21st International Conference Man and Working Environment
SEMSIE
Safety Engineering & Management - Science, Industry, Education

REVIEW PAPER

DOI: 10.46793/SEMSIE25.233B

DEJAN BOGDANOVIĆ[1]

[1]Belgrade University,
Technical Faculty in Bor, Serbia

[1]*dbogdanovic@tfbor.bg.ac.rs*

ANALYSIS OF MEASURES TO MITIGATE THE IMPACT OF UNDERGROUND COAL MINING ON THE ENVIRONMENT

Abstract: *Underground coal mines pose numerous risks of accidents and environmental hazards. The dangers to soil, surface water and groundwater are particularly noteworthy. For this reason, various measures must be taken to monitor, control and mitigate the environmental impact of mining activities. These measures ensure compliance with regulations, protect natural resources and promote sustainable mining practices. The paper discusses ten groups of key measures: air quality measures, water management measures, waste management measures, land reclamation and remediation measures, noise and vibration control measures, energy efficiency and carbon management measures, environmental monitoring and compliance measures, community and stakeholder engagement measures, health and safety measures, and innovative technologies and best practices. The AHP method was used for analysis. The ranking process was performed by workers and managers of different underground coal mines in Serbia using the group decision method. The findings reveal a clear differentiation among individual mitigation measures. Furthermore, the results underscore the significance of the analytical process in facilitating informed decision-making for both management and workers, enabling the identification of the most critical measures to minimize the environmental impact of underground coal mining.*

Keywords: Mine environment; Measures for mitigation; AHP; Underground coal mine

ORCID iDs: Dejan Bogdanović https://orcid.org/0000-0002-4871-4366

INTRODUCTION

Coal is widely regarded as the dirtiest of all fossil fuels. Underground coal mining is the first step in the dirty life cycle of coal, which has many harmful effects on the environment. These include landscape degradation, deforestation, and the release of toxic minerals and heavy metals into soil and water. The environmental repercussions of coal mining persist long after coal extraction has ceased. Furthermore, the environmental problems of underground coal mining also include mine accidents, subsidence and the disposal of mining waste. For instance, poor mining practices can trigger coal fires that may burn for decades, releasing fine ash and smoke laden with greenhouse gases and toxic chemicals. Additionally, mining operations emit methane gas—a greenhouse gas 20 times more potent than carbon dioxide.

To mitigate these adverse effects, it is crucial to identify and address potential environmental impacts at both current and abandoned mining sites. Key measures include assessing geophysical disturbances, implementing technologies to prevent the uncontrolled release of heavy metals into the environment, treating water pollution, and controlling air emissions.

Modern underground mining operations must integrate comprehensive environmental mitigation strategies from the outset. These include pollution control measures, continuous monitoring of mining activities, and systematic land rehabilitation efforts. The overarching goal of underground coal mining should be to minimize its environmental footprint, particularly concerning local communities, ecosystems, and the long-term viability of land use.

Implementing effective environmental engineering solutions in underground coal mines is essential for mitigating ecological damage, ensuring regulatory compliance, and fostering sustainable mining practices. By integrating technological, operational, and managerial strategies, the mining industry can reduce its environmental impact while continuing to meet global energy demands.

This paper aims to conduct a multi-criteria analysis of measures designed to mitigate the environmental impacts of mining activities. Additionally, essential mitigation strategies that significantly reduce the negative consequences of coal mining will be examined. These measures are crucial for regulatory compliance, the protection of natural resources, and the promotion of sustainable mining practices.

LITERATURE REVIEW

A range of measures have been developed and implemented to monitor, control, and mitigate the environmental impact of mining. The analysis of underground coal mining's effects on the environment is a subject of extensive research across multiple scientific disciplines, each approaching the issue from different perspectives. The body of literature on this topic is vast.

Underground coal mining releases significant quantities of toxic gases, including carbon monoxide (CO), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), total suspended particulates (TSP), smoke, and dust. These emissions negatively affect both the working environment (Shihang et al., 2023) and the surrounding ecosystem (Pandey et al., 2014). The aforementioned authors have proposed various mitigation strategies to reduce the environmental impact of these pollutants.

The relationship between coal mining and water resources, as well as its effects on water quality and availability, has been extensively discussed in the literature (Hasii & Gasii, 2024; Masood & Hudson-Edwards, 2020). These studies also explore measures to minimize and prevent the contamination of both groundwater and surface water.

Straupnik (2022) conducted an extensive examination of various waste types generated in coal mining operations, including overburden, host rock, tailings, petroleum products, waste oil, and dust. He highlighted that overburden contains sulphur and coal, along with trace amounts of non-ferrous and rare metals, as well as negligible concentrations of radionuclides such as thorium and uranium.

Lawrence (2003) and Gupta et al. (2006) emphasized that underground coal mining has the most severe environmental impact, particularly due to land subsidence resulting from the collapse of excavated areas.

Furthermore, mining activities can generate considerable noise and vibration, primarily due to underground blasting, the transportation of ore and overburden by trucks within the mining site, stockpiling, screening, and ore crushing. Additional sources of noise include truck and rail traffic associated with the delivery of consumables to the mine and the transportation of extracted materials for further processing (Mocek, 2023). Sensogut (2007) conducted a comprehensive study on noise pollution in mining operations, exploring various mitigation strategies to minimize its environmental impact.

Underground coal mining is a highly energy-intensive process, requiring substantial electrical power for plant operations. Consequently, energy audits are essential to identify and implement energy-saving measures (Kumar et al., 2021).

Coal mining is a significant contributor to carbon emissions. To address this issue, Li et al. (2022) propose a method for quantifying carbon emissions from coal mining as a critical step toward their reduction. Initially, a carbon emission threshold for fully mechanized coal mining is established. Subsequently, a carbon emission accounting model (B-R model) is developed to quantify the total emissions. Zhou et al. (2020) propose gas extraction and utilization and gas utilization as an effective mitigation measure.

Despite advancements in technology, underground coal mining continues to exert a substantial environmental impact. Dramlić et al. (2024) examine this impact, emphasizing the crucial role of environmental monitoring as a key component of environmental protection. Their study aims to analyze the interactions between underground mining and the environment, provide a comprehensive assessment of its environmental footprint, and highlight the importance of monitoring specific environmental parameters.

Sustainability in the mining industry is a critical concern due to its far-reaching social, economic, and environmental implications. Matikainen (2020) explores sustainability through the lens of stakeholder engagement, underscoring its necessity for addressing sustainability challenges. Effective engagement with key stakeholders—including local communities, employees, and governmental bodies—is imperative for developing sustainable mining practices.

The health and safety of underground coal mine workers remain a pressing global issue, given the recurring fatalities and disasters in the industry. Mahdevari (2014) introduces a fuzzy TOPSIS-based methodology for assessing occupational health risks, facilitating the implementation of control measures and informed decision-making. This model primarily serves to identify potential hazards and implement appropriate mitigation strategies to minimize or eliminate risks before accidents occur.

The coal mining industry has undergone continuous evolution, punctuated by several revolutionary advancements that have significantly transformed extraction methods, equipment, and overall productivity. In recent years, technological progress has increasingly emphasized the integration of communication systems, automation, and data science to enhance miner health and safety while optimizing operational efficiency (Bhattacharyya, 2023). Furthermore, the growing emphasis on environmental, social, and governance (ESG) considerations has introduced new dimensions of sustainability, simultaneously presenting complex challenges for the global mining sector. Consequently, the industry has been compelled to modernize, developing economically viable mining techniques that minimize environmental impact.

Koul (2024) investigates the application of robotics in underground coal mining to improve operational efficiency and safety through technological advancements. The deployment of high-tech robotic equipment has demonstrated substantial productivity gains while mitigating occupational health risks for workers. In highlighting these innovations, the study underscores the necessity of continuous advancements in robotics to maximize resource extraction and safeguard worker well-being, positioning robotic systems as a transformative force in the coal mining industry.

DATA AND METHODOLOGY

Research is being conducted in various underground coal mines across Serbia, which currently operates nine such mines with an annual production of up to 400,000 tons. The existing environmental monitoring practices in Serbia's underground coal mines lack systematic and comprehensive procedures (Dramlić et al., 2024). Consequently, further research is necessary to identify the most significant environmental impacts of underground coal mining and to determine appropriate mitigation measures.

This study identifies key measures for mitigating environmental impacts and ranks them based on research findings, expert consultations with coal mining professionals, and a literature review.

Environmental conditions in Serbian underground coal mines vary significantly, and while various mitigation measures are implemented, they are often fragmented and focus on specific impacts rather than providing a comprehensive approach. To develop a holistic set of mitigation strategies, this study engaged numerous mining experts and industry managers, ensuring a robust foundation for generating high-quality results.

AHP method

The Analytic Hierarchy Process (AHP) is a quantitative methodology designed to structure, analyze, and solve complex decision-making problems within a multidimensional hierarchical framework (Saaty, 1980). This hierarchical structure is composed of objectives, criteria, and alternatives.

AHP employs a pairwise comparison matrix to assess the relative importance of each criterion and to evaluate alternatives concerning each criterion. These comparisons are conducted using a numerical scale ranging from 1 to 9 (Table 1.), facilitating a systematic and consistent assessment of priorities.

Table 1. *Pair-wise comparison scale for the AHP method*

Verbal Judgement	Numerical Rating
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
2, 4, 6 and 8 are intermediate values	

Based on a comparison of decision elements, the application of an appropriate evaluation method leads to the final ranking of alternatives.

In this study, only the first step is employed to rank the criteria—identifying the most important working environment parameters—by calculating the relative strength of each criterion.

The research method

The original research methodology was developed to analyze and rank the measures for mitigating the impact of underground coal mining on the environment. The methodology consists of the following four steps: (1) literature review, data collection, (2) determination of the most important measures to mitigate the impact of underground coal mining on the environment, (3) AHP calculations, and (4) results and discussion (Figure 1.).

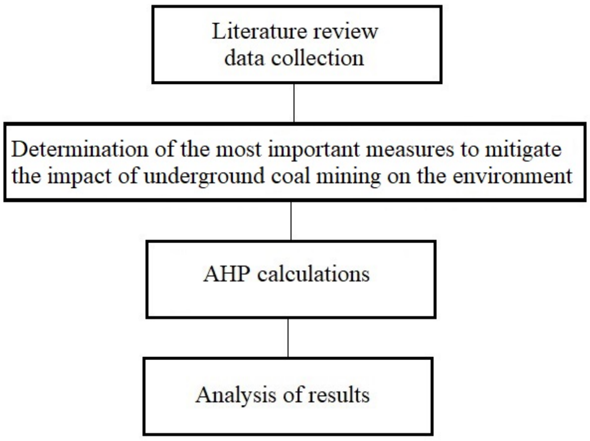

Figure 1. *Schematic overview of the research method*

The study commenced with a comprehensive literature review to identify the most critical measures for mitigating the impact of the underground coal mining on the environmental impact of. Given the vast body of existing research, an extensive review was conducted to encompass all relevant mitigation measures. Additionally, structured interviews were conducted with mining experts and industry managers to collect high-quality data and gain insights into practical decision-making processes. Based on the findings, a final list of key mitigation measures was established.

Subsequently, the identified measures were ranked using the Analytic Hierarchy Process (AHP) to assess their relative influence on mitigation. Upon obtaining the ranking results, the most significant measures were analyzed to provide a solid foundation for future mining practices and environmental protection efforts, thereby enhancing the understanding of priorities in this domain.

RESULTS AND DISCUSSION

Literature review and data collection

As previously mentioned, the research commenced with an extensive literature review and in-depth interviews with mining experts and managers in Serbia. This phase was the most time-intensive and laid the groundwork for the subsequent research stages. Based on the collected data, a structured questionnaire was developed to systematically identify and prioritize key mitigation measures derived from the responses.

Determination of the most important measures to mitigate the impact of underground coal mining on the environment

In this phase, the identified mitigation measures are classified according to their inherent characteristics and effectiveness. This categorization is based on an extensive literature review and expert consultations with mining professionals and industry managers to establish a consensus on each mitigation measure. Following this approach, ten key measures for mitigating the environmental impact of underground coal mining have been defined, namely:

- ***Air quality measures (M1)*** – *Ventilation systems:* install and maintain advanced ventilation systems to effectively dilute and eliminate hazardous gases such as methane (CH_4) and carbon monoxide (CO); *Dust suppression:* implement water spray systems, foam applications, and dust collection mechanisms to mitigate coal dust emissions; *Methane capture:* deploy degasification technologies to extract methane from coal seams and utilize it for energy production; and *Real-time monitoring:* integrate air quality sensors to continuously track gas concentrations and particulate matter levels.
- ***Water management measures (M2)*** – *Mine water treatment:* treat acid mine drainage through neutralization or passive remediation techniques; *Water recycling:* establish water recycling and reuse systems within mining operations to minimize freshwater consumption; *Containment systems:* construct engineered barriers and liners to prevent the infiltration of contaminated water into groundwater and surface water bodies; and *Rainwater harvesting:* implement rainwater collection and storage systems to supplement water supply for mining activities.
- ***Waste management measures (M3)*** – *Backfilling:* utilize coal gangue and other waste materials to backfill mined-out areas, thereby mitigating surface subsidence and minimizing waste accumulation; *Tailings management:* store tailings in engineered containment facilities equipped with liners and leachate collection systems to prevent environmental contamination; and *Waste utilization:* repurpose mining waste for construction materials and land reclamation initiatives.
- ***Land reclamation and remediation measures (M4)*** – *Subsidence monitoring:* employ GPS and satellite-based monitoring systems to assess and mitigate land subsidence; *Revegetation:* restore vegetation cover by planting native species to enhance ecological recovery and prevent soil erosion; *Soil stabilization:* apply soil stabilization techniques such as terracing and mulching to improve land resilience in reclaimed areas; and *Land use planning:* rehabilitate post-mining landscapes for agricultural, forestry, or recreational purposes.
- ***Noise and vibration control measures (M5)*** – *Noise barriers:* install physical barriers or enclosures around high-noise equipment to mitigate sound propagation; *Blasting techniques:* utilize controlled blasting methods to minimize vibrations and noise pollution; and *Equipment maintenance:* implement routine maintenance programs to reduce machinery noise levels and prevent excessive vibrations.
- ***Energy efficiency and carbon management measures (M6)*** – *Energy audits:* conduct comprehensive energy audits to identify and implement energy efficiency measures; *Renewable energy:* deploy solar panels, wind turbines, and other renewable energy solutions to power mining operations; and C*arbon capture and storage:* implement CO_2 capture and sequestration technologies for underground storage or industrial reuse.
- ***Environmental monitoring and compliance measures (M7)*** – *Real-time sensors:* utilize sensor networks to monitor air, water, and soil quality continuously; *Environmental impact assessments:* conduct before initiating mining activities to evaluate and mitigate potential environmental risks; and *Regulatory reporting:* maintain comprehensive environmental records and submit regulatory reports to demonstrate compliance with legal frameworks.
- ***Community and stakeholder engagement measures (M8)*** – *Public consultation:* foster community engagement through transparent communication and stakeholder dialogue; *Compensation and benefits:* ensure equitable compensation and socio-economic benefits for communities affected by mining operations; and *Education and training:* provide environmental awareness programs and safety training for workers and local communities.
- ***Health and safety measures (M9)*** – *Personal protective equipment (PPE):* supply workers with appropriate PPE to safeguard against occupational hazards; *Health monitoring:* conduct periodic medical screenings to detect and prevent occupational diseases; and *Emergency preparedness:* develop and implement emergency response protocols and plans for incidents such as gas leaks or water contamination.
- ***Innovative technologies and best practices (M10)*** – *Automation and robotics:* integrate automated machinery and robotic systems to enhance safety and reduce environmental impact; *Green mining technologies:* adopt environmentally sustainable technologies such as bioleaching and in-situ coal gasification; and *Data analytics:* utilize data-driven insights and machine learning techniques to optimize environmental management and anticipate potential risks.

AHP calculations

The AHP calculations were performed using the group decision-making approach, involving experts and managers from mining companies in Serbia. The Aggregation of Individual Judgments (AIJ) method was employed to facilitate group consensus-based decision-making. Figure 2. presents the hierarchical structure of the AHP model. Mitigation measures were systematically evaluated and ranked until consensus was reached for each assessment, utilizing the scale outlined in Table 1. The 10×10 comparison matrix is presented in Figure 3. The AHP computations were conducted using AHP-OS online software (https://bpmsg.com/ahp/), and the results derived from the comparison matrix are depicted in Figure 4.

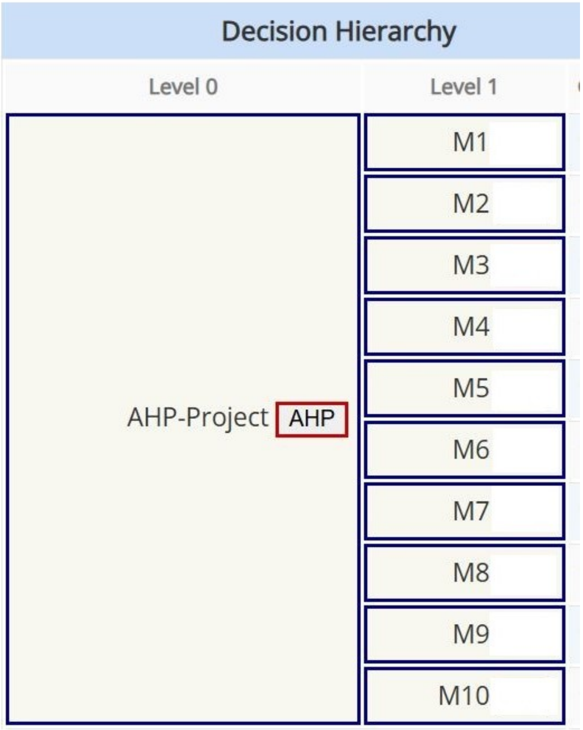

Figure 2. *Hierarchical structure of the AHP problem*

	1	2	3	4	5	6	7	8	9	10
1	1	0.17	0.25	0.14	3.00	0.25	0.33	0.25	0.14	0.20
2	6.00	1	3.00	0.33	4.00	2.00	1.00	1.00	0.25	0.33
3	4.00	0.33	1	0.33	2.00	0.25	0.20	0.25	0.17	0.20
4	7.00	3.00	3.00	1	4.00	2.00	1.00	0.50	0.25	0.33
5	0.33	0.25	0.50	0.25	1	0.25	0.20	0.25	0.17	0.20
6	4.00	0.50	4.00	0.50	4.00	1	0.50	0.33	0.25	3.00
7	3.00	1.00	5.00	1.00	5.00	2.00	1	1.00	0.33	0.50
8	4.00	1.00	4.00	2.00	4.00	3.00	1.00	1	0.50	0.50
9	7.00	4.00	6.00	4.00	6.00	4.00	3.00	2.00	1	1.00
10	5.00	3.00	5.00	3.00	5.00	0.33	2.00	2.00	1.00	1

Figure 3. *Criteria comparison matrix*

Cat		Priority	Rank
1	M1	2.5%	9
2	M2	8.9%	7
3	M3	3.5%	8
4	M4	10.8%	4
5	M5	2.2%	10
6	M6	10.3%	5
7	M7	10.1%	6
8	M8	12.0%	3
9	M9	23.4%	1
10	M10	16.5%	2

Figure 4. *Results obtained by AHP calculations*

Results and discussion

The obtained results clearly identify the measures that exert the most significant influence on mitigating the impact of underground coal mining on the environment. Based on their respective weighting coefficients, the measures can be classified into three distinct categories according to their relative impact on the mitigation process. The first category encompasses measures with weighting coefficients exceeding 0,2 (20%), represented solely by M9 – health and safety measures. The second category includes measures with weighting coefficients ranging between 0,1 and 0,2. These are: M10 – innovative technologies and best practices, M8 – community and stakeholder engagement measures, M4 – land reclamation and remediation measures, M6 – energy efficiency and carbon management measures, and M7 – environmental monitoring and compliance measures. Conversely, the third category comprises measures with weighting coefficients below 0,1, reflecting a relatively lower influence. This group includes M2 – water management measures, M3 – waste management measures, M1 – air quality measures, and M5 – noise and vibration control measures.

In the first, the most influential category of measures is M9 with a weighting coefficient of 0.234 (23,4%). According to mining experts, health and safety measures represent the highest priority. These measures, aimed at preserving the health and lives of workers, are considered the most critical due to the inherently challenging, demanding, and hazardous nature of underground mining operations.

The second major category of measures is considered less influential than the first. Within this category, innovative technologies and best practices (M10) have the highest weighting coefficient. The continuous enhancement of existing methods and the adoption of advanced, more innovative technologies have the potential to substantially mitigate the adverse environmental impacts of underground coal mining. However, the primary drawback of these measures lies in the substantial initial investment they typically require. Ranked second in this category are the measures classified as M8, which pertain to community and stakeholder engagement. These include public consultations, the provision of compensation and benefits, and the implementation of education and training programs. Actively involving both local and broader communities in addressing environmental issues associated with mining operations is essential. This includes facilitating participation in decision-making processes, providing restitution for damages, and acknowledging community concerns and warnings. Such an inclusive approach can significantly diminish the environmental footprint of mining activities. The third-ranking measures in this group are those classified under M4, which relate to land reclamation and remediation. These are designed to mitigate the degradation of land caused by underground mining operations. Experts in the field emphasize their importance, as they encompass actions such as terrain subsidence monitoring, revegetation, soil stabilization, and strategic land-use planning. Following this are measures associated with energy efficiency and carbon management (M6). These are crucial in optimizing energy and gas use while aiming to reduce greenhouse gas emissions, given that mines are substantial sources of such emissions. Finally, M7 pertains to environmental monitoring and compliance measures. These are critical for ongoing surveillance of both the mining site and its surrounding environment. They include monitoring pollution parameters and establishing alert systems to notify stakeholders of incidents that could negatively impact either the mine or the environment.

The third category of measures has the least direct impact on mitigating the environmental consequences of coal mining. Nevertheless, the measures within this category are essential and must be implemented continuously. These measures are generally simpler to apply and demand fewer resources compared to those in the first two categories. Consequently, mining professionals have assigned them a lower priority, as they believe they can yield tangible results within a relatively short timeframe. Within this category, M2 – water management measures exert the most significant influence. Underground coal mines disrupt both groundwater and surface water systems. Therefore, the implementation of measures aimed at water protection, purification, and the provision of sufficient quantities for the uninterrupted operation of mining activities is of critical importance. Ranked second are M3 – waste management measures. Underground coal mining operations generate substantial volumes of waste. The primary objective of these measures is to reduce the amount of generated waste and to enable its further processing and potential utilization in other industrial sectors. In the penultimate position are M1 – air quality control measures. These measures involve air purification, methane capture, dust suppression, and similar activities. Although such practices are applied in Serbian mines to varying degrees, their limited and inconsistent implementation has led to their lower ranking. M5 – noise and vibration control measures occupy the lowest position. Underground coal mining inevitably produces noise due to the operation of main ventilation systems, blasting activities, and other processes. Additionally, while vibration exposure exists, it is generally less pronounced than in other industrial sectors. As a result, these measures are considered less critical and have been ranked accordingly.

Finally, several key challenges in the implementation of environmental protection measures in underground coal mining operations have been identified. Among the most prominent are the high costs associated with advanced technologies and infrastructure, the difficulty of reconciling production targets with environmental protection goals, and the need to address legacy environmental issues and abandoned mine sites. Coal mines in Serbia predominantly rely on outdated technologies and methods of exploitation. The most pressing issue is the lack of financial resources necessary for the modernization of operations, particularly for the procurement of advanced equipment and technologies. Moreover, in practice, production objectives are often prioritized over environmental concerns. In addition, unresolved environmental problems inherited from previous decades continue to pose a serious threat to the environment and remain unaddressed.

CONCLUSION

The implementation of comprehensive environmental engineering interventions in underground coal mining operations constitutes a critical component in mitigating adverse ecological impacts, ensuring rigorous compliance with environmental legislation, and fostering the development of sustainable mining frameworks. Through the deployment of advanced technological innovations, the optimization of operational protocols, and the application of integrated environmental management systems, the coal mining sector can significantly curtail its environmental footprint while sustaining its strategic role in meeting global energy demands.

The Analytic Hierarchy Process (AHP) was employed to evaluate and prioritize the most important measures for mitigating the environmental impacts of underground coal mining. Ten key groups of mitigation measures were assessed and ranked: M1 (air quality measures), M2 (water management measures), M3 (waste management measures), M4 (land reclamation and remediation measures), M5 (noise and vibration control measures), M6 (energy efficiency and carbon management measures), M7 (environmental monitoring and compliance measures), M8 (community and stakeholder engagement measures), M9 (health and safety measures), and M10 (innovative technologies and best practices).

Based on the ranking results, these mitigation measures were categorized into three distinct priority categories. The first and most critical category includes M9 (health and safety measures). The second category, of moderate importance, comprises M10 (innovative technologies and best practices), M8 (community and stakeholder engagement measures), M4 (land reclamation and remediation measures), M6 (energy efficiency and carbon management measures), and M7 (environmental monitoring and compliance measures). The third category, representing measures of comparatively lower priority, includes M2 (water management measures), M3 (waste management measures), M1 (air quality measures), and M5 (noise and vibration control measures).

The prioritization of these key groups of measures provides valuable insights for mining professionals and decision-makers in selecting the most effective strategies for minimizing the environmental footprint of underground coal mining operations.

ACKNOWLEDGEMENTS

This paper is supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia pursuant to agreement № 451-03-137/2025-03/200131 with the University of Belgrade, Technical Faculty in Bor.

REFERENCES

Bhattacharyya, S., Fan, L., Azam, S., & Liu, S. (2023). Advances in coal mining technology and sustainable mining techniques. In D. Osborne (Ed.), *The coal handbook: Volume 1* (2nd ed., pp. 263–321). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-824328-2.00011-X

Dramlić, D., Ristić, V., Zlatanović, D., Ivaz, J., & Đukanović, D. (2024). Development of a conceptual model for environmental monitoring in underground coal mining. *Tehnički vjesnik, 31*(4), 1270–1276. https://doi.org/10.17559/TV-20240503001516

Hasii, O., & Gasii, G. (2024). Coal mining and water resources: Impacts, challenges, and strategies for sustainable environmental management. *IOP Conference Series: Earth and Environmental Science, 1348*(1), 012017. https://doi.org/10.1088/1755-1315/1348/1/012017

Koul, P. (2024). Robotics in underground coal mining: Enhancing efficiency and safety through technological innovation. *Podzemni Radovi, 1*(45), 1–26. https://doi.org/10.5937/podrad2445001K

Kumar, M., Maity, T., & Kirar, M. K. (2021). Energy-use assessment and energy-saving potential analysis in an underground coal mine: A case study. In *2021 IEEE Kansas Power and Energy Conference (KPEC)* (pp. 1–7). IEEE. https://doi.org/10.1109/KPEC51835.2021.9446232

Li, B., Shi, Y., Hao, J., Ma, C., Pang, C., & Yang, H. (2022). Research on a carbon emission calculation model and method for an underground fully mechanized mining process. *Energies, 15*(8), 2871. https://doi.org/10.3390/en15082871

Li, S., Chen, X., Peng, G., Han, M., Guo, Q., Hou, J., & Gao, B. (2023). Research on the evaluation of air quality in underground coal mines based on a generalized contrastive weighted comprehensive scale index method. *Atmosphere, 14*(6), 1021. https://doi.org/10.3390/atmos14061021

Mahdevari, S., Shahriar, K., & Esfahanipour, A. (2014). Human health and safety risks management in underground coal mines using fuzzy TOPSIS. *Science of The Total Environment, 488–489*, 85–99. https://doi.org/10.1016/j.scitotenv.2014.04.076

Masood, N., Hudson-Edwards, K., & Farooqi, A. (2020). True cost of coal: Coal mining industry and its associated environmental impacts on water resource development. *Journal of Sustainable Mining, 19*(3), 135–149. https://doi.org/10.46873/2300-3960.1012

Matikainen, L. M. (2020). *Enhancing sustainability in the mining industry through stakeholder engagement* (Master's thesis). Tampere University, Master's Programme in Business Studies, Management and Organizations.

Mocek, P. (2023). Environmental impact of noise from mining operations. *Scientific Journals of the Maritime University of Szczecin, 73*(145), 15–28. https://doi.org/10.17402/551

Pandey, B., Agrawal, M., & Singh, S. (2014). Assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations and heavy metals, using cluster and principal component analysis. *Atmospheric Pollution Research, 5*(1), 79–86. https://doi.org/10.5094/APR.2014.010

Saaty, T. L. (1980). *The analytical hierarchy process*. McGraw-Hill.

Sensogut, C. (2007). Occupational noise in mines and its control – A case study. *Polish Journal of Environmental Studies, 16*(6), 939–942.

Straupnik, I. A. (2022). An overview of the environmental impact of coal industry waste. *IOP Conference Series: Earth and Environmental Science, 1070*(1), 012004. https://doi.org/10.1088/1755-1315/1070/1/012004

Zhou, A., Hu, J., & Wang, K. (2020). Carbon emission assessment and control measures for coal mining in China. *Environmental Earth Sciences, 79*, 461. https://doi.org/10.1007/s12665-020-09189-8