ЕКОЛОГІЧНІ ПРОБЛЕМИ В ЕНЕРГЕТИЦІ
ENVIRONMENTAL PROBLEMS IN ENERGY

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ESTIMATION OF RISKS FOR DEVELOPMENT OF NATURALLY TECHNOGENIC ENVIRONMENTS

The risks of development of such natural-tech environments as landfills of solid household waste, tailings dams, waste heaps at extraction of minerals for the possibility of their re-use as a basis of structures for civil and industrial construction are carried out in the work. The example of the Boryspil solid waste landfill highlights the main indicators of sources of risk: human impact, risk of explosions and fires, respiratory response, sanitary-epidemic danger, effect on the atmospheric air, impact on the ground cover, accumulation of heavy metals on groundwater in the presence of systems for collecting and draining filtration water, deformation of the surface. The methodology of Failure Mode and Effects Analysis was used to expertly assess the risks of reuse of areas occupied by natural and man-made environments for the construction of civilian and industrial sites. The experts were asked to rank the action by paired comparisons. A pairwise comparison consisted in a consistent comparison of each action with each other. The methodology assumes a risk rating based on the Risk priority number, which is a product of the rankings obtained by expertly assessing the severity of the consequences and the likelihood that an object will not be detected, by the frequency of emergencies. First, the risks with the highest Risk priority number are eliminated. Possible scenarios and combinations of risk spectrum scenarios (technical, environmental, social, economic) have been identified. These priorities were ranked in descending order (from 10 to 0): the highest score was assigned to the maximum value (the most dangerous) that was given effect. The results of the expert evaluation of the signs of severity and non-detection obtained from one expert are presented. We show matrices of related trait severity and non-detection traits, compiled by all experts. 16 experts participated in our work. Based on the ranking of expert indicators, matrices for estimating the impact of sources of risk for the choice of remediation direction and subsequent use of natural-tech environments were constructed. The result was used to quantify the risk presented by the criticality matrix of this indicating system, a measure of its impact on its reliability.

Key words: naturally technogenic environments, solid waste landfill, risk assessment, Risk priority number, sustainability.

Introduction. The urgency of solving problems related to the development of landfills, dumps, tailings and landfills closed for the reception of solid household waste is determined by the shortage of free space in urbanized territories and the need for high-cost rehabilitation of old landfill formations, potentially dangerous in environmental and sanitary and epidemiological terms. Risk assessment in the development of these territories is a key factor in reducing potential negative impacts. The most common method of waste management in Ukraine is their disposal at solid household waste landfills or landfills. Every year Ukraine produces more than 10 million tons of solid household waste at existing landfills and polygons with a total area of 9.4 thousand hectares [1].

Field researches by determination of composition of municipal solid waste were conducted in 2010-2011 on municipal solid waste landfill of Boryspil of Kiev region, the average on classification of Public service of statistics of Ukraine the city with the population of 57.5 thousand inhabitants placed in 15 km from Kiev with big business activity and a share of the population living in the private sector. According to local management of housing and communal services from total amount of educated municipal solid waste a third is the share of administrative and commercial agencies; at the same time 67% of waste are the share of the inhabited sector from which 50.1% – inhabited apartment houses, and 49.9% – the private sector [1-4].

Considering specifics of Boryspil, it was separately studied municipal solid waste which was formed in apartment buildings, the private sector and office rooms. In spite of the fact that such distribution is rather conditional, the composition of municipal solid waste in these three sources considerably differs, and such approach allowed to estimate correctly different streams of municipal solid waste and their contribution to the general the number of formation of municipal solid waste in Boryspil.

Classification of components of the studied municipal solid waste in Boryspil provided in tab. 1 [1-4]. It differs from classification of organic components of the guidelines of IPCC a little, was developed and claimed 2006 for all member countries of the SWC Env Ind project: To Ukraine, Lithuania, Georgia and Russia.

Table 1 Classification of components of municipal solid waste, Boryspil

№	Fraction	Subfraction	Note
1	Paper and cardboard	Mixed paper	
		Office paper	
		Glossy paper	
		Newsprint	
		Cardboard	
2	Plastic	PET bottles	White, Blue, Green, Brown *
		HDPE	Products from rigid polyethylene
		PVC	Polyvinyl chloride products
		PS	Polystyrene products
		Another plastic	Plastic not in other categories
3	TetraPack		Cardboard based multilayer packaging
4	Food waste		All food waste except bone
5	Landscaping waste		Grass, branches, plant residues and other plant material
6	Wood		Large branches, bars, furniture and more
7	Another Organic		Textiles, leather, rubber and more
8	Ferrous metals		
9	Non-ferrous metals	Aluminum	
		Other non-ferrous metals	
10	Glass	Transparent	
		Brown	
		Green	
		Blue	
		Not packing	
		Mixed	
11	Another inorganic		Construction debris, ceramics, stones, sand, bones and more
12	Hazardous waste		Batteries, lamps, sharp objects, medical waste, etc.

The absence of a civilized waste management system for many decades has led to a large variety of old landfill bodies, many of which, despite long lifetimes (60 or even 100 years), the presence of sanitary backfilling from the ground remains sources of methane and groundwater pollution.

Goal and tasks. The purpose of the work is to carry out a risk assessment of the development of natural engineering environments for further use as the basis of civil and industrial construction structures.

Presentation of the main research material. Analysis of physical and chemical processes in the landfill body of the technogenic environment, engineering and technical problems arising on the natural technical environments at the final stages of the life cycle, allows to determine the following environmental risks caused by deposited without preliminary treatment of natural technical environments and prevent active urban planning development (reuse) of the territories of technogenic environments [1-4]:

- emissions and migration of biogas;
- contamination of groundwater, soils with filtrate;
- deformation of polygon working body;
- sanitary-epidemic danger of the territory of solid household waste landfill.

Thus, in order to ensure the most optimal and economical set of measures to prepare the territories for economic use, taking into account the required minimization of risks, it is necessary to find out which of these risks should be managed first.

Ranking risks of this kind is a complex technical and economic task, involving diverse, sometimes disparate, factors. This problem can be solved by means of mathematical and statistical methods combined with heuristic methods, which have been increasingly recognized in recent years by mathematicians, economists and ecologists, which have been developed in ISO 14000 standards in particular [5].

Failure Mode and Effects Analysis (FMEA) is a special system reliability and safety assessment technique designed to detect and eliminate technical problems in complex systems and to analyze and assess risks that differ in nature and direction of impact, strength and time of occurrence [6].

The FMEA analysis methodology is based on an expert assessment of the problem being studied. Experts make up for the lack of quantitative information to a large extent. The methodology involves risk assessment by RPN rank, which is the product of ranks obtained by expert assessment of severity of consequences (A) and probability of non-detection (B) of the object, by frequency of emergency situations (E). First of all, the risks with the highest RPN are eliminated [6].

Expert Group was asked to consider the impact of landfills closed for receiving solid waste on the environment and in terms of the risk of accidents, the severity of the consequences and possibilities of their discovery, and then rank the impact and justify their answers. The severity of the consequences for the environment and humans was determined taking into account legal liability in accordance with ISO 14000 [5]:

•there are no public or legislative restrictions - low hazard potential,

• increased attention in society, presence of special legislative restrictions - medium potential of danger,

• great risk of accidents, causes debate in society, significant legislative restrictions - great potential danger.

Experts were invited to rank impacts by paired comparisons. The pair comparison consisted in a consistent comparison of each exposure with each other: if A is more important than B, 1.0 point is assigned; If B is more important than A, 0 is assigned; If A and B are equal, 0.5 points are assigned. The following were considered as impacts in the post-culturing period:

• human effects:
  - danger of explosions and fires (x_1);
  - effects on the respiratory tract (x_2);
  - sanitary and epidemic hazard (x_3);
• effects on atmospheric air (greenhouse effect, depletion of the ozone layer x_4);
• influence on soil cover (death of the root system of plants in case of violation of the gas regime of soil x_5);
• accumulation of heavy metals in soil (x_6);
• effects on groundwater with filtration water collection and discharge systems (x_7);
• surface deformations (x_8).

For each criterion, a matrix of conjugate characteristics was compiled and the priority value P_k and the total value of all priorities P were determined.

$$P_k = \sum_{i=1}^{8} x_i\,,\ \ k = \overline{1,n}; \tag{1}$$

$$P_i = \sum_{k=1}^{n} P_k\,, i = \overline{1,x_i}; \tag{2}$$

where *n* is the number of independent experts.

Normalization of the priority value was carried out for each impact according to the formula:

$$P_{k\_rel} = P_i / \sum P_i. \tag{3}$$

The ranking of these priorities was carried out in descending order (from 10 to 0): the highest score was assigned to the maximum value (the most dangerous) that received the impact [6]. Tables 2, 4 show the results of an expert assessment of the signs according to the severity of consequences and non-detection, obtained from one expert. Tables 3, 5 show matrices of conjugate signs by severity of consequences and by non-detection, compiled according to the results of evaluations by all experts. 16 experts took part in our work.

Table 2 Table of ranging on weight of consequences by one expert

Impacts	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	$\boldsymbol{P_k}$
X_1	0,5	0,5	0,5	0,5	0	1	0,5	1	4,5
X_2	0,5	0,5	1	1	0	0	0	0,5	3,5
X_3	0,5	0	0,5	0,5	0	0,5	1	0,5	3,5
X_4	0,5	0	0,5	0,5	1	0,5	0,5	0	3,5
X_5	1	1	1	0	0,5	0	0,5	0,5	4,5
X_6	0	1	0,5	0,5	1	0,5	0,5	0	4
X_7	0,5	1	0	0,5	0,5	0,5	0,5	1	4,5
X_8	0	0,5	0,5	1	0,5	1	0	0,5	4

Table 3 Matrix of conjugated characteristics by severity of consequences (A)

	Experts																
Impacts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	***P_i***	**$\sum P_i$**	***P_{k_rel}***
X_1	4,5	1,5	0,5	3,5	3,5	4,5	0,5	3,5	3,5	7,5	1,5	3,5	0,5	6,5	45	459	0,0980
X_2	3,5	6,5	4,5	2,5	2,5	3,5	4,5	2	2,5	0,5	6,5	2,5	4,5	5,5	51,5		0,1122
X_3	3,5	5	4,5	1,5	1,5	3,5	4,5	1	1,5	6,5	5	1,5	4,5	2,5	46,5		0,1013
X_4	3,5	5,5	5,5	6,5	6,5	3,5	5,5	5	6,5	1,5	5,5	6,5	5,5	1,5	68,5		0,1492
X_5	4,5	5	4,5	4,5	4,5	4,5	4,5	3,5	4,5	3,5	5	4,5	4,5	5,5	63		0,1373
X_6	4	5	6	2,5	3,5	4	6	4,5	3,5	4,5	5	3,5	6	1,5	59,5		0,1296
X_7	4,5	1	5	4,5	5,5	4,5	5	6,5	5,5	4,5	1	5,5	5	4,5	62,5		0,1362
X_8	4	2,5	2	6,5	7,5	4	2	6,5	7,5	3,5	2,5	7,5	2	4,5	62,5		0,1362

Table 4 Ranking table by non-detection by one expert

Impacts	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	***P_k***
X_1	0,5	0	0	0	0	0	0,5	0,5	1,5
X_2	1	0,5	1	0,5	0,5	1	1	1	6,5
X_3	1	0	0,5	0	0	0,5	1	1	4
X_4	1	0,5	1	0,5	0,5	0,5	1	1	6
X_5	1	0,5	1	0,5	0,5	0,5	1	1	6
X_6	1	0	0,5	0,5	0,5	0,5	1	0,5	4,5
X_7	0,5	0	0	0	0	0	0,5	0	1
X_8	0,5	0	0	0	0	0,5	1	0,5	2,5

Table 5 Matrix of conjugated characteristics by probability of non-detection (B)

	Experts																
Impacts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	***P_i***	**$\sum P_i$**	***P_{k_rel}***
X_1	1,5	4,5	1,5	6,5	6,5	1,5	4,5	6,5	5,5	6,5	5,5	5,5	5,5	3,5	65	440,5	0,1476
X_2	6,5	5,5	6	5,5	5,5	6	5,5	2,5	2,5	5,5	5	2,5	2,5	3	64		0,1453
X_3	4	1,5	4,5	3,5	3,5	4,5	1,5	3,5	2,5	3,5	7	2,5	2,5	2	46,5		0,1056
X_4	6	6,5	5,5	0,5	2,5	5,5	6,5	1,5	7,5	0,5	4,5	7,5	7,5	4	66		0,1498
X_5	6	4,5	2,5	5,5	6,5	2,5	4,5	4,5	1,5	5,5	2,5	1,5	1,5	5	54		0,1226
X_6	4,5	5,5	5,5	2,5	3,5	5,5	5,5	3,5	3,5	2,5	2	3,5	3,5	4	55		0,1249
X_7	1	1,5	4,5	2,5	2,5	4,5	1,5	3,5	2,5	2,5	1,5	2,5	2,5	6	39		0,0885
X_8	2,5	2,5	1	5,5	1,5	1	2,5	1,5	6,5	5,5	3,5	6,5	6,5	4,5	51		0,1158

Table 6 Ranking table by RPN

Impacts		**A**		**B**	**E**	**RPN**
X_1	0,098	4	0,1476	9	9	**324**
X_2	0,1122	6	0,1453	8	8	**384**
X_3	0,1013	5	0,1056	4	6	120
X_4	0,1492	10	0,1498	10	7	**700**
X_5	0,1373	9	0,1226	6	3	162
X_6	0,1296	7	0,1249	7	5	245
X_7	0,1362	8	0,0885	6	4	192
X_8	0,1362	8	0,1158	5	10	**400**

Based on the resulting conjugate feature matrices according to the FMEA methodology, factors are ranked by the total criterion RPN (Table 6), the value of which is defined as the product of ranks A, B, E:

$$RPZ = A \cdot B \cdot E. \tag{4}$$

The RPN risk parameter indicates the relationship between the causes of the hazards. First of all, the risks with RPN index most exceeding the allowed value of RPN = 125 are eliminated. If one of indicators A, B, E is 9 or 10, risk reduction measures should be developed. RPN values from 40 to 100 mean risk, RPN < 40 negligible risk. Correction parameters for risk reduction are developed in the following sequence: elimination of causes of emergency situation (reduction of parameter E); Decrease of cause effect (decrease of parameter A); High probability of detecting an emergency situation for this reason (reduction of parameter B).

Based on the evaluation of expert views on RPN, it can be concluded that the indicators with high severity of effects (RPN > 125) are:

- atmospheric air exposure (greenhouse effect, ozone depletion x_4) RPN = 700;
- surface deformations (x_8) RPN = 400;
- airway exposure (x_2) RPN = 384;
- explosion and fire hazard (x_1) RPN = 324.

It should be noted that experts find it difficult to assess the sanitary and epidemic danger of landfill soils and the degree of danger of developing vehicle surface deformations.

Selection of the direction of recultivation and subsequent use of the CAT territory should be carried out taking into account minimization of these risks, first of all - formation, accumulation, migration of landfill gas, reduction of impact on the ozone layer, reduction of risk of surface deformation.

A set of measures, including preliminary mechanical and biological treatment of natural media before burial, filtrate collection-removal systems and biogas, will also reduce RPN environmental risks to medium and negligible risks.

Conclusion. The work using the methodology Failure Mode and Effects Analysis carried out an assessment of the risks of re-development of the territory using the example of Boryspil landfill of solid household waste. The main indicators of the sources of risks are identified: human impact; Danger of explosions and fires; Effects on the respiratory tract; sanitary and epidemic danger; Effects on atmospheric air; Impact on soil cover; Effects on groundwater when filtration water collection and discharge systems are available; deformations of a surface. Possible scenarios and their combinations of risk spectrum (technical, environmental, social, economic) were identified. Based on the ranking of experts 'indicators, matrices are constructed to estimate the impact of risk sources. Based on an evaluation of the expert opinion on RPN, it was found that the high-severity indicators were atmospheric air effects (greenhouse effect, ozone depletion RPN = 700; deformations of a surface RPN=400; Respiratory effects RPN = 384; Explosion and fire hazard RPN = 324. The result was used to select the direction of recultivation and subsequent use of natural-man-made media.

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ОЦІНКА РИЗИКІВ ПРИ ОСВОЄННІ ПРИРОДО-ТЕХНОГЕННИХ СЕРЕДОВИЩ

У роботі проведена оцінка ризиків освоєння таких природно-техногенних середовищ як полігони твердих побутових відходів, хвостосховища, відвали при видобутку корисних копалин для можливості їх повторного використання як основи споруд для цивільного і промислового будівництва. На прикладі Бориспільського полігону твердих побутових відходів виділені основні показники джерел виникнення ризиків: дії на людину, небезпека вибухів і пожеж, дія на дихальні шляхи, санітарно-епідемічна небезпека, дія на атмосферне повітря, вплив на грунтовий покрив, накопичення важких металів в грунті, впливи на грунтові води за наявності систем збору і відведення фільтраційних вод, деформації поверхні. Використовувалася методологія проведення аналізу Failure Mode and Effects Analysis для експертної оцінки ризиків вторинного використання територій, зайнятих природно-техногенними середовищами для будівництва цивільних і промислових об'єктів. Проведено визначення можливих сценаріїв і комбінацій сценаріїв спектру ризику (технічного, екологічного, соціального, економічного). На основі ранжирування показників експертів побудовані матриці оцінка впливу джерел ризику для вибору напряму рекультивації і подальшого використання природно-техногенних середовищ. Результат використовувався для кількісної оцінки ризиків, представлений матрицею критичності цієї системи тієї, що показує, міру впливу на її надійність.

Ключові слова: природно техногенні середовища, полігон твердих побутових відходів, оцінка ризиків, RPN, стійкість.

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