Southeastern Europe Tunnelling Conference (SETC-2025)
1-3 October 2025, Belgrade, Serbia

DOI: 10.5937/SETC25039K

Methodology for Geoecological Risks Assessing during the Operation of Metro Facilities

Elena Kulikova[a], Sergey Zhukov[b]*

[a] Russian Technological University MIREA, National University of Science and Technology "MISIS", Department of Environmental and Industrial Safety, Moscow, Russia; fragrante@mail.ru
[b] JSC "Mosmetrostroy"; reception-3@metrostroy.ru

Abstract: When assessing the geo-ecological risk of operating underground facilities, it is necessary to take into account dangerous hydrogeological (the nature of groundwater migration, its temperature regime, composition and mineralization, hydrostatic and piezometric pressure, etc.) and geological (karst, suffusion-erosion, landslide processes, rock collapse, etc.) processes. The most visible type of geological risk assessment is the compilation of geological risk maps and the development of a system of indicators of the level of geological danger for a specific mining area, which is implemented through a matrix of the level of geological risks for various territorial objects. The geo-ecological risk has been calculated for each technological process for shallow and deep tunnels. An expert method was used to rank geo-ecological risks and determine their quantitative characteristics at the stage of operation of metro facilities. The paper shows the software module of the information and analytical model, which makes it possible to quantify the risk. A geo-ecological risk management system has been developed, which makes it possible to determine the distribution zones of the most dangerous processes in the "rock mass – technology –tunnel" system based on forecast calculations. The presented methodology for assessing geo-ecological risks during the operation of metro facilities makes it possible to predict the development of emergency situations and assign monitoring and protective measures based on the establishment of acceptable geo-ecological risk values in each specific case.

Keywords: geoecological risk; metro facilities; management system; emergency; monitoring

1. Introduction

Geoecological risk in underground construction is the probability of adverse events resulting in a disruption of the stability of the existing natural and technical geosystem "rock mass – technology – underground structure" as a result of geotechnical activities.

The levels of geo-ecological risk that must be considered in tunnel construction are as follows:

- negligible geo-ecological risk is the maximum level set by regulatory authorities that requires special measures to eliminate it;
- acceptable geo-ecological risk – the maximum level justified from ecological, geotechnical, socio-economic and ecological positions;
- maximum permissible geo-ecological risk – the maximum level allowed by the policy of a mining and construction organization in the field of environmental safety.

When assessing the geo-ecological risk of operating metro facilities, it is primarily necessary to take into account dangerous hydrogeological (the nature of groundwater migration, its temperature regime, composition and mineralization, hydrostatic and piezometric pressure, etc.) and geological (karst, suffusion-erosion, landslide processes, rock collapse, etc.) processes.

The most obvious type of geological risk assessment, as already noted, is the compilation of geological risk maps and the development of a system of indicators of the level of geological danger for a specific

*Corresponding author: gidrotehnik@inbox.ru (E. Kulikova).

mining area, which is implemented through a matrix of the level of geological risks for various territorial objects, while according to international practice, there are 7 groups, each of which characterizes a certain type of or a significant geological risk factor, for example, suitability for the development of underground space, the presence of tectonic processes., groundwater activity, terrain features, karst activity, etc.

2. Methodology

The level of potential geological risk is determined for each specific situation:

- low level, not requiring managerial decision-making;
- the average level, which determines the recommendatory nature of the applied risk management measures;
- a high level that determines the need to take risk management measures;
- a very high level, which necessarily prescribes the adoption of risk management measures.

The identified level of geological risk determines the nature of filling in the matrix as the basis for drawing up risk maps. The maps show the distribution of the potential geological risk of this type in the considered operational area.

The assessment of geoecological risk also determines the consideration of socio-man-made factors that manifest themselves through non-compliance with the operating regime, violation of the work passport, violation of the ventilation regime, non-compliance with safety regulations and sanitary protection standards, etc. In addition, at the stage of operation are taken into account:

- modification of the heat and mass transfer system between the underground structure and the host rock mass;
- changes in soil composition and structure;
- air pollution of the working area by dust and gases from the operation of equipment or rolling stock;
- depletion and pollution of groundwater, changes in the nature of their migration, temperature regime, composition, etc.;
- geomechanical transformation of the Earth's surface.

The calculation of geoecological risk is carried out in relation to each technological process, while coefficients of significance of the consequences of a particular technological process are introduced:

$$R_i = \frac{N_{ij} \sum k_{ij}}{N_j \sum k_j}, \tag{1}$$

where i – the index of the technological process; j – the index of abnormal consequences from the technological process; N_{ij} и N_j – the number of potential undesirable consequences of the i-th process on the natural and technical system and on the totality of potential consequences, respectively; k_{ij} и k_j – coefficients of significance of the consequences of the i-technological process and all possible j-consequences.

The generalized geo-ecological risk R_0 will be determined from the formula:

$$R_o = \sum_i^j P_i k_i, \tag{2}$$

where P_i – the probability of the manifestation of the i-th process; k_j – the coefficient of significance of the i-th process within the boundaries of the natural and technical geosystem.

To rank geoecological risks and determine its quantitative characteristics at the stage of operation of metro facilities, an expert method was used, the results of which are shown in Table 1.

The types of geoecological risk indicated in Table 1 can be assessed by introducing normalization coefficients that characterize the proportion of the most unfavorable event taken as a unit.

Thus, the geoecological risk during the operation of shallow tunnels can be calculated using the formula:

$$R_g = R_s + R_h + R_a + R_{gw}, \tag{3}$$

where R_s – the risk of geomechanical transformation of the territory; R_h – the risk of changing the heat and mass transfer system between an underground object and the host rock mass; R_a – risk of contamination inside the tunnel atmosphere; R_{gw} – the risk of pollution and depletion of the water basin.

Table 1. Quantitative values of geoecological risks.

No.	Negative environmental processes	The degree of manifestation of the negative process	Code	Coefficient of significance of the negative process indicator
	Shallow tunnels			
1.	Geomechanical transformation of the territory			0,3
	Potential precipitation of the Earth's surface	Small	1	
		Big	2	
	Development of surface forms of karst	Small	1	
		Big	2	
2.	Modification of the heat and mass transfer system between an underground structure and the host rock mass	Small	1	0,2
		Big	2	
3.	Atmospheric pollution	Small	1	0,15
		Big	2	
4.	Pollution and depletion of groundwater			0,35
	Flooding of the territory	Small	1	
		Big	2	
	Changes in temperature conditions and migration patterns	Small	1	
		Big	2	
	Deep-laid tunnels			
1.	Pollution inside the tunnel atmosphere	Small	1	0,1
		Big	2	
2.	Changes in the underground hydrosphere			0,6
	Infiltration into groundwater tunnels	Small	1	
		Big	2	
	Changes in the hydrological regime of groundwater	Small	1	
		Big	2	
3.	Geomechanical transformations of the host rock mass			0,3
	Changing the composition and structure of soils	Small	1	
	The development of underground forms of karst	Big	2	
		Small	1	
		Big	2	

The risk of geomechanical transformation of the territory is determined as follows:

$$R_s = (\delta_{ss} q_{ss} + \delta_k q_k) p, \tag{4}$$

где δ_{ss} – coefficient of significance of geomechanical transformation of the territory; q_{ss} – the value of the indicator code for geomechanical transformation of the territory; δ_k – coefficient of significance for the development of karst processes; q_k – the value of the karst process development indicator code; p – the normalizing indicator.

The risk of pollution and depletion of a water basin will be defined as:

$$R_{gw} = \left(\delta_f q_f + \delta_r q_r\right)w, \tag{5}$$

где δ_f – coefficient of significance of flooding of the territory; q_f – the value of the territory flooding indicator code; δ_r – coefficient of significance of changes in the regime of groundwater and surface waters; q_r – the value of the indicator code for changes in the regime of groundwater and surface waters; w – the normalizing indicator.

The risk of atmospheric pollution is calculated using the formula:

$$R_a = \delta_a q_a \lambda, \tag{6}$$

where δ_a – coefficient of significance of atmospheric pollution; q_a – the value of the atmospheric pollution indicator code; λ – the normalizing multiplier.

The risk of a change in the heat and mass transfer system between the tunnel and the host array is calculated as follows:

$$R_h = \delta_h q_h m, \tag{7}$$

where δ_h – coefficient of significance of the change in the heat and mass transfer system between the tunnel and the host array; q_h – the value of the indicator code for the change in the heat and mass transfer system between the tunnel and the host array; m is the normalizing multiplier.

The geoecological risk during the operation of deep tunnels can be calculated using the formula

$$R_{ug} = R_m + R_{ua} + R_{ugw}, \tag{8}$$

where R_m – the risk of geomechanical transformation of the host rock mass; R_{ua} – risk of contamination inside the tunnel atmosphere; R_{ugw} – the risk of pollution and depletion of the water basin.

The risk of geomechanical transformation of the host rock mass is determined as follows:

$$R_m = \left(\delta_m q_m + \delta_{uk} q_{uk}\right)p_1, \tag{9}$$

where δ_m – coefficient of significance of changes in soil composition and structure; q_m – the value of the indicator code for changes in soil composition and structure; δ_{uk} – coefficient of importance for the development of underground karst forms; q_{uk} – the value of the indicator code for the development of underground karst formations; p_1 – the normalizing indicator.

The risk of contamination and depletion of the underground hydrosphere is defined as:

$$R_{ugw} = \left(\delta_{inf} q_{inf} + \delta_{hr} q_{hr}\right)w_1, \tag{10}$$

where δ_{inf} – coefficient of importance of infiltration into groundwater tunnels; q_{inf} – the value of the indicator code for infiltration into groundwater tunnels; δ_{hr} – coefficient of significance of changes in the hydrogeological regime; q_{hr} – the value of the hydrogeological regime change indicator code; w_1 – the normalizing indicator.

The risk of contamination inside the tunnel atmosphere is calculated using the formula:

$$R_{ua} = \delta_{ua} q_{ua} \lambda_1, \tag{11}$$

where δ_{ua} – coefficient of importance of pollution inside the tunnel atmosphere; q_{ua} – the value of the tunnel's atmospheric pollution indicator code; λ_1 – the normalizing multiplier.

3. Results

A quantitative analysis of these risks and the establishment of their acceptable values makes it possible to form a geoecological risk control system for the operation of metro facilities (Fig. 1).

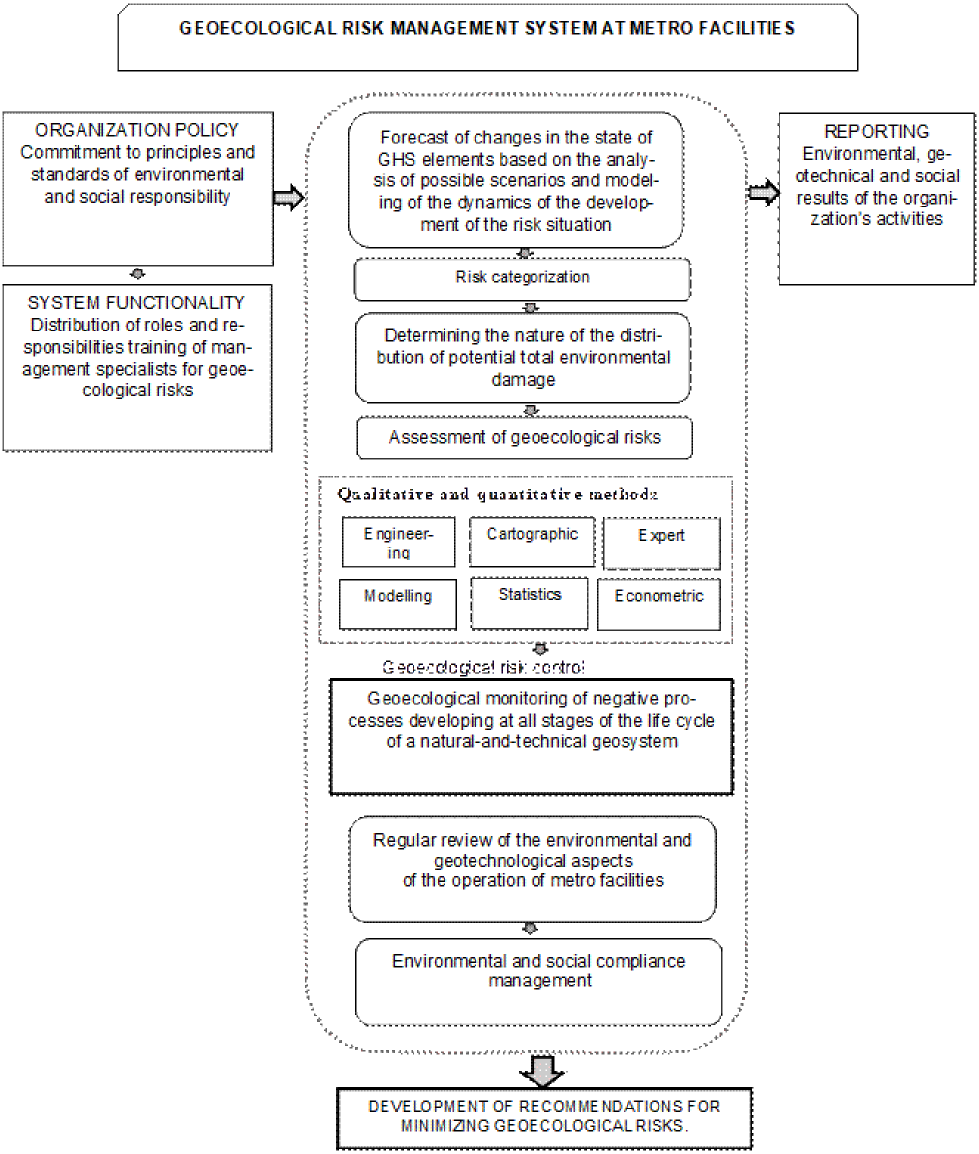

Fig. 1. Geoecological risk management system at metro facilities.

A quantitative risk assessment can be determined based on an information and analytical model, the program module of which is shown in Fig. 2.

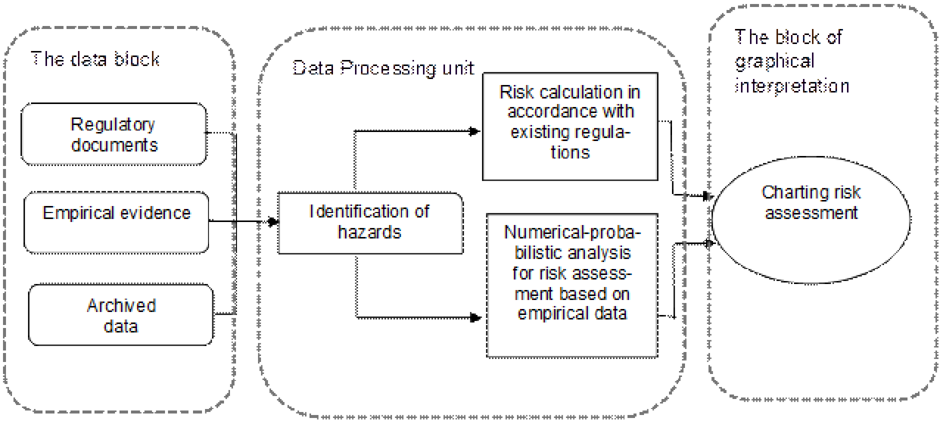

Fig. 2. Functional diagram of the software module.

For a qualitative analysis of the risk level, mapping can be used to identify the zone of maximum damage caused by negative processes caused by technological work during the operation of metro facilities.

The developed geoecological risk control system makes it possible to determine the distribution zones of the most dangerous processes in the rock mass – technology – tunnel system based on forecast calculations.

The presented methodology for assessing geoecological risks during the operation of metro facilities makes it possible to predict the development of emergency and assign monitoring and protective measures based on the establishment of acceptable geoecological risk values in each specific case.

4. Conclusion

1. For the first time, the question was raised about the concept of acceptable risk at the stage of operation of underground metro facilities, i.e. about the level according to which the threshold levels of acceptable and desired environmental safety are set in each specific case. The concept of acceptable risk is associated with a high probability of reducing the safety of technological processes due primarily to the environmental incompatibility of the methods used with natural factors. Moreover, engineering and geological factors are of primary importance.
2. A methodology for managing geoecological risks during the operation of metro facilities has been developed, which makes it possible, based on forecast calculations, to determine the distribution zones of the most dangerous processes in the "rock mass – technology – underground equipment" system.

References

Bourget ,A.P.F., Chiriotti E., Patrinieri E., 2019. Evolution of risk management during an underground project's life cycle. Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani&Celestino (Eds). London, Taylor & Francis Group. pp. 4375 – 4385.

Garber, V.A., 2018. Abnormal situations at underground transport facilities. Podzemnye gorizonty. (16):20–25 [In Russ.].

He, X.C., Xu, Y.S., Shen, S.L., Zhou, A.N., 2020. Geological environment problems during metro shield tunnelling in Shenzhen, China. Arabian Journal of Geosciences. vol. 13(2), art. 87. DOI: 10.1007/s12517-020-5071-z.

Hongjun, W., 2016. Earth human settlement ecosystem and underground space research. Procedia Engineering, vol. 165. pp. 765-781. DOI: 10.1016/j.proeng.2016.11.774.

Konyukhov, D.S., 2022. Analysis of mechanized tunneling parameters to determine the overcutting characteristics. Mining Science and Technology (Russia). 7(1):49-56. DOI: 10.17073/2500-0632-2022-1-49-56

Konyukhov, D.S., 2021. Criteria analysis of modern technologies of underground construction. Geotekhnika. no. 1, pp. 40–55. [In Russ].

Kim, D.Y, Farrokh, E., Song, M.K., Hyun, K.S., 2017. Cutting tool wear evaluation for soft ground TBMs. Proceeding of the World Tunnel Congress 2017. Surface challenges – Underground solutions. 9-15th June 2017, Bergen, Norway. Bergen

Kulikova, E. Yu., 2020. Methodical principles for improving the ecological and technological reliability of urban underground structures. MIAB. Mining Inf. Anal. Bull. (6–1):176-185. [In Russ]. DOI: 10.25018/0236-1493-2020-61-0-176-185

Kulikova, E.Yu., 2021. Safety and risk management in underground construction as a complex information process. MIAB. Mining Inf. Anal. Bull. (2–1):134-143. [In Russ]. DOI: 10.25018/0236-1493-2021-21-0-134-143

Kulikova, E.Yu., Balovtsev, S.V., Skopintseva, O.V., 2023. Complex estimation of geotechnical risks in mine and underground construction. Sustainable Development of Mountain Territories. 15(1):7-16. [In Russ]. DOI: 10.21177/1998-4502-2023-15-1-7-16.

Lebedev, M.O., 2018. Choosing a calculation method for stress-strain of supports and lining of transport tunnels. 16thWorld Conference of the Associated Research Centers for the Urban Underground Space (ACUUS 2018), 5-7 November, Hong Kong, pp. 678-687

Mahdi, S., Gastebled, O., Ningre, H., Senechal, M., 2019. Grand Paris Express, Line 15 East – predictive damage analysis combining continuous settlement trough modeling, risk management, automated vulnerability checks and visualization in GIS. – Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani&Celestino (Eds) – London, Taylor & Francis Group, pp. 5855-5864

Merisalu, J., Sundell, J., Rosén L., 2023. Probabilistic cost-benefit analysis for mitigating hydrogeological risks in underground construction. Tunnelling and Underground Space Technology. vol. 131(7): 104815. DOI: 10.1016/j.tust.2022.104815

Potapova, E. V., 2021. Typology of metro structures for the tasks of geotechnical risk classification. Mining Science and Technology (Russia). no. 6, pp. 52-60. [In Russ]. DOI: 10.17073/2500-0632-2021-1-52-60

Xing-Tao, Lin, Ren-Peng, Chen, Huai-Na, Wu, Hong-Zhan Cheng, 2019. Deformation behaviors of existing tunnels caused by shield tunneling undercrossing with oblique angle. Tunneling and Underground Space Technology. vol. 89, pp. 78-90. DOI: 10.1016/j.tust.2019.03.021

Xu, Y.S., Shen, J.S., Zhou, A.N., Arulrajah, A., 2018. Geological and hydrogeological environment with geohazards during underground construction in Hangzhou: a review. Arabian Journal of Geosciences. vol. 11, art. 544. DOI: 10.1007/s12517-018-3894-7.