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DEVELOPMENT OF METHODOLOGICAL APPROACHES TO ENVIRONMENTAL EVALUATION OF THE INFLUENCE OF MAN-MADE MASSIFS ON THE ENVIRONMENTAL OBJECTS

Приведено методологічні підходи до комплексної екологічної оцінки наслідків розміщення гірничопромислових відходів на земній поверхні. Проаналізовано вплив техногенних масивів, що утворились внаслідок накопичення гірничих відходів на стан ґрунтів, атмосферного повітря, водних об'єктів та біоту із застосуванням напівкількісних (бальних) методів і матричної оцінки впливів. Наведені основні етапи оцінки впливу техногенних відходів на компоненти довкілля.

Ключові слова: *гірничопромислові відходи, техногенні масиви, екологічна оцінка, матриця Леопольда, функція Харрінгтона.*

1. Introduction

A significant number of industrial enterprises of various economic sectors are concentrated in Ukraine, as a result of which more than 30 billion tons of industrial wastes have accumulated. Annually, about 1 billion tons of waste is generated, located in more than 1.5 thousand man-made massifs, such as dumps, sludge and tailing dumps, which generally occupy an area of more than 150 thousand hectares [1, 2].

The overwhelming majority of man-made massifs formed as a result of the activities of mining and energy enterprises. And in combination with the unresolved issue of critical overfilling of landfills, the global problem of waste acquires a catastrophic scale in Ukraine [3–5]. That is why it is urgent to create methodological bases for an integrated evaluation of danger level of waste disposal facilities for mining enterprises.

2. The object of research and its technological audit

The object of research is environmental safety of mining enterprises. The level of environmental danger of mining enterprises at different stages of the life cycle depends on the energy and resource intensity of applied technologies, as well as the effectiveness of the applied environmental measure. The extraction of minerals is accompanied by the formation of significant volumes of mining waste placed on the earth's surface and a source of complex negative impact on the components of the environment, both at the stage of operation of the enterprise and after its liquidation.

One of the most problematic places in systemic studies is the insufficient number of specialists who can be involved in a comprehensive evaluation of the environmental consequences of the long-term disposal of mining waste on the earth's surface. Therefore, there is a need to develop unified methods, the use of which will allow to analyze the technological processes of mining enterprises and to be more dangerous from the ecological point of view, on which significant amounts of waste are generated. This will allow the timely development and implementation of technological schemes aimed at reducing the volume of waste generation, as well as their use in various sectors of the economy.

3. The aim and objectives of research

The aim of research is determination of the patterns of changes in the environmental state of environmental objects in the areas adjacent to the locations of mining waste.

To achieve this aim, the following tasks are set:

1. Development of a methodological approach to the environmental evaluation of mining waste location.
2. Investigation of the environmental consequences of waste disposal of mining enterprises in rock dumps.
3. Evaluation of the environmental state of the areas adjacent to the sludge depositories of waste from mining and processing of minerals.

4. Research of existing solutions of the problem

Long-term mining of minerals on the territory of Ukraine is accompanied by the formation of multi-factor impacts on environmental components and the emergence of environmental risks at various stages of field development [4]. It should be noted that the waste of the liquidated mining enterprises forms a special danger to the environment [5]. In [3], an environmental reserve criterion was developed for evaluation of the environmental state of territories adjacent to waste storage sites, which determines the risk factors for emergencies.

In the authors' studies [6–9], attention is focused on the need to study the environmental risks of the functioning of both individual industrial facilities and natural and man-made complexes, in order to ensure the sustainable development of man-made-loaded regions of Ukraine.

In [10], checklists are developed for a comprehensive evaluation of the negative consequences of the impact of man-made massifs (tailing dumps) on the components of the environment. The authors of [11] propose a generalized algorithm for the diversification of technologies for handling waste from coal mines located in rock dumps. The typology of waste heaps of the Lviv-Volyn Coal Basin according to the degree of disturbance of landscapes [12] allows to determine the most effective ways of their reclamation.

Most of the considered studies allow to identify certain problems in the formation and operation of man-made massifs, but do not solve the problem of a comprehensive evaluation of the environmental consequences of waste disposal.

Evaluation of the impact of man-made massifs on the environment is a complex scientific task, since the negative impact of industrial waste on the components of the environment is difficult to formalize in the form of quantitative indicators. That is why for the purposes of rapid environmental evaluation and further monitoring of the state of man-made massifs, it is possible to apply semi-quantitative methods of scoring expert judgment with subsequent use of matrix analysis.

5. Methods of research

Environmental danger occurs at different stages of the formation and further development of man-made massifs (rock dumps and sludge depositories). To evaluate its levels, it is recommended to take into account the intensity and periodicity of negative impacts on the components of the environment and biota using the matrix method proposed by L. Leopold, as well as the generalized Harrington desirability function.

Evaluation of the impact of man-made massif on environmental components included the following stages:

1. Justification of the lists (checklists) of environmental objects and the types of impact on these components, which later form in the form of matrices.
2. Determination of the levels of anthropogenic massif impact on the components of the environment at different stages of its operation, for example, during development, conservation, reclamation, etc.
3. Determination of the total indicators of the impact of man-made massifs on individual components and their analysis in order to determine the critical objects of impact, that is, the components of the environment that are most affected.
4. Conducting an evaluation of the consequences of the impact of a single man-made massif on the environment using Harrington's generalized desirability function and interpreting the evaluation results using a normalized comparative scale.

6. Research results

As an example of implementation of the proposed methodological approach, let's present the results of an environmental impact evaluation for a typical waste dump and sludge depositories facility for waste processing and after the completion of their operation.

For the compilation of matrices, two checklists were justified: a list of the types of impact of man-made massifs and a list of environmental objects are the targets of the impact. The evaluation results of the effect of typical sludge depositories and tailings dumps on environmental components during and after operation are summarized in Tables 1 and 2.

As can be seen from Table 1, in the exploitation of man-made massifs in the form of sludge depositories, underground and surface waters, as well as fauna in the adjacent to the sludge depositories, are vulnerable, and after their operation – flora and fauna, as well as ground water. The most dangerous types of impact on environmental components during operation of sludge depositories are pollution of aquifers and anthropogenic eutrophication of surface water bodies. Thus, the total impact on environmental objects during operation of slurry storage facilities is estimated at 107 points, and after their operation – 98 points.

Table 1

The influence matrix of typical sludge depository on the environmental components during/after operation

Types of impact / Components of the environment		Atmospheric		Hydrospheric				Geomechanical			The amount of influence on the components of the environment
		Dust emission	Gas emission	Pollution of aquifers	Land Flooding	Wastewater discharge	Anthropogenic eutrophication	Surface subsidence	Excavations, hills	Development	
Air basin	Microclimate	1/1	0/0	2/1	2/2	1/1	2/2	0/0	0/0	0/0	8/7
	Chemical composition	2/1	1/1	2/1	1/1	1/1	2/2	0/0	0/0	0/0	9/7
Water basin	Surface water	1/1	0/0	3/2	2/2	2/2	3/2	1/1	1/1	1/1	14/12
	Ground water	2/1	0/0	3/2	2/2	2/2	2/2	2/2	1/1	1/1	15/13
Earth surface	Soils	1/1	1/1	2/2	2/2	1/1	2/1	1/1	1/1	1/1	12/11
	Landscape changes	1/1	1/1	2/2	1/1	2/2	2/2	2/2	2/2	1/1	14/14
Subsoil		0/0	0/0	2/2	0/1	2/2	0/0	1/1	3/1	0/0	8/8
Biota	Flora	2/2	1/1	2/2	2/2	2/2	1/1	1/1	1/1	1/1	13/13
	Fauna	2/2	1/1	2/2	2/1	1/1	2/2	1/1	2/2	1/1	14/13
Amount by type of impact		12/10	5/5	20/16	14/14	14/16	16/14	9/9	11/10	66	107/98

Note: the influence characteristics are determined by the peer review method: 0 – no effect; 1 – influence is insignificant; 2 – influence is average; 3 – influence is strong.

Table 2

Matrix of influence of a typical rock dump on environmental components during/after operation

Types of impact / Components of the environment		Atmospheric		Hydrospheric				Geomechanical			The amount of influence on the components of the environment
		Dust emission	Gas emission	Pollution of aquifers	Land Flooding	Wastewater discharge	Anthropogenic eutrophication	Surface subsidence	Excavations, hills	Development	
Air basin	Microclimate	1/0	1/0	1/0	1/1	1/1	1/1	0/0	0/0	1/1	7/4
	Chemical composition	3/2	2/1	0/0	0/0	0/0	1/0	0/0	0/0	1/1	7/4
Water basin	Surface water	2/1	1/0	3/2	3/2	3/2	3/2	2/1	2/1	1/1	20/12
	Ground water	1/0	0/0	2/1	2/1	1/1	1/1	2/1	2/1	1/1	12/7
Earth surface	Soils	2/1	1/0	2/1	1/1	1/1	1/1	2/1	2/1	2/1	14/8
	Landscape changes	1/1	1/0	3/2	2/2	1/1	2/1	2/1	3/1	3/2	18/11
Subsoil		0/0	0/0	0/0	0/0	0/0	0/0	1/1	2/1	0/0	4/2
Biota	Flora	1/1	1/0	2/1	2/1	2/1	2/1	1/1	2/1	3/2	17/9
	Fauna	1/1	1/0	2/1	2/1	1/1	2/1	1/1	2/1	3/2	16/9
Amount by type of impact		14/7	8/1	15/8	13/9	10/8	13/8	11/7	16/7	15/11	115/66

Based on the results of the evaluation of the impact of man-made massifs in the form of rock dumps (Table 2), it is found that the most vulnerable are surface waters, landscapes and flora on the territory adjoining the dumps, after their exploitation – the landscape, groundwater, flora and fauna. The most dangerous types of impact on the components of the environment in the operation of rock dumps are geomechanical changes in the relief, as well as pollution of aquifers and the atmosphere. The total impact on environmental objects during the exploitation of man-made massifs in the form of rock dumps is estimated at 115 points, and after completion of their operation, significantly less – in 66 points.

To interpret the results of the impact evaluation of man-made massifs on the environmental components, the generalized Harrington desirability function and the approach proposed in [13] are used.

Harrington desirability function is one of the effective methods for determining the generalized recall of the influence of industrial objects, including the man-made massifs on the components of the environment. The construction of this generalized function is based on the idea of converting the natural values of reviews (in this case, the intensity of the impact of man-made massifs) into a dimensionless scale of desirability or the benefits of the consequences of these impacts. The desirability scale refers to psychophysical scales. Its purpose is establishment of a correspondence between physical and psychological parameters. Here, physical parameters are understood as possible reviews caused by the functioning of man-made massifs.

Parameters of a function can be not only statistical, but also aesthetic, and psychological parameters are understood as purely subjective evaluations by the researcher of the desirability (advantage) of a particular value of the response.

The Harrington desirability function is given by the following equation:

$$d = \exp[-\exp(-y)],$$

where d – desirability value varying from 0 to 1; y – the response value recorded in a conditional scale.

The value of 0 is chosen as the origin, which corresponds to a desirability value of 0.37. The choice of this particular point is due to the fact that it is the inflection point of the curve, which in turn creates certain convenience in the calculations. The same is true for the desirability value corresponding to 0.63. The choice of such equation is not the only possibility. However, it arose as a result of observations of real solutions of researchers and possesses such useful properties as continuity, monotonicity, smoothness. Symmetrically with respect to zero on the y-axis (y is the coded scale), the encoded response values are located. The value on the coded scale is from –3 to 6

Although in practice, in order to obtain more accurate feedback, it is advisable to narrow this interval a little (from –2 to 5). For example, the authors of [13] propose to use the minimum value of the force of the impact of the man-made object – 100, which corresponds to 2, and the maximum – to 300. This corresponds to 5 according to the original scale of the abscissas of the Harrington function.

To obtain estimates on the desirability scale, it is necessary to use the developed correspondence tables between the relationships in the verbal and numerical systems. In this case, to determine the verbal characteristics of the impact desirability of man-made objects on the environment, a scale is used, presented in Table 3.

Table 3

Scale of desirability characteristics of consequences for the environment from the impact of man-made massifs with the Harrington function

Desirability characteristics	Desirability value (d)
Very good	0–0.2
Good	0.2–0.37
Satisfactorily	0.37–0.63
Bad	0.63–0.8
Very bad	0.8–1

The results of determining the parameters and evaluating the effect with the Harrington functions for man-made massifs are summarized in Table 4.

Table 4

Evaluation of the impact of man-made massifs with the Harrington function during and after operation

Parameters for evaluation of the effect of objects with the Harrington function	Sludge depository		Dump	
	during	after	during	after
The number of non-zero values in matrices	67	68	66	56
Significance of all impacts, g	1.49	1.47	1.52	1.79
Amount for all impacts on objects	107	98	115	66
Total impact force, I	159.7	144.12	174.24	117.86
Minimum impact force, $I_{\min}$ ($y=-2$)	100.00	100.00	100.00	100.00
Maximum impact force, $I_{\max}$ ($y=5$)	300	300	300	300
Scale y	28.57	28.57	28.57	28.57
Conversion of the impact force to the scale y (–2; 5)	0.09	–0.46	0.60	–1.38
Axis value, d	0.40	0.21	0.58	0.02
Desirable characteristics	satisfactory	good	satisfactory	very good

In the course of the work it is established that man-made massifs in the form of sludge depositories and rock dumps have «satisfactory» characteristics of desirability for the environment during their operation. While, after operation for sludge depositories, the desirability characteristic is «good», and for rock dumps it is «very good». It should also be noted that obtained results depend on the parameters and indicators of the incoming matrices, which in turn are evaluated by experts.

7. SWOT analysis of research results

Strengths. The methodological approach proposed in the work allows obtaining a generalized evaluation of the impact of a certain man-made massif on the environment and identifying the most sensitive components of the environment at different stages of exploitation of the man-made massif. The main advantage of this technique is the ability to compare and rank man-made massifs according to the hazard factor, as well as to justify the necessity of implementing environmental measures for the most vulnerable components of the environment from their impact. Based on the methods of peer review, it is advisable to apply the approach when it is impossible to obtain complete and accurate information on the component composition of an anthropogenic massif in a timely manner and evaluate its impact on environmental objects. In addition, the availability of data on the state of anthropogenic massif from observations by direct and calculated methods helps to increase the reliability of the environmental impact evaluation of the waste impact on environmental objects.

Weaknesses. The environmental danger of man-made massifs depends on many factors: chemical and mineralogical composition of rocks, the peculiarities of physico-chemical internal and external transformations in combination with climatic and hydrogeological conditions, and the like. The nature and intensity of the impact of man-made massifs on the environment depends on the conditions of its location and the objects to which negative influence is directed. In the process of accumulation, the chemical composition of mining waste experiences serious transformations and does not coincide with the initial, which also means a discrepancy between the pre-determined hazard class. That is why research into the environmental consequences of industrial waste disposal requires the availability of specialized equipment and personnel that is able to control the concentration of pollutants in the surrounding areas.

To determine the environmental consequences of the location of man-made massifs, including with various options for their operation, it is necessary to attract engineering and technical staff of mining enterprises, leading experts in the extractive industry, scientists, and representatives of environmental inspections. This, in turn, increases the accuracy of the research, but increases the cost and duration of the research.

Opportunities. The results of a comprehensive evaluation of the environmental state of environmental objects on the territories of location of man-made massifs in the form of rock dumps and sludge depositories are a theoretical and practical basis for solving applied problems, namely:

– planning of an environmentally sound level of man-made load;
– development of schemes for extracting useful components from waste;
– development of methods for reclamation of man-made objects.

The use of research results will allow the enterprise to identify ecologically dangerous technological production processes in a timely manner and to reduce pollution levels of adjacent territories. This, in turn, will improve the working conditions of the company's employees, as well as reduce the number of environmentally-dependent diseases of the population in mining cities, will contribute to increasing the social responsibility of the enterprise and ensuring its sustainable functioning.

The availability of information on the quantitative and qualitative composition of waste will allow enterprises to increase the volumes of their utilization and reduce the costs of transportation and storage of waste and payment of an environmental tax for their formation. In addition, it is expected to reduce the area of land allocated for the placement of large-tonnage waste production and processing of minerals.

The possibility of using Leopold matrices and Harrington logistic function for complex evaluation of environmental danger of typical bulk man-made massifs (rock dump and sludge depository) at various stages of their life cycle is substantiated in the work. This allows the enterprise to promptly identify critical technological processes from an environmental point of view and to implement appropriate environmental measures in a timely manner. Such approaches will contribute to the greening of the mining industry, the successful environmental audits of mining enterprises, the receipt of international environmental certificates and, accordingly, the development of new product markets.

Threats. To implement effective environmental protection measures in the sphere of waste management, there is a need to involve an environmental specialist in the staff of the enterprise. The environmental specialist will ensure timely monitoring of waste generation volumes,

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justification of the directions of their further use in various industries, and development of ways to reduce the environmental hazard of waste.

8. Conclusions

1. A methodological approach to the environmental evaluation of mining waste sites is developed, which includes the following stages:

– collection, processing and systematization of information on volumes and component composition of waste;
– compilation of checklists of environmental consequences of waste disposal at various stages of the life cycle of man-made massifs;
– environmental evaluation of danger levels of man-made massifs;
– identification of environmental components that are most affected by waste sites;
– development of environmental decisions and effectiveness evaluation of their implementation.

The implementation of the proposed methodology will make it possible to comprehensively evaluate the environmental risks of certain technological links of mining enterprises, and develop ways to minimize them. This will reduce the levels of environmental pollution and increase the comfort of living in the mining regions.

2. The environmental consequences of waste disposal of mining enterprises in rock dumps are investigated. The most dangerous types of impact on the components of the environment during the operation of rock dumps are geomechanical changes in the relief, pollution of aquifers and the atmosphere. The total impact on environmental objects during the exploitation of man-made massifs in the form of rock dumps is estimated at 115 points, and after completion of their operation, significantly less – in 66 points.

3. An evaluation of the environmental condition of the areas adjacent to the sludge depository of waste from mining and processing of minerals is made. The greatest danger to the components of the environment during the operation of sludge depository is the contamination of aquifers and anthropogenic eutrophication of surface water bodies. The total impact on environmental objects during operation of sludge depository is estimated at 107 points, and after their operation – 98 points.

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РАЗРАБОТКА МЕТОДОЛОГИЧЕСКИХ ПОДХОДОВ К ЭКОЛОГИЧЕСКОЙ ОЦЕНКЕ ВЛИЯНИЯ ТЕХНОГЕННЫХ МАССИВОВ НА КОМПОНЕНТЫ ОКРУЖАЮЩЕЙ СРЕДЫ

Приведены методологические подходы к комплексной экологической оценке последствий размещения горнопромышленных отходов на земной поверхности. Проанализировано влияние техногенных массивов, которые образовались в результате накопления горных отходов на состояние почв, атмосферного воздуха, водных объектов и биоты с применением полуколичественных (бальных) методов и матричной оценки воздействий. Приведены основные этапы оценки воздействия техногенных отходов на компоненты окружающей среды.

Ключевые слова: горнопромышленные отходы, техногенные массивы, экологическая оценка, матрица Леопольда, функция Харрингтона.

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