Preventive measures to minimize natural hazards in the Polish underground mining industry

K. Trzop¹, D. Palka², D. Szurgacz³*, L. Sobik⁴

¹KWK Ruda Ruch Bielszowice ul. Halembska 160, 41-711 Ruda Śląska, Poland
²Politechnika Śląska Wydział Organizacji i Zarządzania, ul. Roosevelta 26-28, 41-800 Zabrze, Poland
³Polska Grupa Górnictwa S.A., ul. Powstańców 30, 40-039 Katowice, Poland
⁴KWK ROW Ruch Chwałówice, ul. Przewozowa 4, 44-206 Rybnik, Poland

*Corresponding author: dawidszurgacz@vp.pl

Abstract. The process of underground hard coal mining and various types of natural hazards are inextricably bound up with each other. The occurrence depends on the response of the rock mass to the disturbance of its balance caused by mining activity determines the occurrence of natural hazards that can lead to a series of events that significantly disturb the safety and efficiency of the entire coal production process. Consequently, there is a constant search for methods that would support the available preventive measures. There are several solutions that can be applied during the mining process designed to either limit the frequency of hazards and/or limit their consequences. The paper reviews the current natural hazards in underground mining with particular emphasis on their consequences. Based on the experience of the authors and the review of papers that deal with natural hazards, possible solutions were analysed to reduce the potential for events associated with these hazards and their consequences. The research team focused mainly on preventive measures. The protection of human health and life was a key priority. It is also important to ensure continuity of exploitation and its economic efficiency, and to reduce the negative impact on the environment, the operation, working conditions, and mining costs. The analysis of the existing hazards and the possible ways of limiting their negative effects should improve work safety and the efficiency of the entire mining industry.

1. Introduction

Hard coal mining is one of the most important branches of the Polish industry. In terms of annual output, Poland is ranked tenth in the world and first in the European Union [5]. In Poland, hard coal is the basic raw material used to generate electricity and heat, thus guaranteeing energy security. Currently, Polish coal mines employs nearly 180 thousand people. This includes employees in the mines and the companies involved in the mining industry. This sector is particularly significant for the Upper Silesian region, which is an area with a great mining tradition, and where hard coal is referred to as "black gold". Despite numerous changes in the structure of the functioning of mining plants, restructuring of the mining industry, automation of the mining processes, underground mining is often the only source of income for thousands of families in the region. Therefore, it is essential to launch a variety of actions to ensure the efficiency of this industry [5]. The social factor, therefore, plays a key role. The process itself is inseparably connected with the occurrence of various types of threats and hazards and natural hazards are considered particularly dangerous. They have a significant impact on the performance of this sector [1]. One should also remember that the mining production process
impacts on the environment—not only in Poland but in each country where the mining activity is being conducted [2, 23].

Given all these factors, it can be concluded that working in underground mines is extremely difficult and dangerous. Complex natural (environmental) conditions make the process of coal mining integral with both natural and technical hazards. The accumulation of negative factors, such as methane, rock bursts, ejecting rocks, and so on, calls for actions to improve working conditions and comfort [8]. Furthermore, as already mentioned, underground mining harms the external environment, including the natural environment, as well as the infrastructure on the surface. These include all kinds of deformations, called mining damage caused by the cave-in, deflection, or cracking of rock layers, geological or hydrogeological changes and deformations of the foundation. The results of these events are very inconvenient for the entire infrastructure built within the mining areas. To ensure safety and comfort at work, reduce the negative impact of mining on the environment, and maintain operational efficiency, increasingly modern technologies and reliable technical means are implemented, in particular advanced machinery and equipment.

The authors assumed that that natural hazard have the most negative impact on the mining production process and therefore the paper discusses such hazards and presents the consequences the hazard leads to. The authors also presented measures that have the potential to limit the damages.

2. Hazards in the mining industry in Poland
Hazards in the mining industry constantly lead to a large number of accidents. Developing industry and related solutions have led to a significant reduction in the number of events. Hazards involving mining and geological factors are limited by preventive measures. Hence, it is not always possible to have a direct influence on the level of the hazard. Figure 2 shows a set of accidents in the Polish mining industry between 2010 and 2019. The following sections discuss individual natural hazards occurring during mining.

![Figure 1. Accidents in mines in the years 2010–2019 [19].](image)

2.1. Methane release hazard
Methane is a source of potential danger, which leads to a large number of group accidents [3, 4, 18]. The record of the events that occurred indicates how dangerous the explosion or fire of this gas is [10]. Table 1 presents events that significantly affected hard coal mining.
Table 1. Disasters in the Polish mining industry involving methane between 1985 and 2014 [6].

| Hard coal mine                        | Number of fatalities |
|---------------------------------------|----------------------|
| Wałbrzych (22 Dec 1985)               | 18                   |
| Mysłowice (04 Feb 1987)               | 17                   |
| Halemba (10 Jan 1990)                 | 19                   |
| Bielszowice (12 Dec 1996)             | 5                    |
| Halemba (21 Nov 2006)                 | 23                   |
| Borynia (04 Jun 2008)                 | 6                    |
| Wujek-Ruch Śląsk (18 Sep 2009)        | 20                   |
| Mysłowice-Wesola (06 Oct 2014)        | 5                    |

In hard coal mining, about 70–85% of the seams are rich in methane. Methane severely limits the operation. Because of the consequences of the explosion of this gas, the mining industry is forced to take preventive measures to eliminate it. There are several factors that contribute to the accumulation of methane:

- deeper mining,
- high intensity of works,
- voids and faults in the rock mass,
- higher methane bearing capacity of seams.

In Poland, methane has caused accidents involving workers and has led to production stoppages. The latter is a safety factor because if the permissible methane concentration in the excavation site is exceeded, machines and equipment are shut down. The application of preventive measures to combat methane leads to increased mining costs. Nevertheless, the use of modern and costly solutions to combat the effects of methane contributes to safety being essential. Between 2010 and 2019 there were thirty-one events related to methane in Polish mines causing five fatalities [19].

2.2. Rock burst hazard
A rockburst is a sudden discharge of energy of potential elasticity of rocks. This leads to a change in the structure of the surrounding rocks resulting in the displacement of rock masses. This natural phenomenon is followed by an air blast, bang, and tremor and is common in the mining industry [6]. It is felt in the workings and on the surface. It can lead to the destruction of the support, machines, and equipment and put the life and health of workers at risk. There were forty-five events between 2010 and 2019 recorded in Polish underground mines that caused twenty-eight fatalities and four severe injuries. The scale of the problem is large as there were as many as 178 minor accidents. Two hundred and ten people were involved in a total of forty-five accidents that occurred from 2010 to 2019 [19].

2.3. Fire hazard
Fire hazards in Polish underground mining are endogenous and exogenous. Endogenous hazards are caused by spontaneous heating of coal which is a natural phenomenon. It is mainly caused by the mining of coal deposited at greater depths. Exogenous hazards are triggered by a human factor and they are caused by a lack of caution, non-compliance with regulations, and incorrect operation of the machinery and devices. Figure 2 presents data recorded from 2010 to 2019 [19] and clearly shows that the endogenous hazards were related to most of the events.
Figure 2. Endogenous and exogenous fire hazards in the years 2010–2019 [19].

Ninety-one events that occurred between 2010 and 2019 were classified as fire hazards. Interestingly, these hazards do not always lead to minor, major, or fatal accidents [19]. A fire hazard is defined as the occurrence of an open fire or exceeded concentrations of carbon monoxide (0.0026%).

2.4. Gas and rock ejection hazard

Here, the rocks or coal are rapidly moved/ejected through the energy that has accumulated. The gases that are usually involved are methane (CH$_4$) or carbon dioxide (CO$_2$). There were six cases recorded between 2010 and 2019 in Polish mines that were classified as the gas and rock ejection hazard. They did not cause any injuries [19, 21].

Table 2. Gas and rock ejection hazard in the years 2010–2019 [19, 21].

| Year | Event                        |
|------|------------------------------|
| 2010 | No events                    |
| 2011 | No events                    |
| 2012 | KWK Budryk                  |
| 2013 | No events                    |
| 2014 | No events                    |
| 2015 | O/ZG Polkowice-Sieroszowice  |
|      | (2 events)                  |
| 2016 | No events                    |
| 2017 | O/ZG Polkowice-Sieroszowic  |
| 2018 | O/ZG Rudna                   |
| 2019 | O/ZG Polkowice-Sieroszowic  |
|      | No events                    |

2.5. Water hazard

A water hazard is common in underground mining. It results from the hydrogeological conditions prevailing in Poland. The mining of coal deposited in difficult conditions of aquifers leads to an increase in the level of the water hazard. This is intensified by the decommissioning of mines located in the vicinity. Protecting mines from the hazard means constant monitoring of changes in the rock mass and aquifers.
2.6. Coal dust explosion hazard
Between 2010 and 2019 there was no only one recorded case of coal dust explosion hazard in Polish mines—in 2008 at the Mysłowice-Wesoła coal mine, where coal dust exploded as a result of spontaneous combustion of coal, and methane ignited and exploded in the dammed part of the pavement [19,20].

2.7. Technical hazard
Technical hazards in the years 2010 to 2019 led to eighty-six fatal and fifty-nine severe accidents [19,22]. The causes of these accidents included:
- failure to comply with safety precautions when working with electric power,
- presence of workers on the routes of the machines,
- unsecured work at heights,
- work in prohibited places.

| Year | Fatal | Severe |
|------|-------|--------|
| 2010 | 10    | 15     |
| 2011 | 12    | 8      |
| 2012 | 12    | 7      |
| 2013 | 9     | 4      |
| 2014 | 10    | 5      |
| 2015 | 4     | 2      |
| 2016 | 7     | 5      |
| 2017 | 5     | 6      |
| 2018 | 6     | 1      |
| 2019 | 11    | 6      |

2.8. Hazard when using blasting materials
The hazard related to the use of blasting materials has led to three fatal, five severe, and twenty-one minor accidents between 2010 and 2019. It results from a lack of caution, routine, and insufficient training of workers. The reasons include a misfire, the lack of use of the wadding or the execution of blasting works not following the technology, and the conditions of the regulations [19].

2.9. Cave-in and roof rockfall hazard
Cave-in hazard leads to a rapid, uncontrolled displacement of rocks towards the excavation site, causing a lack of functionality for more than eight hours. The reasons are:
- corrosion of the components of the roof support,
- cavities that are not secured through the use of the components of the roof support,
- no control by the supervisory personnel.

This hazard in the years 2010 to 2019 led to forty-eight fatal and thirty severe accidents [20].

3. A method to minimize the impact of natural hazards
Over several years, it has been observed that the measures implemented to reduce the hazards in underground mining are effective. The awareness of workers regarding hazards has increased. The technology of mining works has also evolved considerably. This does not mean that the number of events involving people is at a level that can be referred to as “satisfactory”. Many solutions and safety measures should be upgraded in order to improve safety and comfort at work. The following section presents solutions that can potentially improve work safety. The solutions are designed to deal with the hazards that are discussed in the paper.

3.1. Methane release hazard
Methane is one of the most dangerous natural hazards in the underground mining industry. The measures are taken to prevent the presence of this gas lead largely to a reduction in its concentration.
The use of modern technologies is effective, but it is not possible to eliminate it—at the moment. Preventive measures applied in underground mining to minimize methane release hazard are [8]:

- prior determination of the methane capacity of the deposits,
- drilling holes in the rock mass to drain the methane,
- advance boreholes during operation,
- the use of automatic methanometry,
- proper ventilation of the workings,
- spraying in longwall shearer, roadheaders, and belt transfer units,
- effective protection of inactive and dammed excavations.

3.2. Rock bursts hazard

Measures to prevent the rockburst are mainly based on solutions designed to lower the pressure in the rock mass [6]:

- mining the remaining mineral in the deposits,
- mining works carried out based on proper mining practices—mining the coal toward the body of coal,
- mining the seams of the top layer in order to relax the seams of the lower layer,
- advance boreholes to relax the rock,
- blasting off the roof of the excavation to relax the rock,
- the use of technology that enables the operation to be carried out in a way that is safe for life and health,
- planning of mining operations concerning the prevailing mining and geological conditions.

3.3. Gas and rock ejection hazard

The activities aimed to identify the formation of the phenomenon of gas and rock ejection are based on measurements of the concentration of gases at places of their accumulation. The measures to limit the hazard are [10]:

- linear mining of the longwall,
- filling the voids in the roof in order to eliminate areas where gas can accumulate,
- the use of automatic gas measurements,
- research and testing boreholes.

3.4. Fire hazard

Fires in the mines are open fires in an underground working with fumes in the air of the mine or an accumulation of carbon monoxide above 0.0026% concentration. The exception is when this level of carbon monoxide is detected during the blasting or welding, or using machines with a diesel engine. The measures to prevent it include [8]:

- works in the longwall face conducted fast,
- works in the roof with respect to the prevailing mining and geological conditions,
- mining the remaining mineral,
- proper ventilation system,
- workers trained to act properly in the case of the fire hazard,
- machines and equipment used as intended,
- automatic gas detection sensors.

3.5. Water hazard

The water hazard in the years 2010–2019 did not lead to accidents involving a large number of injuries. The measures designed to limit this hazard include [7]:

- adequate drainage machines and equipment,
- levels of aquifers treated as an integral part of the planning stage,
- protection of excavations by watertight dams, against uncontrolled groundwater intrusion,
- construction of water reservoirs and use of accumulated water for technological purposes,
- drainage boreholes,
• protective pillars for the existing groundwater accumulation site.

3.6. Cave-in hazard
The cave-in hazard and possible fall of roof rocks led to forty-eight fatalities between 2010 and 2019. The following measures should be intensified to prevent the cave-in hazard [5]:
• proper selection of the roof support in excavations where there is a high possibility of the cave-in,
• additional reinforcement of the roof support,
• modern solutions for the development of cross headings,
• control of the roof support by supervisory personnel using suitable instruments,
• the use of steel with higher strength parameters,
• additional chock and rockbolt support.

3.7. Hazard when using blasting materials
The following steps should be taken to prevent incidents with the use of blasting agents in hard coal mines [8]:
• intensified training in the use and application of blasting agents,
• intensified control by supervisors in order to improve the quality of use of blasting agents,
• compliance with the guidelines, securing the site of the works,
• controlling the knowledge of the regulations on blasting agents,
• applying the wadding,
• adequate protection during transport,
• providing workers with safer means of transporting explosives.

3.8. Technical hazard
Technical hazards resulting from improper use of machinery and equipment and failure to comply with health and safety regulations led to 149 incidents between 2010 and 2019. In order to reduce accidents related to technical hazards, the mining industry should [8]:
• increase the quality of training in occupational safety,
• increase control checks at worksites,
• conduct control checks by the supervision personnel over the on-the-job training,
• provide additional training for employees on machinery and equipment operation,
• increase the control of the authorization of persons operating machines and equipment,
• increase the frequency of technical tests for employees,
• increase investment in modern technologies,
• apply preventive measures in the form of safety devices.

4. Conclusion
The hard coal mining companies in Poland constantly search for new and innovative preventive measures designed to limit or control natural hazards as such hazards are an integral part of the mining process in Poland. The measures significantly impact on the manner of operation and costs. They are primarily aimed at improving two key aspects—safety and comfort at work. All measures, in particular the introduction of new technical solutions, should include them.

The events related to the hazards presented in the paper often affect the workers and the equipment. More resources should be invested in machinery and devices equipped with modern safety features as well as training to ensure safety and comfort at work.

A knowledgeable and well-trained team is the foundation of safe coal production. When hazardous events occur, the workers are equipped with tools that help them to minimise the consequences. The presented solutions to limit the effects of hazardous events should make it possible to prevent or reduce accidents in the mining companies in Poland. It is crucial to determine the cause of the event. Natural hazards can be prevented without always having a direct impact on their consequences. It also seems reasonable that hazardous events involving the human factor can be significantly reduced through appropriate investments, the use of modern technologies, safety devices, and quality of trainings.
References

[1] Brodny J and Tutak M 2019 *Energies* **12** 2505
[2] Brodny J and Tutak M 2020 *Energies* **13** 1925
[3] Brodny J, Tutak M, John A 2018 *Mechanika* **24** (5) pp 695-702
[4] Brodny J and Tutak M 2019 *Arch. Control Sci.* **29** (1) pp 25-39
[5] Burtan Z, Stasica J, Rak Z 2017 *Wydawnictwo Głównego Instytutu Górnicztwa (Katowice)* [in Polish]
[6] Frolik A and Kubica J 2015 * Ocena zagrożenia wodnego i jego ryzyka w kopalniach węgla kamiennego* pp 61-75
[7] Matuszewski K 2009 *Zapobieganie katastrofom górniczym w kopalniach węgla kamiennego* Wyższy Urząd Górniczy pp 20-23
[8] Ministerstwo Energii 2019 *Program dla sektora górniczego węgla kamiennego w Polsce (obiegujący okres do 2030 i prezentujący warunki rozwoju górnictwa węgla kamiennego w Polsce wraz z celami i działaniami niezbędnymi dla ich osiągnięcia).*
[9] Rospondek A and Katan D 2014 *Zagrożenia gazowe w polskim górnictwie* pp 2-27
[10] Sobik L, Brodny J, Buyalich G, Strelnikov P 2020 *E3S Web Conf.* **174** (01011)
[11] Szurgacz D, Sobik S, Brodny J 2019 *E3S Web Conf.* **105** (01013)
[12] Szurgacz D and Brodny J 2019 *Sustainability* **11**(9)
[13] Szurgacz D and Więcek P 2019 *Bezpieczeństwo Pracy i Ochrona Środowiska w Górnicztwie* **6**(298) pp 10-15 [in Polish]
[14] Szurgacz D 2019 *Zmechanizowana obudowa ścianowa w zmiennych warunkach górniczo-geologicznych* Oficyna Wyd. Politechniki Wrocławskej
[15] Tutak M and Brodny J 2018 *Energies* **11**(11)
[16] Tutak M and Brodny J 2019 *Energies* **12**(20)
[17] Tutak M 2020 *Sustainability* **12** (1) art. no. 16
[18] Wyższy Urząd Górniczy 2020 *Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo-geologiczną w 2019 roku (porównanie od roku 2015)* pp 8-36
[19] Wyższy Urząd Górniczy 2019 *Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo-geologiczną w 2018 roku (porównanie od roku 2014)* pp 9-31
[20] Wyższy Urząd Górniczy 2011 *Stan bezpieczeństwa i higieny pracy w górnictwie w 2010 rok* pp 11-56
[21] Wyższy Urząd Górniczy 2014 *Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo-geologiczną w 2013 roku (porównanie od roku 2008)* pp 7-25
[22] Zhironkin S, Selyukov A, Gasanov M 2020 *Energies* **13**(13) 3305