ANALYSIS OF ENVIRONMENTAL RISK FACTORS IN SELECTED MINING ACTIVITIES

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Mining of raw materials and their modification has a negative impact on the environment. During the mining and processing of mineral raw materials (coal, oil, ore), solid, liquid and gaseous wastes are created. The production of waste is linked to the mining site, respectively production. Many of the negative phenomena can be minimized or even eliminated by using appropriate technologies and work procedures. At the present, the search and secondary use of large-volume waste is gaining more and more importance. In the underground, possibilities are offered in the field of fire prevention, closing and disposal of mine works, fill and so on. A thorough assessment of the criteria and their compliance during implementation creates a basic prerequisite for the use of underground waste with the verification that there will be no release of hazardous pollutants from the source of harmful substances as well as that the elements of the environment will not be endangered and the use of waste will be safe.

KEYWORDS

Mining, environmental risk, safety

1 INTRODUCTION

The fact is that coal is the most polluting energy source and the world's dominant source of CO_2 emissions. The production of electricity in coal-fired power plants annually releases 11 tons of CO_2 into the atmosphere. In 2005, coal-fired power plants produced up to 41% of all CO_2 emissions from fossil fuels. If plans to build new coal-fired power plants are implemented, CO_2 emissions from coal will increase to 60% by 2030 [Eurocoal 2021]. It is planned to use renewable energy sources, either in the form of biomethane or in the form of hydrogen as a carbon-free fuel [Pokorny 2016, Rimar 2022].

The article describes the Handlovske and Novacke coal deposits, which are located in the Hornonitrianska kotlina basin in the Slovak Republic. The Handlovska deposit is located in an area roughly bounded by the villages of Veľka Lehota, Cigeľ, Podhradie, Nova Lehota, Handlova and Morovno (the mining area has an area of 72.17 km^2). The Novacke deposit is bordered by the villages of Opatovce nad Nitricou, Novaky, Kamenec p. Vtacnikom, Lehota p. Vtacnikom (the mining area has an area of 30.5 km^2), Fig.1. Mining on the Novaky and Handlova deposits is mining under a weak overburden. The predominant mining method is long wall method for a controlled broken ground with a reaming in the roof hanging wall [Act No. 51/1988]. When mining with a over roof, the process of caving already takes place in the phase of coaling of the over roof sheet of the pillar, after cutting off a certain number of miters on the front pillar. During long wall method mining, the technological recovery rate ranges from approximately 75% to 87%, while the extraction rate is affected by: technical factors – construction reinforcement, technological and geological factors.

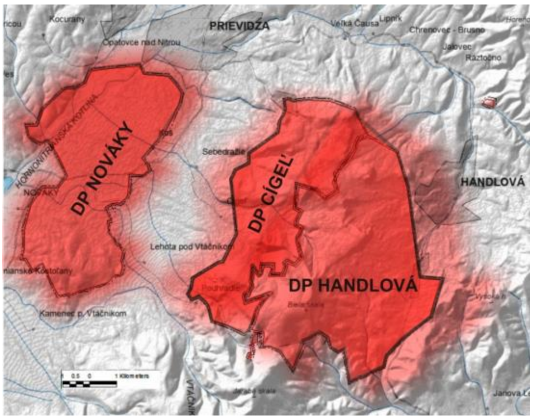

Figure 1. Defined territory, the studied area - the wider vicinity of the mining areas (DP) of the Novaky, Cigeľ and Handlova lignite deposits

The broken ground is therefore composed of coal losses from the over roof and overlying rocks. Based on the results of the drilling survey, it can be concluded that the composition, or the layering of the cave-in is such that in its lower part there is a continuous layer of lumpy coal material reaching a thickness of 2 to 6 m, then on top of this layer lies overlying rocks, the so-called overlying clays. Other minerals pyrite - FeS_2, realgar - As_4S_4, arsenopyrite - FeAsS, aurypigment - As_2S_3 are included in the coal substance. Starting from the place of tributaries, three basic types of underground water can be distinguished into: overlying , underlying and ancient water [Straka 2022].

The hydrochemical characteristics of the underground water at the Novaky deposit are as follows:

-Overlying waters - are groundwaters from the water-bearing strata system of the detrital-volcanic formation (DVF - Lehotske formation). From the basic mathematical-statistical analysis (n=76) of water samples of the overlying water- bearing strata system (overlying water), it can be concluded that the water in question is characterized by mineralization (RL) up to 600 mg.l-1 with significant Ca-Mg-HCO_3 chemistry.

-Underlying waters – are groundwaters from the water-bearing strata system, the so-called underlying tuffites (stone formation). The total mineralization of these waters is slightly "increased" (500-800 $mg.l^{-1}$), while the chemistry is more or less Na-HCO_3, or Na-Ca-HCO_3 type.

-Ancient waters they represent the most heterogeneous group of groundwaters, which are connected to mine areas. They are characterized by increased mineralization (0.6-4.2 $mg.l^{-1}$) with a shift in chemistry to the Ca-SO_4 type. High sulfate contents are the result of oxidative degradation of the dispersed sulfide phase (pyrite - FeS_2, realgar - As_4S_4, arsenopyrite - FeAsS, aurypigment - As_2S_3) in the coal substance, which largely depends on the presence of biochemically active microorganisms (bacteria). From a genetic point of view, they belong to sulfidogenic groundwaters.

-Mine water the chemical composition of the mine waters in the Novaky and Handlovova deposits exploited from underground to the surface is the product of the process of mixing waters from overlying, underlying and ancient waters, to which, during underground distribution, technological waters from the mining process are added.

According to [Lukac 1998] during the formation of coal, approximately 90 to 150 m^3 of methane is formed for each ton of coal, but the amount actually adsorbed in most types of coal is much lower, usually 2.5 to 40 m^3.t^{-1}. At the beginning of mining, about 220 million tons of geological reserves were registered at the Novaky deposit, which corresponds to 550-8,800 million m3 of gas [Fazekas 2009, Sebestova 1996].

2 THE IMPACT OF BROWN COAL MINING ON THE ENVIRONMENT

Mining of coal reserves is naturally accompanied by negative consequences in the affected area. Mining activity causes extensive deforestation, soil erosion, pollution and water scarcity, smoldering coal fires and greenhouse gas emissions. Excavation of massive pits leaves the surrounding land bare, the bottom water drops, huge piles of waste are created and the surrounding area is covered with dust and excavated rocks. Due to erosion caused by mining activity, the upper fertile part of the soil is lost, which thus reaches to the nearest water flows, silting up the rivers and is a threat to aquatic animals. Coal mining is also dangerous for miners, who can lose their lives during an accident, or worse, slowly die from pneumoconiosis (dusting of the lungs). Last but not least, mining activity displaces the original population, who has to leave their homes due to coal mines, coal fires, landslides and contaminated water. Due to the geological structure of the deposit, hydrogeological characteristics and methods of exploitation, over a 100-year period of mining in Novaky and Handlova deposit in the Slovak Republic showed almost all types of impacts that are typical for deep and surface mining, [Recka 2017, Lapcik 2011].

2.1 Analysis of risks at the end of mining activity

Occupational risk is an expression of the probability and severity of an injury or illness caused by the hazard. Risk assessment helps to minimize possible damage to employees and the environment caused by work activities, Table 1 [Annex No.1].

The subject of the risk analysis is the impact on the following elements of the environment:

-rock environment,
-soil and soil air,
-ground water.
Negative impacts depend on the rock environment, the hydrogeology of the environment in which the mining activity is carried out and the technological process of the mining activity. The impacts can represent a serious threat to human health and the environment. The analysis of the risk of the polluted area is based on the principles of caution.

Identification of risks at the end of mining activity, impact on the environment and the population

To identify risks and threats in this article, the Universal Checklist is used:

-if there is a threat, write "YES"
-if there is no threat "NO"
Before that, it is necessary to know:
-the location of the workplace and/or the work performed;
-who works there,
-used work equipment, materials and activities,
-performed work tasks (e.g. how and for how long they are going to be performed),
-threats that have already been identified and their sources;
-possible consequences of existing threats,
-protective measures used,
-accidents, occupational diseases and other cases of illness that have been recorded;
-legal and other requirements applicable to the workplace

In order to minimize the risks from mining activity, the proposed solutions are:

-the reclamation of surface deformations, cracks and subsidence basins, wetlands and lakes (for example) during the creation of slag-heaps and coal ash setting basin in compliance with the principles of securing disposal of mining works - for example, using waste and building materials that meet specific requirements [Zelenak 2003, Oravec 2018]. The risks in mining activity are summarized in Tables 2 and 3.

Table 1. Risks during mining activity

Risk mining activity:
soil erosion
smoldering coal mines
pollution and lack of water
greenhouse gas emissions
drop in the groundwater level
miners' injuries, accidents, or consequences of pneumoconiosis
coal fires
landslides
Coal burning:
smoke containing toxic substances endangers the population and the environment
a cloud of coal fires
Source of dangerous emissions:
carbon dioxide sulfur oxides nitrogen
methane
smog
Waste from burned out coal:
toxic, contains lead, arsenic and cadmium
seepage of acid water from mines
the impossibility of returning the devastated country to its original state after the end of mining
Impacts of mining:
mine collapse
damaged soil and mullock- waste that becomes toxic in contact with water and air
wet and waterlogged areas
underground drainage
Consequences of termination of mining activity:
carbide cal
heavy metals
chemical toxicity of wastes
ash containing arsenic
calcium arbide CO gas

Table 2. Risk matrix [Pacaiova 2021]

Severity		**Frequency**				
		Very frequent	Frequent	Occasional	Infrequent	Rare
		A	B	C	D	E
Catastrophic	I	3	3	2	2	1
Critical	II	3	2	2	1	-
Borderline	III	2	1	1	-	-
Low	IV	1	-	-	-	-

3 – extremely high risk, 2 – high risk, 1 – low risk

Questions in the check list	Yes	P	C	R
LANDSLIDES				
Landslides of material, rocks, etc. may occur. from the slopes in the surface mine?		B	II	2
Are there any unmarked or uncontrolled pits?		B	II	2
Are any unsafe dumps, pit slopes and excavations created?		A	II	3
Did during the works arose unsupported or unsecured overhangs and undercuts?		B	II	2
Is manual extraction of raw materials carried out simultaneously on the two created height levels in the mine?		C	II	2
Can there be a random change in the situation of the surface of the mine during work?		C	II	2
Are transport routes threatened by landslides?		C	II	2
Are the side walls higher than 1.5 m and are they not secured against sliding?		B	II	2
WATER				
Does water threaten the operation in an open-pit mine?		A	II	3
Sudden discharge of water when it accumulates underground?		B	II	2
TRANSPORT ACTIVITIES				
Do employees move along or across conveyor routes? Is the slope of the mining zone greater than 4°?		B	II	2
Is the slope of the mining zone greater than 4°?		B	II	2
Do the loading devices move above the level of the driver's cabine?		A	II	3
Can employees get into the vehicle path?		A	II	3
IMPACTS AFTER TERMINATION OF MINING ACTIVITIES				
Deformation of the surface, formation of lakes in subsidence basins and soil degradation?		A	I	3
Cracks, sinkholes, their rehabilitation, or protection against the fall of the inhabitants, control of these pitfalls and their rehabilitation after the demise of the company?		A	I	3
Contamination of waterways?		B	II	2
Air pollution from drifts?		C	II	2
Contamination of waterways?		A	II	3
Discharge of contaminated mine waters (Antique waters containing arsenic)?		A	I	3
The risk of the pit body collapsing and the creation of a basin in the case of incorrect rehabilitation?		A	II	3
Output of mine gases to the surface, methane, carbon dioxide, hydrogen sulphide?		A	I	3

Table 3. Check list for Handlova and Novaky coal deposits

3 CHARACTERISTICS OF WASTES AND SPECIFIC PREVENTIVE MEASURES

In Table 4 are listed examples of preventive measures that can be used to reduce specific risks.

Table 4. Examples of preventive measures that can be used to reduce risks

LANDSLIDES	Fencing of areas of mining operations, landfills or unstable terrain.
	Mark dangerous workplaces with warning symbols.
	Adapt the height and slope conditions at the mining site to the geological situation and rock properties.
	Apply a terraced mining system instead of creating steep slopes.
	The slope of the slopes should not exceed a slope of 45° from the point of view of stability.
	Mark the upper and lower edges of dangerous wall parts.
	Under no circumstances allow the formation of free overhangs or undercuts.
	Protect the walls with nets.
	Clean the mining zone from top to bottom.
	Always monitor the overall behavior of the mining section.
	If the formation of an undercut area cannot be avoided, the area must be perfectly supported.
WATER	Remove unnecessary water tanks if possible.
	Check the drainage system of the mine.
	Establish routes for leaving workplaces in the event of a water hazard.
	Carry out mining works in such a way that the water can flow naturally to lower areas.
	Drain water to collection points and, if necessary, install water pumps.
TRANSPORT ACTIVITIES	Ensure crossings over conveyors.
	Equip conveyors with devices against material falling.
	Prohibit manual transport of carts if the slope of the mining zone is above 4°.
	Ensure communication and signalling between employees during transport.
	Determine in which types of cabins the employee may not stay during loading.
	Mandatory checking of ropes and cableway mechanisms at the beginning of each work shift.

4 THE PRODUCTION OF MINING CONSTRUCTION MATERIAL

Currently, the search for the secondary use of large-volume waste is gaining more and more importance [Vostova 2003]. In the underground, possibilities are offered in the field of fire prevention, closure and elimination of mine works, fill etc. Before utilization begins, it is necessary to assess geological and hydrogeological, engineering-geological, geotechnical, mining and geochemical criteria.

The criteria serve for the selection of suitable wastes and a comprehensive assessment of their suitability. A thorough assessment of the criteria and their compliance during implementation creates a basic prerequisite for the use of waste in the underground, with the verification that there will be no release of hazardous pollutants from the source or harmful substances, that elements of the environment will not be endangered and that the use of waste will be safe [Annex No.1, Balas 2017].

Based on the above mentioned but also from literary knowledge [Slivka 2000], it is possible to assume that the following wastes will be suitable for the production of mining building materials:

a) clastic material:

- blast furnace and steel slag
- ash from coal combustion,
- blast furnace, steelmaking dust and sludge,
- used foundry sands with inorganic and organic binders,
- dust and sludge from stone and aggregate processing,
- waste from the sewage treatment plant
- waste from the sewage treatment plant

b) hydraulic and air binders:

- dry ashes from classic coal combustion,
- dry ashes from fluid coal combustion,
- calcium sulfate,
- carbide sludge,
- waste from cement production.

4.1 Examples of waste use in the underground

Composition of ashes and flake ashes

Ash and flake ash represent a heterogeneous mixture of particles that differ in shape, size and chemical composition. These parameters are primarily determined by the chemical and mineralogical composition of the ash in the coal (non-burnable residue), the quality of the burned coal, especially its calorific value, and subsequently the type of combustion equipment (type of mills, coal grinding method, boiler system and combustion temperature).

Depending on the type of coal and combustion conditions, ash and flake ash can contain from 1 to 20% by weight of unburned coal residues (expressed as loss on ignition during chemical analysis), from approximately 35 to 65% by weight of silica, from 20 to 40% by weight of oxides of aluminum and iron together, from 2 to 20% by weight of calcium oxide CaO (higher percentages of CaO are contained in fly ash only in the case of burning lignites, the CaO content is mostly around 3%, in our case 4-7% ash from burning).

The alkaline content (Na, K), which varies from 2 to 5% by weight (expressed as sodium and potassium oxides) and the sulfur content (expressed as sulfur oxide - SO_3), or the sulphide content (S_2), are important. The mineralogical composition of the ashes is different depending on the combustion temperature. At a combustion temperature of 1100°C and above, an amorphous glassy phase and a crystalline phase are formed. The glassy phase does not occur in fluid combustion, where combustion takes place at temperatures around 800-850°C.

Mostly, an alkaline additive is added to the process, which also results in an increased accumulation of sulfur compounds and trace elements. Flake ashes have significant puzzolano properties. Materials capable of reacting at normal temperature with lime in the presence of water, i.e. with calcium hydroxide, are considered puzzolano. Very little soluble calcium silicate hydrates, calcium aluminosilicate hydrates and other hydrated calcium compounds are formed by the reaction.

Carbide sludge is dusty waste produced during the production of calcium carbide, the production of which can be described by the chemical equation $CaO + 3C = CaC_2 + CO$.

Lime and coke enter the reaction in a ratio of 2:1 and in the prescribed quality.

The reaction takes place in an electric carbide furnace. During the production itself, in addition to calcium carbide, carbon monoxide (hereinafter referred to as CO gas) is also produced. The resulting CO gas contains dust particles that are captured in sleeve filters. The captured particles contain cyanides in the amount of 0.5-1.0% and carbon and organic components, which are further burned in a rotary furnace [Skvarekova 2005]. Thesis [Lukac 1998] examines the possibility of using the mentioned material in construction for the production of mortar and compares it with ground quicklime. On the basis of the achieved results, it can be concluded that CO dust can be used as a binder and classified as air lime of the 5th quality class.

With the same mixing ratio, lower strengths were achieved than with lime, which can be eliminated by a higher content of CO dust [Skvarekova 2016]. In the literature [Stala-Szlugaj 2018] a comparison was made of the content of harmful substances in leachates from the waste itself and from the solidified agglomerate (after 28 days). The results are shown in Table 5. pointing out that the leachate from the solidified agglomerate has a significantly lower content of harmful substances than it is in the original waste [Blazkova 2015, Krbalova 2015].

Table 5. Content comparison of harmful substances in leachates from original raw materials and from solidified and stabilized agglomerate

Indicator	Unit	Carbide sludge: Flake ashes TeHa[1] 40:60		Carbide sludge: Flake ashes ENO[2] 40:60		Carbide sludge		Flake ashes TeHa	
		Value	Category of each leach	Value	Category of each	Value	Category of each	Value	Category of each
Conductivity	$mS.m^{-1}$	58,6	I	87,5	I	2,858	III	125	II
Content of dissolved salts	$mg.kg^{-1}$ of dry matter	13,000		18,800		330,000			
As		0.006	I	0.015	I	0.002	I	0.31	III
B		1.9	II	<1.0	II	0.19	I	12.00	III
Ca		73	I	75	I	62.12	III	306	II
Mg		0.1	I	0,05	I	68.09	III	35.3	II
V		0.037	I	0.034	I	0.058	II	0.19	III
Sn		0.03	I	0.01	I	0.838	III	<0.05	I
F		0.24	I	0.19	I	11.0	III	9.45	III
Chlorides		74,4	I	94.4	I	857.89	III	8.89	I
Sulfates		361.2	II	270.9	II	213.3	III	864.1	II
Ammonia		0.18	II	0	I	5.4	III	1.36	II

TeHa[1] – Flake ashes from heating plant

ENO[2]- Flake ashes from heating plant Novaky

5 CONCLUSIONS

The entire process – or the processing chain – from mining to incineration to landfilling and in some cases reclamation has an extreme impact on the environment, human health and the social structure of communities living near mines, power plants and waste dumps. This process seriously disrupts ecosystems and produces other greenhouse gases, such as nitrous oxide, methane, and poisonous chemicals such as mercury and arsenic. Leaking liquid waste destroys fish farms and agriculture, thereby destroying people's livelihoods [Variny 2022, Malerova 2017].

It directly contributes to health problems and diseases, such as pneumoconiosis (lung dust). The price of coal does not take into account any of these costs, and that is why it is called the so-called external costs. Mining activities lead to violations of the rock environment, releases and exhalations into the mine atmosphere. From an economic point of view, the economic benefits of this energy source and the payback period of invested funds in the purchase and commissioning of the technology are important.

For the use of CH_4, it is mainly necessary to have the existing degassing sources mapped and to know the parameters of the achieved concentrations in the gas mixture. The release of mine gases into the air is subject to environmental control and air cleanliness, which is currently receiving increased attention. From the assessment of the risks in the check list using the risk matrix, Table 4, the most serious risk arises for landslides, water hazards and injuries during the movement of loading equipment during transport activities.

At the end of the mining activity, it is the deformation of the surface in subsidence basins and sinkholes, the contamination of watercourses, ancient water containing arsenic, the output of mining gases, methane, carbon dioxide and hydrogen sulfide. Preventive measures are listed in Table 3. Research into the environmental risks associated with coal mining is essential to fully understand the environmental impacts of coal mining. This document enables the identification and quantification of selected environmental hazards and associated risks, such as greenhouse gas emissions, water and soil pollution, ecosystem degradation and others. This knowledge is important for making informed decisions about managing coal mining and minimising its negative impacts. The presented scientific research results provide new tools and methodologies for assessing and monitoring environmental risks associated with coal mining and processing. These assessments, when applied over the long term, will allow environmental changes to be tracked, key problem areas to be identified and the effectiveness of environmental protection measures to be monitored.

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