backfill materials for the identified systems has been determined, followed by grading of quarries according to the predicted lifespan.

Originality. The "quarry cavities – backfill material" systems, which have the greatest advantages, are specified by ranking them according to a complex of technological, environmental, economic and social factors.

Practical implications. The results obtained provide valuable information for the development of a government strategy and environmental programs for the restoration of land areas disturbed by mining operations based on backfill technologies and their subsequent use for industrial purposes.

Keywords: *quarry cavities, industrial waste, backfill material, backfill mass, earth's surface restoration, environmental hazard*

1. Introduction

Modern society has entered an era of intensive consumption of natural resources, which is a major challenge to sustainable development and environmental conservation. The rapid exponential growth of the planet's population has led to an increase in the consumer activity level, which in turn increases the demand for natural resources [1]-[3]. A special place is occupied by mining of various minerals, which are used in various sectors of the economy, making it possible to create products, technologies and goods necessary for human life and development [4]-[6]. Mining generates significant foreign exchange earnings for the economies of many countries, but at the same time causes severe damage to the natural environment. The open-pit mining method is currently considered the most efficient and economical method due to its high level of productivity and lower primary capital costs for operation [7], [8].

The greatest damage to the state of the environment is caused by quarrying, because the subsoil and topography, the hydrogeological regime of water resources are disturbed on a significant scale, ecosystems are impoverished and destroyed, and valuable land areas are alienated [9]-[13]. Special attention should be given to the earth's surface failures caused by the influence of underground mining, which destroys the upper layer of the earth's crust, creating a danger to the population and infrastructure [14]-[16]. Technological operations for mining and processing of minerals generate huge volumes of industrial waste, such as rock dumps and tailings, and in mining-metallurgical complexes metallurgical slag dumps are also added. These wastes, often containing hazardous substances, pose a serious threat to the environment and human health and are capable of creating emergency situations (landslides, dam breaks, etc.). Industrial waste occupies large land areas and is constantly expanding, and if

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underground mine workings are located below it, the waste may even affect its geomechanical condition [17]-[19].

During underground mining, one of the effective environmentally oriented measures is the backfilling the mined-out space, which allows the removal of valuable reserves, prevent the formation of critical earth's surface deformations and dispose of various types of industrial waste in the underground space [20]-[25]. In the case of the open-pit method, the implementation of land reclamation measures is better known. After the completion of mining the fields, the most common reclamation forms of quarry cavities are the creation of artificial water bodies, forestry, recreational areas or various architectural and cultural objects [26]-[30]. The full earth's surface level is usually not restored due to the lack of sufficient volumes of fractured and hard rocks near the quarries.

These problematic aspects are also typical for Ukraine, where complex mining of mineral deposits causes the greatest damage to the earth's surface and the environment. According to the State GeoCadastre, the disturbed land area in Ukraine is estimated at 142.7 thousand hectares, among which the following oblasts are the leaders: Dnipropetrovsk Oblast – 377 thousand hectares, Donetsk Oblast – 25.3 thousand hectares, Lviv Oblast – 10.7 thousand hectares, and Luhansk Oblast – 10.3 thousand hectares. It is obvious that the mining industry, widely developed in these areas, has the greatest influence [31], [32]. In pre-war times, up to 7-8 thousand hectares of land, owned primarily by agricultural or forestry enterprises, were allocated annually for the needs of the mining industry, as the most land-intensive [33].

In addition to the most common methods of quarry restoration, a reclamation method is also known, which is performed by filling the mined-out space with waste rocks to the earth's surface level [34]-[36]. This is usually possible in the case when there are dumps nearby with a sufficient volume of overburden rocks from other quarries. Despite the fact that this method is environmentally friendly and characterized by relative simplicity, it has a number of disadvantages: low rate of filling quarry cavities, significant porosity of reclamation material and a high filtration coefficient with a subsequent probability of contamination [37], [38]. Further use of land areas reclaimed in this way in the construction direction of restoration is doubtful and risky. In this case, the priority vision of complete earth's surface level restoration should be based primarily on the geomechanical stability and reliability of the formed artificial mass [39]-[41].

Creating a stable backfill mass in quarry cavities to restore the earth's surface level, given geomechanical reliability, may turn out to be a very promising and perspective direction. However, to achieve successful implementation, it is necessary to take into account several key factors – the presence of cavities themselves and availability of sufficient volumes of the necessary backfill material. It is in this context that a new idea and concept of the "quarry cavities – backfill material" system arises. The concept implies the use of industrial waste to fill quarry cavities based on the selection of sound best methods and technologies for backfilling, which not only eliminates the negative impact of quarries on the environment, but also creates new opportunities for the rational use of restored territories.

Restoration of the earth's surface level to its original state may have significant prospects. If we look in the context of the further restored earth's surface use, the location of open-pit mining facilities is observed in most cases in industrial zones, which typically have high levels of environmental pollution [42], [43]. Therefore, the subsequent use of reclaimed lands in agriculture, forestry and other areas may have low efficiency and risks. In such regions, the development of industrial and civil infrastructure after the restoration of a stable earth's surface level will be of priority importance, especially in the conditions of post-war restoration and reconstruction of Ukraine.

However, to date, it has not been determined where exactly on the territory of Ukraine there are prospects for the formation of backfill masses for restoring the earth's surface state. To date, the spatial location of the resulting quarry cavities and industrial waste heaps, which can potentially be considered as backfill materials, has not been sufficiently studied. This research can provide an opportunity to identify closely located groups of quarries and industrial waste heaps. Studying and understanding the parameters and characteristics of the discovered "quarry cavities – backfill material" systems will allow us to develop effective strategies for backfill methods during the reclamation of mined-out quarries and ensure the effective earth's surface use.

This research is aimed at identifying and further studying the characteristics of promising "quarry cavities – backfill material" systems on the territory of Ukraine, which will create the basis for further development of effective methods for restoring the earth's surface and its rational use.

2. Peculiarities of the "quarry cavities – backfill material" system concept

The "quarry cavities – backfill material" system is a new methodology or approach that consists of using quarries mined-out by filling their space with specially selected, closely located backfill material based on industrial waste, followed by the formation of a stable backfill mass. This system provides a number of benefits, including optimal use of the space mined-out by quarries, reduced environmental impact, the ability to recover resources and develop infrastructure, as well as create jobs and attract investment for land restoration projects. The system should be aimed at geomechanically reliable restoration of the earth's surface disturbed by mining operations for its further use in various infrastructure projects, especially for industrial and construction purposes.

When identifying promising "quarry cavities – backfill material" systems, in which there are closely spaced quarry cavities and industrial waste heaps, it is necessary to use this unique opportunity to restore the earth's surface level disturbed by mining operations and wisely use the vacated land area. Figure 1 illustrates the conceptual relationship of the above-mentioned aspects.

In our view, there are a number of important conditions for the harmonious existence and effective implementation of identified promising "quarry cavities – backfill material" systems, which play a key role in the successful and sustainable implementation of the earth's surface restoration technology based on the formation of sustainable backfill masses. The list of specified basic conditions, according to the authors, is illustrated in Figure 2, with the observance of which the formation of a stable backfill mass in quarry cavities make it possible to achieve complete earth's surface restoration.

Compliance with the specified conditions makes it possible to optimize the filling process, reduce economic costs, ensure environmental safety and receive support from society and government authorities.

Figure 1. Conceptual relationship between industrial waste heaps and quarry cavities through backfill technology

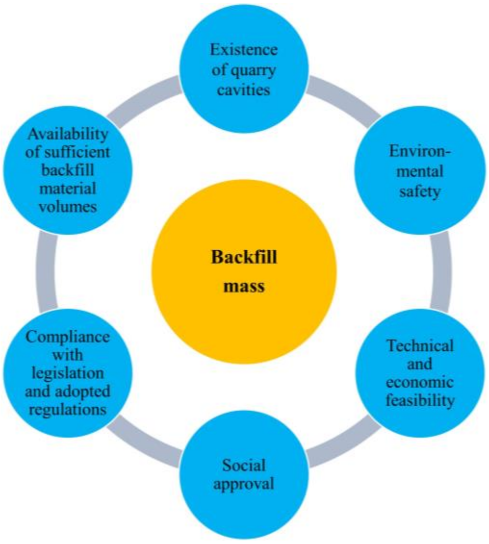

Figure 2. A set of conditions for the existence and effective implementation of the "quarry cavities – backfill material" system

Thus, the conditions for harmonious existence and implementation of the "quarry cavities – backfill material" system need balance between economic, technical, environmental and social aspects. In the process of sustainable development of industrial regions, it is necessary to strive for maximum efficiency in the use of resources, minimizing the negative impact on the environment and meeting the needs of society.

It is worth noting that the strategy for restoring the earth's surface according to the proposed conceptual approaches should be supported by central and local government authorities. Funding for such programs should be shared between the government and the private sector. The identification and selection of promising "quarry cavities – backfill material" systems will help the government coordinate and determine the vectors of the strategy for restoring the earth's surface using optimal backfill technologies for the purpose of sustainable development of industrial regions, environmental preservation, as well as the safety and health of the population.

3. Research methods

To achieve the purpose set, the research is conducted in several sequential stages.

I stage. To determine the geographical location and identification of the mined-out spaces of active and closed quarries, information data of valid and invalid special permits for the subsoil use from the State Geologic and Subsoil Survey of Ukraine have been studied. Attention is paid to the types of quarries in Ukraine that, as a result of mining, have formed significant cavities both in surface area and in depth (S >5 ha, H > 20 m). Quarries developing deposits of such minerals as kaolin, clay, loam, sand, manganese and titanium ores, etc., are not taken into account, where mining systems with internal overburden dumping and restoration measures are used immediately after the advancement of the mining front. No quarries are considered on the territory of Ukraine, occupied by the russia from 2014 until the beginning of military aggression on February 24, 2022. Based on the annual productivity of active quarries and the volumes of available balance reserves, they are graded according to the projected lifespan to understand the priority cavities to be filled. To determine the parameters of the resulting quarry cavities (occupied areas, volumes), the following tools are used: the Google Earth satellite program, an online topographic map of Ukraine (OpenStreetMap) and Blender program for constructing 3D models (Fig. 3). The volume of resulting cavities is determined from the position of restoring the earth's surface level, that is, from the bottom to an imaginary horizontal area along the quarry surface at the lowest absolute elevation of the quarry contour. It is obvious that certain volumes of cavities are predicted and have some error, which is due to inaccurate reproduction of the relief on satellite images (flattening of quarry benches). However, these aspects are relatively minor and do not have a critical influence on the total volumes of cavities.

(a)

(b)

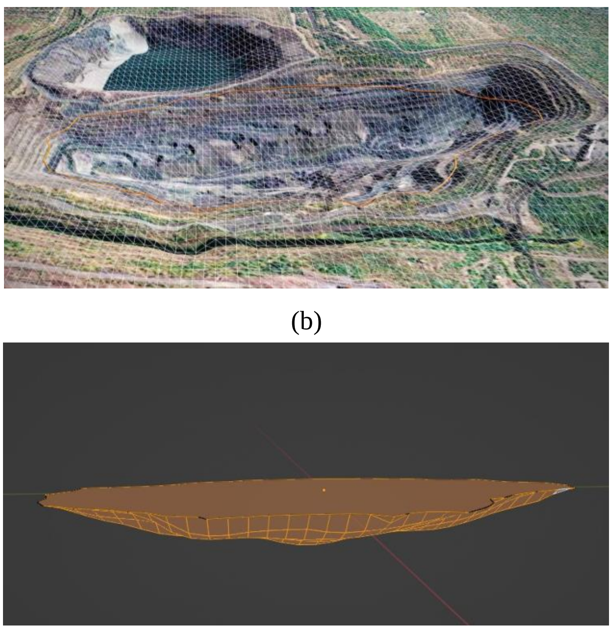

Figure 3. Fragments of the presented tools for determining the parameters of formed quarry cavities: (a) creating a grid and scanning the relief of the quarry cavity; (b) creating a three-dimensional model of a quarry cavity

II stage. Based on the study of successful global practice of backfilling the mined-out space during mining of mineral deposits, it becomes possible to identify a group of wastes of natural-technogenic origin used as backfill materials [44]-[48]. Thus, for the development of directions for backfilling the technogenic cavities during mining of mineral deposits, the most common materials are metallurgical slag, ash-slag materials (fly ash, furnace slag), and waste rock, beneficiation tailings, which, according to the environmental legislation of Ukraine, belong to the IV hazard class and are low-hazard (Table 1). The specified materials are considered in the research. Industrial waste heaps in volumes of more than 1 million tons are studied.

Table 1. Priority materials of natural-technogenic origin, promising for use as backfill components

Potential backfill materials	Origin	Waste hazard class	Source of the formation	Storage site
Overburden and mine rocks	Natural	IV	Mines and quarries	Dumps of overburden and mine rocks
Metallurgical slag	Technogenic	IV	Metallurgical plants	Slag dumps
Tailings and sludge beneficiation	Technogenic	IV	Mining and beneficiation plants	Tailings dams
Ash slag and dry fly ash	Technogenic	IV	Thermal power plants	Ash dumps, ash-slag dumps

Geographical location and identification of industrial waste heaps from the mining-metallurgical complex are determined based on a study of the State register of waste disposal sites for oblasts for 2020-2023 (Table 2). Each enterprise annually reports to local and government authorities on the generated waste volume for the calendar year and in general. Then, annual registers of waste disposal sites are formed, indicating their characteristics for regions of Ukraine. Additionally, environmental passports and regional reports on the environmental state for oblasts are studied, as well as a number of reports and scientific-informational resources of the mining industry. The stockpiled waste volume (m^3) is determined taking into account the value of its density in the loosened state.

Table 2. Fragment of the register of waste disposal sites in Dnipropetrovsk Oblast [49]

Registration No. / date	Last revision date	Name of waste disposal site	Location	Owner's full name and address	Operating mode	Ecosafety category	Characteristics of waste disposal sites	Characteristics of waste disposal sites
160/16 25.07.2016	160/22 20.01.23	Overburden dump Persho-travnevy	500-700 m north of Oleksiivka village, 12110 37200	PJSC Northern GOK USREOU 00191023, 50079, Kryvyi Rih city, Ternivsky district	Active	V (Ukr. – B)	Volume: 910 million m^3 (2507 million tons) Area: 849 ha Open surface	Waste from iron ore quarrying (overburden rocks) Group: 13 Hazard class: 4

III stage. To identify promising "quarry cavities – backfill material" systems on the territory of Ukraine, a set of comprehensive scientific-methodological tools are used, which provides for the determination of the geographical group location of industrial waste as potential backfill materials and resulting quarry cavities, with their subsequent integration into a single information-analytical map and selection of appropriate systems using the Google Earth online program (Fig. 4). Subsequently, the peculiarities and characteristics of the regions are studied.

IV stage. To determine the priority "quarry cavities – backfill material" systems for the implementation, a complex of technological, environmental, economic and social factors is formed, which are divided into scales. The priority level of the factors is divided into the categories "very low", "low", "medium", "high", and "extremely high". The promising "quarry cavities – backfill material" systems are analyzed according to the following factors: population size, the disturbed land area, the existing balance between formed cavities and backfill material, the level of infrastructure development, the industrial potential of the territories and the level of their contamination, the degree of readiness for backfilling, the potential for creating a geomechanically stable mass. By analyzing the results, systems with more favorable factors are distinguished.

4. Research results

4.1. Identification of promising "quarry cavities – backfill material" systems

As a result of comprehensive research on the spatial location of formed quarry cavities and significant places of industrial waste heaps, which are potentially considered as backfill materials, 13 promising "quarry cavities – backfill material" systems have been identified (Fig. 4). These systems combine closely spaced quarry cavities and industrial waste heaps, which in the future opens the possibility of planning different backfill methods depending on the specifics of the region, quarry cavities and varieties of backfill materials. For other quarries on the territory of Ukraine that are not included in the identified systems, after the end of the lifespan, reclamation methods will be adopted, which do not provide for the complete earth's surface level restoration due to the lack of sufficient volumes of closely located backfill material reserves.

The individual naming and zoning of the identified promising "quarry cavities – backfill material" systems have been performed: (1) Kryvyi Rih system No. 1; (2) Kryvyi Rih system No. 2; (3) Kryvyi Rih system No. 3; (4) Kryvyi Rih system No. 4; (5) Petrovsk system; (6) Pokrov-Nikopol system; (7) Zaporizhzhia system; (8) Zavallia system; (9) Dnipro system; (10) Horishni Plavni system; (11) Mariupol system; (12) Novotroitske-Dokuchaievsk system; (13) Lysychansk system

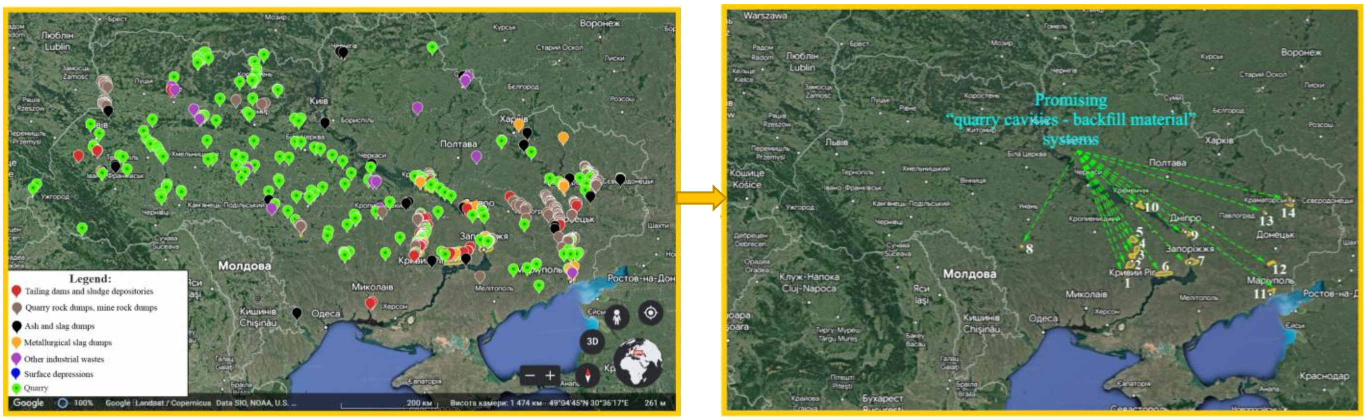

Figure 4. Schematic representation of the developed information-analytical spatial location map of quarry cavities and waste heaps, as well as identified “quarry cavities – backfill material” systems

According to the authors, in order to develop strategies for the complete restoring the earth’s surface disturbed by mining operations based on various technologies for backfilling the mined-out space on the territory of Ukraine, today, first of all, it is the 13 above-mentioned identified systems should be considered, taking into account the close location of the resulting cavities and potential backfill material reserves within their boundaries.

The following are the research results of the characteristics of promising “quarry cavities – backfill material” systems on the territory of Ukraine, which will create the basis for the selection of priority systems for the earth’s surface restoration by government and the further development of effective methods for restoring the earth’s surface and its rational use.

4.2. Characteristics and parameters of the identified promising “quarry cavities – backfill material” systems

Kryvyi Rih system No. 1. The objects of this identified system, such as quarry cavities and industrial waste heaps, are located in Dnipropetrovsk Oblast in the southern area of the Kryvyi Rih city, occupying the southern area of Inhuletskyi District of the city (Fig. 5). This area is located in the south-western direction, 17 km from the main part of the city of Kryvyi Rih.

Figure 5. Kryvyi Rih system No. 1, schematic representation

In the specified area, open-pit mining of oxidized quartzite and magnetite quartzite ore deposits is used. Within a diameter of 10 km, the system includes 1 large active quarry, 3 overburden and rock dumps, and 1 tailing dam for iron ore beneficiation. The system has a well-developed transport infrastructure, and only mining enterprises operate in the industrial sector. The number of residents is about 16 thousand people. With the specified number of the mining industry facilities, the environment and the population experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is classified as “extremely polluted” (category 5) according to the environmental state map of Ukraine.

During the operation of these industries, 2.91 billion tons of industrial waste have been accumulated in the system. According to the analysis of disturbed lands of the Kryvyi Rih system No. 1, their total area is 2404 hectares, of which the quarry is 643 hectares, the rock dumps are 784 hectares, and the tailings dam is 977 hectares. According to the analytical assessment of the “quarry cavities – backfill material” Kryvyi Rih system No. 1, the total volume of resulting quarry cavities is estimated at 0.88 billion m^3, the total volume of accumulated waste as potential backfill materials is 1.33 billion m^3. Consequently, the balance of “quarry cavities – backfill material” is positive from the future perspective of backfill operations. The level of backfill material supply is sufficient.

Kryvyi Rih system No. 2. System objects, such as quarry cavities and industrial waste heaps, are located in the southern area of the Kryvyi Rih city, occupying the northern area of Inhuletskyi District and parts of the Tsentralno-Miskyi and Metallurgical districts of the city (Fig. 6).

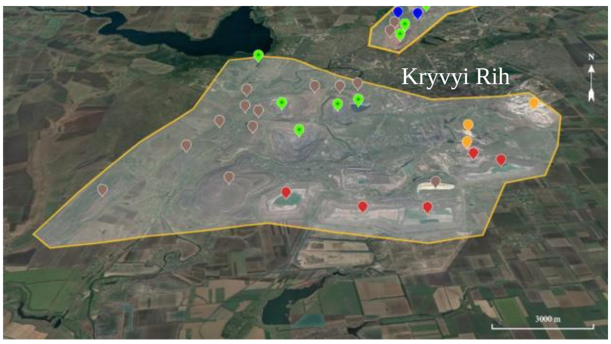

Figure 6. Kryvyi Rih system No. 2, schematic representation

In the specified area, open-pit mining of ferruginous quartzite and quartzite-magnetite ore deposits is used. Within a diameter of 15 km, the system includes 5 quarries (3 active and 2 closed), 12 overburden and hard rock dumps, and 5 tailing dams for iron ore beneficiation, and 3 dumps of metallurgical slag from a metallurgical plant. Of the 12 dumps, 5 dumps are not included in the State register, which is probably due to their invalid status. At the same time, the land areas occupied by them are registered. Industry, urban and public buildings, as well as transport infrastructure are significantly developed within the system. The number of residents is about 100 thousand people. It is obvious that with such a density of mining, processing and metallurgical industry facilities, the environment and the population experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is classified as "extremely polluted" (category 5) according to the environmental state map of Ukraine.

During the operation of these industries, 4.32 billion tons of industrial waste have been accumulated in the system. According to the analysis performed for the disturbed lands of the Kryvyi Rih system No. 2, their total area is 6000 hectares, of which the quarries are 1080 hectares, the rock dumps are 2660 hectares, the tailings dams are 1930 hectares, and the slag dumps are 331 hectares. According to the analytical assessment of the "quarry cavities – backfill material" Kryvyi Rih system No. 2, the total volume of resulting quarry cavities is estimated at 1.45 billion m^3, the total volume of accumulated waste as potential backfill materials is 1.78 billion m^3. Consequently, the balance of "quarry cavities – backfill material" is positive from the future perspective of backfill operations. The level of backfill material supply is sufficient.

Kryvyi Rih system No. 3. In the mentioned system, quarry cavities and industrial waste heaps are located in the central area of the Kryvyi Rih city, occupying Saksahanskyi District and Pokrovsky District of the city (Fig. 7).

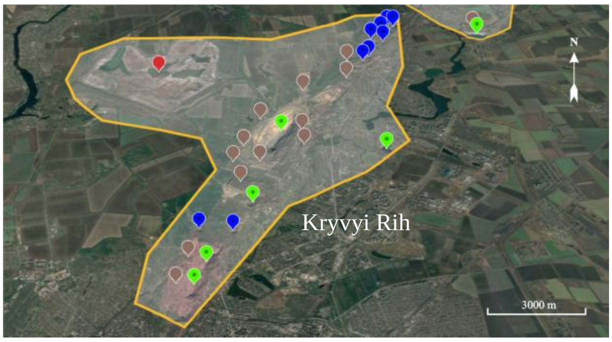

Figure 7. Kryvyi Rih system No. 3, schematic representation

The system uses complex mining of oxidized quartzite and high-grade iron ores by open-pit and underground methods. Within a diameter of 15 km, the system includes 6 quarries (3 active, 2 closed, and 1 at the stage of filling), 6 mines, 12 dumps of quarry and mine rocks, 1 tailing dam for iron ore beneficiation. Of the 12 dumps, 7 dumps are not included in the State register, but the land areas occupied by them are registered. Industry, urban and public buildings, and transport infrastructure are also significantly developed within the system. The number of residents is about 260 thousand people. The environment and the population in this system experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "extremely polluted" (category 5). It should be noted that on the earth surface within the mine land allotments there are significant failures and shear zones caused by the influence of mining operations. Iron ores are mined without backfilling the mined-out space [50]-[52]. The number of formed failures is 9 (blue marks, Fig. 7).

During the operation of mining and processing facilities, according to an analysis of the register of waste generation sites, 0.85 billion tons of industrial waste have been accumulated in the system. The industrial waste volume requires further specification, because the research on the earth's surface state shows that 7 unregistered dumps have a significant rock volume. According to the analysis of the Kryvyi Rih system No. 3 disturbed lands, their total area is 3235 hectares, of which quarries are 720 hectares, rock dumps are 730 hectares, tailings dams are 1705 hectares, and mine failure zones are 80 hectares. The total volume of resulting quarry cavities and system failure zones is estimated at 0.765 billion m^3, the total volume of accumulated waste as potential backfill materials is 0.49 billion m^3. According to official data, the existing balance of quarry cavities and backfill material is negative, but the real industrial waste volume is greater, which requires specification and further research.

Kryvyi Rih system No. 4. In the mentioned system, quarry cavities and industrial waste heaps are located in the northern part of the Kryvyi Rih city, occupying the Ternivsky District of the city (Fig. 8).

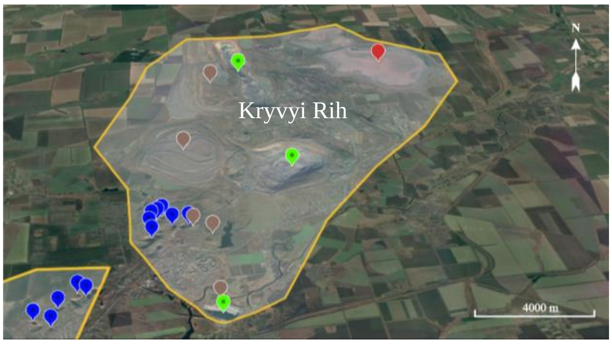

Figure 8. Kryvyi Rih system No. 4, schematic representation

The system also uses complex mining of oxidized quartzite and high-grade iron ores by open-pit and underground methods. Within a radius of 15 km, the system includes 4 quarries (2 active, 1 mothballed, and 1 at the stage of filling), 2 mines, 5 dumps of quarry and mine rocks, 1 tailing dam for iron ore beneficiation. Of the 5 dumps, 3 mine rock dumps are not registered and require specification. Industry and transport infrastructure are significantly developed within the system. The number of residents is about 80 thousand people. The environment and the population in this system also experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "extremely polluted" (category 5). It should be noted that on the earth surface within the mine land allotments, there are significant failures and shear zones caused by the influence of mining operations. Iron ores are mined without backfilling the mined-out space. The number of formed failures is 7 (blue marks, Fig. 8).

The system has accumulated 6.18 billion tons of industrial waste. According to the analysis of the Kryvyi Rih system No. 4 disturbed lands, their total area is 4545 hectares, of which quarries are 1175 hectares, rock dumps are 1880 hectares, tailings dams are 1410 hectares, and mine failure zones are 79 hectares. The total volume of resulting quarry cavities and failure zones is estimated at 1.44 billion m^3, the total volume of accumulated waste as potential backfill materials is 2.54 billion m^3, which indicates a positive balance. The level of backfill material supply is sufficient.

In further research, it is planned to specify for the Kryvyi Rih systems the amount and volume of rocks stockpiled in dumps that are not included in the State register of waste.

Petrovsk system. In the mentioned system, quarry cavities and industrial waste heaps are located in Kirovohrad Oblast, near the village of Petrovske and the city of Zhovti Vody (Fig. 9).

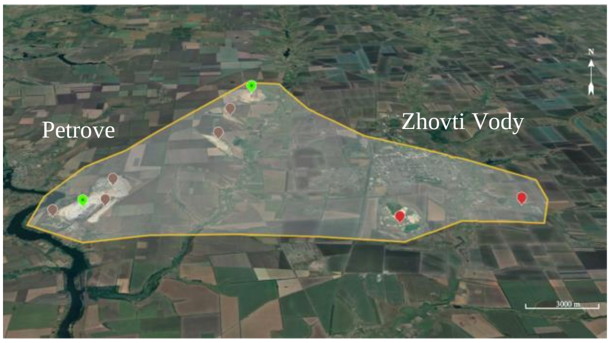

Figure 9. Petrovsk system, schematic representation

The system conducts mining of ferruginous quartzite using open-pit mining method. Within a diameter of 15 km, the system includes 2 quarries (active), 5 overburden and hard rock dumps, 2 tailing dams for beneficiation of iron and uranium ores. The system has only developed mining and uranium processing industries, agriculture, as well as traffic interchanges. The number of residents is about 50 thousand people. The environment and the population in this system also experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "highly polluted" (category 4).

The system has accumulated 0.52 billion tons of industrial waste. According to the analysis, the total disturbed land area is 1330 hectares, of which quarries are 320 hectares, rock dumps are 558 hectares, and tailings dams are 455 hectares. The total volume of resulting quarry cavities is estimated at 0.214 billion m^3, the total volume of accumulated waste as potential backfill materials is 0.246 billion m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Pokrov-Nikopol system. In the specified system, quarry cavities and industrial waste heaps are located in Dnipropetrovsk Oblast, within the boundaries of the cities of Pokrov and Nikopol (Fig. 10).

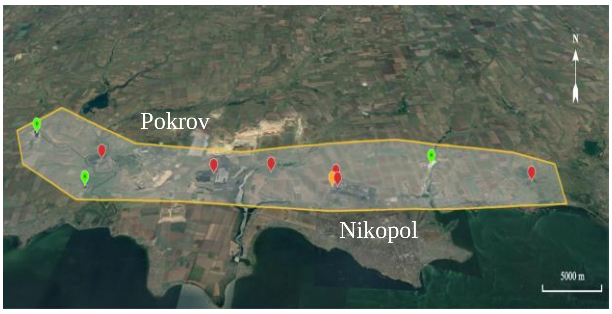

Figure 10. Pokrov-Nikopol system, schematic representation

The system conducts large-scale open-pit mining of manganese ores and granites. Manganese ores are mined by a mining system with internal dumping after the advancement of the front of stope operations, which leads to almost complete reclamation of disturbed lands, so these quarries are not explored. Within the diameter of this system, there are 3 granite quarries (1 active and 2 closed), 4 sludge repositories for the beneficiation of manganese ores, of which 1 is not registered, and 1 metallurgical slag dump of ferroalloy production. Mining, metallurgical industry and agriculture are developed within the system. The transport infrastructure is sufficiently developed. The number of residents is about 50 thousand people. The environment and the population in this system also experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "highly polluted" (category 4).

The system has accumulated 230 million tons of industrial waste. According to the analysis, the total disturbed land area is 1160 hectares, of which quarries are 130 hectares, tailings dams are 1019 hectares, and slag dump is 11 hectares. The total volume of resulting quarry cavities is estimated at 38 million m^3, the total volume of accumulated waste as potential backfill materials is 145.6 million m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Zaporizhzhia system. In the specified system, quarry cavities and industrial waste heaps are located in Zaporizhzhia Oblast in the vicinity of the city of Zaporizhzhia in the Shevchenkivskyi, Dniprovskyi and Zavodskyi districts (Fig. 11).

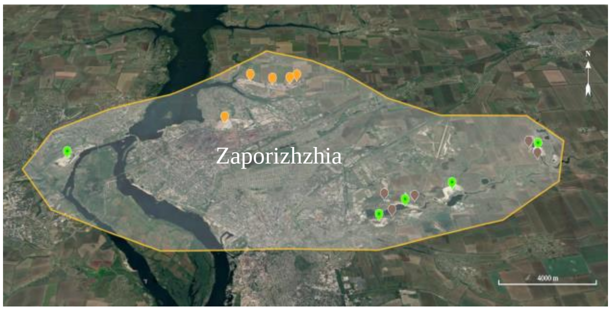

Figure 11. Zaporizhzhia system, schematic representation

The system conducts open-pit mining of granite deposits. Within a diameter of 25 km, the system includes 5 granite quarries (4 active and 1 closed), 4 metallurgical slag dumps (steel-smelting and furnace), 5 overburden dumps, which are not included in the State register, but occupy land areas. The system has developed machine building industry, ferrous and non-ferrous metallurgy, chemical and construction industries, urban and public buildings, as well as an important road and railway hub. The number of residents is about 200 thousand people. The environment and the population in this system also experience a powerful harmful impact. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "highly polluted" (category 4).

The system has accumulated 56 million tons of industrial waste from the above-mentioned facilities, recorded by the register. The total disturbed land area is 555 hectares, of which quarries are 251 hectares, overburden dumps are 65 hectares, and slag dumps are 240 hectares. The total volume of resulting quarry cavities is estimated at 106 million m^3, the total volume of accumulated waste as potential backfill materials is 33 million m^3, which indicates a negative balance and and a low overall level of backfill material supply. The information on overburden rock accumulations in 5 overburden dumps requires further specification.

Zavallia system. In the specified system, quarry cavities and industrial waste heaps are located in Kirovohrad Oblast in the area of the village of Zavallia (Fig. 12). The system conducts open-pit mining of graphite ore deposits.

Figure 12. Zavallia system, schematic representation

Within a diameter of 4.5 km, the system includes 1 quarry (active), 1 overburden dump and 1 tailing dam. Agriculture and the mining industry are mainly developed in the system. The number of residents is about 4 thousand people. Based on the degree of contamination of the territory and technogenic load, the system is also classified as "medium polluted" (category 2).

The system has accumulated 155 million tons of industrial waste from the above-mentioned facilities, recorded by the register. The total disturbed land area is 410 hectares, of which quarry is 115 hectares, overburden dump is 109 hectares, and tailing dam is 186 hectares. The total volume of resulting quarry cavities is estimated at 47 million m^3, the total volume of accumulated waste as potential backfill materials is 72.3 million m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Dnipro system. In the specified system, quarry cavities and industrial waste heaps are located in Dnipropetrovsk Oblast, mainly in the south-eastern area of the city of Dnipro, in the Samarskyi district of the city (Fig. 13).

Figure 13. Dnipro system, schematic representation

The system conducts open-pit mining of granite deposits. The system has 3 quarries (active), 1 ash slag dump, 1 ash dump, 1 sludge depository, 2 overburden dumps, which are not included in the regional waste register. The system also has developed machine building industry, chemical and construction industries, urban and public buildings, as well as an important road and railway hub. The number of people living in places where quarries and industrial waste heaps are concentrated is about 75 thousand people. Industrial enterprises have a powerful impact on the environment and the population. Based on the degree of contamination of the territory and technogenic load, the system is classified as "extremely polluted" (category 5).

The system has accumulated almost 50 million tons of industrial wastes from the above-mentioned facilities, recorded by the register. The total disturbed land area is 540 hectares, of which quarry is 66 hectares, overburden dumps are 16 hectares, and ash slag dumps are 460 hectares. The total volume of resulting quarry cavities is estimated at 30 million m^3, the total volume of accumulated waste as potential backfill materials is 59.5 million m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Horishni Plavni system. In the specified system, quarry cavities and industrial waste heaps are located in Poltava Oblast within the boundaries of Horishni Plavni and Kremenchuk cities (Fig. 14).

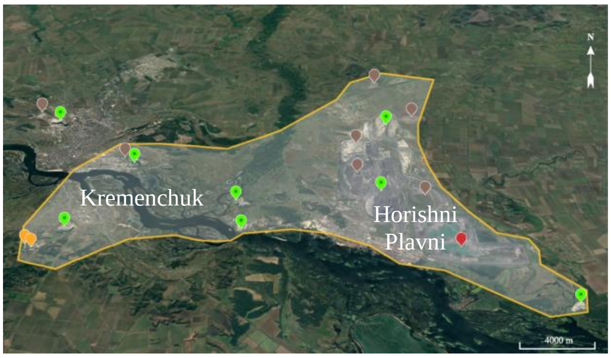

Figure 14. Horishni Plavni system, schematic representation

The system conducts open-pit mining of ferruginous and magnetite quartzites, as well as granite deposits. Within a diameter of 21 km, the system includes 6 quarries (5 active, 1 mothballed), 6 overburden dumps, 1 tailing dam for iron ore beneficiation, and 2 metallurgical slag dumps. The system has a well-developed industry, agriculture and transport infrastructure. The number of residents is about 260 thousand people. Industrial enterprises have a powerful impact on the environment and the population. Based on the degree of contamination of the territory and technogenic load, the system is classified as "highly polluted" (category 4).

The system has accumulated almost 2.86 billion tons of industrial wastes from the above-mentioned facilities, recorded by the register. The total disturbed land area is 4397 hectares, of which quarries are 1073 hectares, overburden dumps are 1835 hectares, tailing dam is 1468 hectares, and slag dumps are 21 hectares. The total volume of resulting quarry cavities is estimated at 0.871 billion m^3, the total volume of accumulated waste as potential backfill materials is about 1.26 billion m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Mariupol system. In the specified system, quarry cavities and industrial waste heaps are located in the south of the Donetsk Oblast, within the boundaries of the city of Mariupol, on the coast of the Sea of Azov (Fig. 15). However, since May 2022, the city has been occupied by the russia.

Figure 15. Mariupol system, schematic representation

The system conducted open-pit mining of granite deposits. Within a diameter of 15 km, the system includes 2 non-active quarries, 1 overburden dump, 4 metallurgical slag dumps, and 1 ash dump. The system has well-developed metallurgical, machine building, construction industries, as well as urban and public buildings and transport infrastructure. The number of residents is about 420 thousand people. Industrial enterprises have a powerful impact on the environment and the population. Based on the degree of contamination of the territory and technogenic load, the system is classified as "extremely polluted" (category 5).

The system has accumulated 92 million tons of the indicated industrial wastes. The total disturbed land area is 460 hectares, of which quarries are 43 hectares, overburden dump is 14 hectares, slag dumps are 350 hectares, and ash dump is 53 hectares. The total volume of resulting quarry cavities is estimated at 14.6 million m^3, the total volume of accumulated waste as potential backfill materials is about 64.7 million m^3, which indicates a positive balance and a sufficient level of backfill material supply.

Novotroitske-Dokuchaievsk system. In the specified system, quarry cavities and industrial waste heaps are located in the southern area of the Donetsk Oblast in the vicinity of the cities of Novotroitske and Dokuchaievsk (Fig. 16), which are currently occupied by the russia. The city of Dokuchaievsk has been occupied since 2014, and the city of Novotroitske since 2022.

Figure 16. Novotroitske-Dokuchaievsk system, schematic representation

The system conducts open-pit mining of dolomite, flux limestone, limestone, and dolomitized limestone deposits. The system includes 6 quarries (5 active and 1 inactive), 12 overburden dumps and waste from crushing and beneficiation plants, of which only 6 are included in the State register. The system has well-developed mining and agriculture. Transport infrastructure is moderately developed. The number of residents is about 27 thousand people. Industrial enterprises have a powerful impact on the environment and the population. Based on the degree of contamination of the territory and technogenic load, the system is classified as "highly polluted" (category 4).

The system has accumulated 400 million tons of waste overburden and waste from beneficiation plants. The total disturbed land area is 1730 hectares, of which quarries are 1020 hectares, and overburden and waste dump is 710 hectares. The total volume of resulting quarry cavities is estimated at 0.462 billion m^3, the total volume of accumulated waste as potential backfill materials is about 0.211 billion m^3, which indicates an overall negative balance and a low level of backfill material supply. It should be noted that due to the occupation of the territory on which the system is located, consideration of this system is further significantly complicated by the lack of data on the state of quarry reserves and projected data of the completion of mining operations, especially in the city of Dokuchaievsk, since this territory has been occupied since 2014.

Lysychansk system. In the specified system, quarry cavities and industrial waste heaps are located in the western area of the Luhansk Oblast in the vicinity of the city of Lysychansk (Fig. 17), which has been occupied by the russia since the summer of 2022.

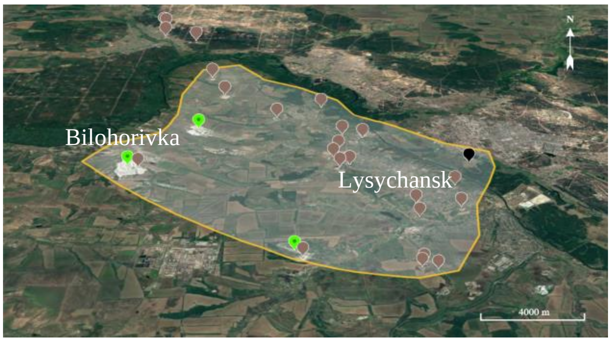

Figure 17. Lysychansk system, schematic representation

The system uses the open-pit method for mining chalk deposits and underground method for mining hard (bituminous) coal. Within a diameter of 21 km, the system includes 3 quarries (1 active and 2 inactive), 2 overburden dumps (not included in the State register), 17 mine rock dumps, and 1 ash dump. The system has a widely developed industrial complex, the basis of which is enterprises of the coal, chemical, construction industries, and agriculture. The system has a well-developed transport infrastructure. The number of residents is about 95 thousand people. Industrial enterprises have a powerful impact on the environment and the population. Based on the degree of contamination of the territory and technogenic load, the system is classified as "extremely polluted" (category 5).

The system has accumulated 55 million tons of the indicated industrial wastes. The total disturbed land area is 388 hectares, of which quarries are 150 hectares, and overburden dump of quarries is 58 hectares, mine rock dumps are 147 hectares, and ash dump is 33 hectares. The total volume of resulting quarry cavities is estimated at 23.2 million m^3, the total volume of accumulated waste as potential backfill materials is about 32.7 million m^3, which indicates an overall positive balance and a sufficient level of backfill material supply.

Based on the conducted research, a histogram has been compiled illustrating the balance between the cavities formed in the depths of the mining industry and accumulations of large-tonnage industrial waste as potential backfill materials in the identified "quarry cavities – backfill material" systems (Fig. 18). As can be seen from the histogram, in Ukraine there are systems of different scales. It is worth noting that over time, the cavities of active quarries will increase in volume, as will the industrial waste accumulation in the region. It is believed that the balance will be maintained.

Figure 18 analysis shows that the largest scale of cavities formed in the subsoil and industrial waste accumulations are observed during mining of iron ore and flux limestone deposits in the following systems: Kryvyi Rih system No. 1 (1); Kryvyi Rih system No. 2 (2); Kryvyi Rih system No. 3 (3); Kryvyi Rih system No. 4 (4); Horishni Plavni system (10); Novotroitske-Dokuchaievsk system (12).

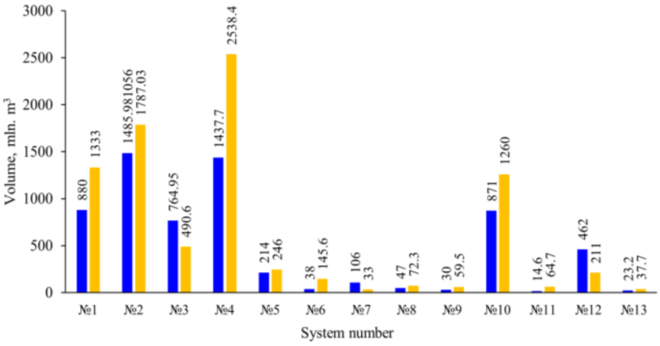

Figure 18. Formation of a balance between cavities formed in the subsoil and accumulations of backfill materials: volume of the cavities formed, mln. m³; accumulated backfill material volume, mln. m³

The histogram illustrates the current balance of systems relative to cavities formed in the subsoil and industrial waste accumulations, describing, above all, the overall supply of systems with backfill material volumes calculated for all cavities. The negative balance of cavities and backfill materials in some systems (Fig. 19) does not mean that backfilling the mined-out space is impossible.

In the identified systems, the order of backfilling the mined-out space in certain quarries will depend on their lifespan, the social-economic situation in the region, legislative norms and environmental policy, as well as on the responsibility of enterprises and the development of the government strategy for restoring the disturbed land areas. The histogram shows the general balance situation in the system and if negative, it only characterizes the possible lack of sufficient volumes of backfill materials. However, for investment projects on the earth's surface restoration, a positive balance is important to minimize risks.

Of significant importance in the "quarry cavities – backfill material" system is directly the state of the quarry cavities (active/inactive), which at different times may be subject to backfilling the mined-out space. It is important to understand that some quarries in the regions may have already been closed, while some continue their economic mining activity.

For this purpose, for each identified "quarry cavities – backfill material" system, a gradation of quarries has been compiled according to the predicted lifespan. All systems have a total of 46 quarries (Fig. 19).

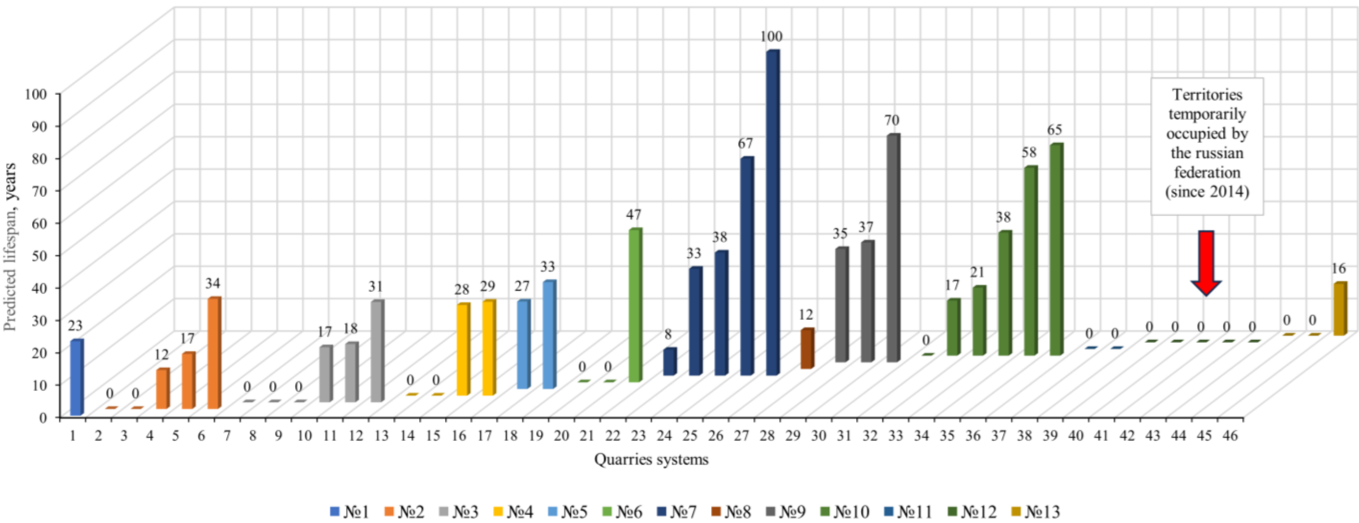

Figure 19. Distribution of quarries by predicted lifespan for the identified "quarry cavities – backfill material" systems (value "0" means that the quarry is inactive)

Figure 19 analysis shows the situation regarding the already existing quarry cavities for the development of projects for backfilling the mined-out space and those that will gradually be decommissioned over time. Thus, in systems No. 1, 5, 7, 8, 10, there are currently no ready cavities for considering the possibility of their backfilling. The projected decommissioning of quarries occurs both in the relatively short-term perspective – 8-17 years, and in the long-term perspective of 20-70 and even 100 years. The situation is different in systems No. 2, 3, 4, 6, 10, 11, where there are inactive quarries in different statuses: temporarily stopped, mothballed or closed, however, compared to active quarries, they have priority in restoring the earth's surface level disturbed by mining operations. On the one hand, the presence of inactive quarry cavities in the specified systems indicates a priority for backfilling. On the other hand, if agricultural or forestry activities are too developed in the system, priority will be given to backfill technologies using bulky backfill material, since it does not require the high geomechanical earth's surface stability, which is the focus of research. To achieve geomechanical stability in technogenic cavities, in the future it is planned to consider backfill technologies with the formation of an artificial monolithic mass or a combination with a bulky one.

Thus, determining the general level of priority for the "quarry cavities – backfill material" systems requires the consideration of a significant set of factors that will influence the need for the earth's surface restoration. Some factors of the analyzed systems are considered and compared further in the research.

4.2. Priority for implementation of identified "quarry cavities – backfill material" systems

An important task is to assess and select precisely from the 13 identified promising "quarry cavities – backfill material" systems on the territory of Ukraine for the implementation of technologies for backfilling the technogenic cavities and restoring the earth's surface level. It is the understanding of the backfill mass formation in technogenic cavities (quarries, mine failure zones) that presupposes the achievement of its geotechnical reliability for the further use of restored land for the development of industrial and civil infrastructure. Research has chosen a number of factors, the significance of which is explained further.

Population size. A higher population density in the region, where the "quarry cavities – backfill material" system is considered for implementation in the future, means a more urgent need for land restoration and the creation of new infrastructure facilities. This may also be important from an environmental and social point of view, as land restoration can improve the living conditions, safety and health of local people.

Number of areas disturbed by mining operations. The area of land disturbed by mining operations should be an indicator of the urgency of restoration. The more the disturbed area, the more important becomes the "quarry cavities – backfill material" system for the restoration of these areas and their environmental rehabilitation.

Balance of cavities and backfill material. This factor is critically important, since for the successful system implementation, it is necessary to have an available backfill material volume that meets the needs for restoring the technogenic cavities. This is a priority when the volumes of backfill material exceed the volumes of technogenic cavities. The balance is determined by the ratio of the volume of backfill materials to the volume of cavities formed.

Degree of readiness for backfilling. This factor indicates how quickly backfilling of technogenic cavities for the purpose of restoration can begin. If the quarries are in the final phase of mining, this can significantly accelerate the system implementation, since the cavities can already be considered ready for backfilling. In addition, the presence in the system of mine failure zones, which represent additional ready-made cavities, is of no small importance.

Industrial and construction potential of restored areas. The development of industry and construction in the region can create additional demand for new facilities and infrastructure, requiring new land areas. This may increase the economic efficiency and feasibility of implementing the system. The factor is considered in the context of the existing industrial-construction potential in the regions where the systems exist.

Potential for creating a geomechanically stable mass. The creation of stable geomechanical masses in cavities will ensure the safety and stability of new infrastructural facilities on the restored earth's surface, such as industrial enterprises, structures and buildings for various purposes, including energy and civil ones. Geomechanical earth's surface stability can be achieved by creating an artificial monolithic backfill mass, which requires reserves of binding and inert materials. Therefore, if there is an accumulation of relevant waste in the system, the system is considered to be of higher priority.

Level of environmental pollution of territories. In regions with a high environmental pollution level, the implementation of the "quarry cavities – backfill material" system can contribute to the disposal of industrial waste, the reduction of technogenic landscapes and the cleanup of contaminated areas, which has a positive effect on the environment and public health.

Development of transport and communications. The level of infrastructure development, the availability of transport communications and logistics capabilities can significantly influence the choice of a system. The more infrastructure developed areas are more attractive.

Each of these factors plays its role in prioritizing the "quarry cavities – backfill material" system and ensures a balance between the environmental, economic and social policies of the government for sustainable development and restoration of the earth's surface.

Based on the studied quantitative and qualitative values of selected factors in promising "quarry cavities – backfill material" systems, their distribution by the level of priority has been compiled: very low, low, medium, high, extremely high (Table 3).

When compiling the correspondence of the actual factor values to the developed scale of values, it is possible to qualitatively assess both the level of priority of each factor of the system, and the systems themselves as a whole. For this purpose, according to the "quarry cavities – backfill material" systems, a matrix of values for a set of factors has been developed, given in Table 4.

Table 4 data analysis shows that the following systems have the greatest advantages in terms of above factors: Kryvyi Rih system No. 2, Kryvyi Rih system No. 3, Kryvyi Rih system No. 4, Horishni Plavni system, and Mariupol system. These systems combine the largest number of factors with maximum priority levels: "high" and "extremely high". It is in these systems that optimal conditions have been created for the further development of effective technologies for backfilling the technogenic cavities and investments.

Table 3. Scale of factor values of the "quarry cavities – backfill material" systems by priority level

Priority level of factor values	Very low	Low	Medium	High	Extremely high
Population, thousand residents (I_1)	0-50	50-100	100-150	150-200	> 200
Disturbed land areas, ha (I_2)	0-1000	1000-2000	2000-3000	3000-4000	> 4000
Balance of cavities and backfill material (I_3)	< 0.5	0.5-1.0	1.0-1.5	1.5-2.0	> 2
Degree of readiness for backfilling, years (I_4)	> 40	30-40	20-30	10-20	0-10
Industrial potential of restored areas (I_5)	Very low	Low	Medium	High	Extremely high
Potential for creating a geomechanically stable mass (I_6)	Very low	Low	Medium	High	Extremely high
Pollution level of territories (I_7)	Very low	Low	Medium	High	Extremely high
Development of transport and communications (I_8)	Very low	Low	Medium	High	Extremely high

Table 4. Qualitative presentation of the matrix of values for a set of factors according to the "quarry cavities – backfill material" systems

Factors / systems	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
I_1													
I_2													
I_3													
I_4													
I_5													
I_6													
I_7													
I_8													

It should be noted that the concept of developing a complete restoration of the earth's surface disturbed by mining operations in identified potential systems is possible in the conditions of synergistic interaction between government authorities and the pivate sector. Thus, the results obtained provide valuable information for the development of government strategy and environmental programs for the restoration of land areas disturbed by mining operations and their subsequent use for industrial purposes. The identified 5 systems are the most promising and can bring the maximum benefit for the environment, economy and society. The economic efficiency of restoring the disturbed earth's surface based on backfill technologies is in the future benefits of using the territory in multidirectional infrastructure projects and exempting enterprises from paying environmental taxes for environmental pollution.

Directions for further research should be the scientific substantiation of rational and optimal methods for backfilling the technogenic cavities in the identified 5 promising "quarry cavities – backfill material" systems.

5. Conclusions

This research makes an attempt to identify and assess the parameters and characteristics of the "quarry cavities – backfill material" systems on the territory of Ukraine to create a basis for determining an effective mechanism and effective measures to fully restore the earth's surface state disturbed by mining operations, thereby strengthening the domestic and international image of Ukraine as a responsible and environmentally conscious country. The following results of the research have been obtained.

1. Attention is focused on creating a stable backfill mass in resulting technogenic cavities (quarry cavities, failure zones) for restoring the earth's surface level in regions with developed industrial and construction infrastructure, given geomechanical reliability, which could prove to be a very promising and perspective direction. It has been revealed that today it is not precisely determined where on the territory of Ukraine there are prospects for the formation of land masses for restoring the earth's surface state. To date, the spatial location of the resulting quarry cavities and industrial waste heaps, which can potentially be considered as backfill materials, has not been sufficiently studied.

2. A new concept and theoretical representation of "quarry cavities – backfill material" has been formulated. The presented characteristics of a number of important conditions for the harmonious existence and effective implementation of promising "quarry cavities – backfill material" systems will allow optimizing the backfill process, reducing economic costs, ensuring environmental safety and receiving support from society and government authorities.

3. A methodical approach to identifying promising systems has been developed, which will be useful for scientists and government authorities to focus on certain regions where it is possible to successfully achieve earth's surface restoration based on backfill technologies. It has been revealed that on the territory of Ukraine, backfilling of the mined-out space of quarries for the complete earth's surface restoration is expedient to consider in 13 regions where potential "quarry cavities – backfill material" systems are located. Each system has been analyzed in terms of its geographical location, number of active quarries and places of industrial waste accumulation, level of industrial and infrastructural development, population size, level of contamination of the territory, volume of cavities formed and backfill materials with their balance, total number of disturbed land areas and individual objects.

4. A histogram has been compiled illustrating the current balance in systems for cavities formed in the depths and accumulations of industrial waste, which characterizes, first of all, the overall supply of systems with backfill material volumes calculated for all cavities. For each identified "quarry cavities – backfill material" system, a gradation of quarries (46 pcs.) has been compiled according to the predicted lifespan, illustrating the situation regarding the already existing quarry cavities for the development of projects for backfilling the mined-out space and those that will gradually be decommissioned over time.

5. It has been determined that the following systems have the greatest advantages according to the set of technological, ecological, economic and social factors: Kryvyi Rih system No. 2, Kryvyi Rih system No. 3, Kryvyi Rih system No. 4, Horishni Plavni system, and Mariupol system. These systems combine the largest number of factors with maximum priority levels: "high" and "extremely high". It is in these systems that optimal conditions have been created for the most economical, environmental and technological implementation of operations for backfilling the mined-out space of the formed technogenic cavities and restoring the earth's surface level disturbed by mining operations.

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Аналітичні дослідження параметрів та характеристик нових систем “кар’єрні пустоти – закладний матеріал”: на прикладі України

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Мета. Виявлення, дослідження та вивчення параметрів і характеристик систем “кар’єрні пустоти – закладний матеріал” на території України із використанням нового комплексного методичного інструментарію, що формує підґрунтя для розробки ефективних способів відновлення земної поверхні з акцентом на промислове та будівельне використання.

Методика. Використано комплексний підхід, який включає: аналіз просторового розташування на території України накопичень промислових відходів як потенційних закладних матеріалів та утворених кар’єрних пустот, що не підлягають повному відновленню земної поверхні, визначення об’ємів утворених пустот і закладних матеріалів. За комплексом факторів виконано ранжування за пріоритетністю систем “кар’єрні пустоти – закладний матеріал”. Використані наступні інструменти: інформаційні дані Державного геологічного фонду України, реєстри місць накопичення промислових відходів за регіонами, супутникова програма Google Earth, топографічна онлайн-карта (OpenStreetMap) та програма Blender для побудови 3D-моделей.

Результати. Сформульовано нове поняття та теоретичне уявлення “кар’єрні пустоти – закладний матеріал”. Надана характеристика низки важливих умов гармонійного існування й ефективної реалізації перспективних систем “кар’єрні пустоти – закладний матеріал”. Створено нову інформаційно-аналітичну карту просторового розташування потенційних закладних матеріалів та утворених кар’єрних пустот. Визначено 13 перспективних системи та їх параметри, у межах яких доцільно розглядати технології закладання для повного відновлення земної поверхні. Визначено існуючий баланс пустот і закладних матеріалів по виявлених системах, а також складено градацію кар’єрів за прогнозним терміном їх існування.

Наукова новизна. Уточнено системи “кар’єрні пустоти – закладний матеріал”, що володіють найбільшими перевагами, шляхом їх ранжування за комплексом технологічних, екологічних, економічних та соціальних факторів.

Практична значимість. Отримані результати є цінною інформацією для розробки державної стратегії та екологічних програм щодо відновлення порушених гірничими роботами територій на основі технологій закладання та їх подальшого використання у промислових цілях.

Ключові слова: *кар’єрні пустоти, промислові відходи, закладний матеріал, закладний масив, відновлення земної поверхні, екологічна небезпека*