

CLASSIFICATION OF OCCUPATIONAL HAZARDS IN COAL MINING BASED ON CHARACTERISTIC FEATURES

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Purpose: The aim of this article is to analyze the process of occupational hazard identification in underground coal mining operations. Given the inherently high level of risk associated with mining activities, particular emphasis is placed on the accurate identification and characterization of hazard sources as a foundation for effective occupational risk assessment. The paper also seeks to propose a systematic classification of hazards that takes into account both their sources and their potential health and accident-related consequences.

Design/methodology/approach: The article is based on a comprehensive review of scientific literature and applicable legal regulations related to occupational health and safety in underground mining. The study was conducted using secondary data analysis, incorporating a review of normative documents and academic publications addressing occupational hazard issues.

Findings: As a result of this analysis, a structured classification of hazards was developed, including the determination of their characteristic features. This provides a foundation for further application in the context of selecting appropriate risk assessment methodologies.

Research limitations: Despite the broad analytical approach, which encompasses a review of scientific literature, legal frameworks, and accident causation data in the coal mining industry, the study remains theoretical and statistical in nature. It does not include data obtained directly from workplace observations in mining operations. The accident analysis is based on publicly available statistical reports and documents issued by mining supervisory authorities, which may limit the ability to fully capture the organizational and technical context of each event.

Implications: The presented classification of occupational hazards in the mining industry may serve as a foundation for optimizing occupational risk assessment processes by enabling a better alignment of assessment methods with the specific characteristics of identified hazards. A more in-depth characterization of hazard sources and their consequences can also contribute to a more accurate definition of preventive measures and more effective planning of protective strategies. The article contributes to the development of the theoretical foundations of safety management in mining by systematizing the hazard identification process within the framework of occupational risk assessment.

Practical implications: The findings of the study may provide a foundation for developing a more comprehensive methodology for occupational risk assessment that incorporates the

characteristic features of hazards. Consequently, they can facilitate the definition and optimization of preventive measures targeted at the sources of hazards.

Keywords: occupational safety, underground coal mining, occupational hazards, occupational risk assessment.

Category of the paper: research paper.

1. Introduction

Occupational risk is a critical factor contributing to workplace accidents and occupational diseases, and in specific circumstances, it may also lead to major failures or disasters. Ensuring the safety of workers is one of the fundamental objectives of any enterprise. Achieving this goal is possible through the systematic identification of hazards and reliable assessment of the associated risks. A key element of the hazard identification process is the detailed analysis of the factors influencing the likelihood and consequences of their occurrence. The more precisely hazards present in the work environment are identified and characterized, the more accurate and credible the risk assessment will be.

Every organization undertakes efforts aimed at eliminating or at least reducing the consequences and frequency of hazardous events. This is particularly important in industrial sectors, where threats are constant and effective safety management requires the consistent implementation of risk management principles. The risk assessment process begins with identifying its sources, that is, the factors underlying the occurrence of hazards. The more thoroughly these factors and the hazards they generate are identified and described, the more accurate the estimation of health-related risks assessment will be. This, in turn, enables the implementation of precise and adequate preventive measures directly targeting the control or elimination of hazard sources, ultimately improving workplace safety.

Guidelines for hazard identification are primarily determined by applicable legal acts and industry standards. In the Polish legal system (Regulation of the Minister of Health, 2011; Regulation of the Minister of Labor and Social Policy, 2014), various hazard classification criteria have been adopted, which include, among others, the level of detail and measurability. Among hazards resulting from measurable physical factors, harmful environmental factors have been distinguished, for which permissible exposure values (NDS, NDN) are specified, such as:

- chemical substances,
- industrial dusts,
- noise (within the audible and ultrasonic range),
- mechanical vibrations (hand-arm and whole-body exposure),
- extreme microclimates (hot and cold),
- optical radiation (laser and non-laser),
- electromagnetic fields and radiation (in the range of 0-300 GHz).

An additional classification of hazards is included in the "Z-10 Workplace Conditions Assessment" form (Statistic Poland, 2023), which distinguishes:

1. Hazards arising from the work environment:
 - chemical substances – toxic, irritating, sensitizing, carcinogenic, and mutagenic,
 - dusts – fibrogenic, carcinogenic, and others,
 - noise and mechanical vibrations,
 - microclimate,
 - ionizing and non-ionizing radiation,
 - electromagnetic fields,
 - biological factors (e.g., bacteria, viruses, fungi).
2. Hazards related to work strain:
 - excessive physical workload,
 - inadequate lighting,
 - ergonomic factors such as forced body posture and monotonous work.

Workplace accident rates may result from a combination of technical, organizational, and human factors (Gul, 2018; Nyoni et al., 2018; PN-N-18002, 2011; PN-Z-08052, 1980; Tian et al., 2024).

The sources of hazards include, among others:

Technical (mechanical) factors:

- design and construction errors,
- improper use of machinery and equipment,
- material defects,
- inadequate maintenance and operation.

Organizational factors:

- poor work organization,
- suboptimal workplace layout,
- lack of or improper use of personal protective equipment (PPE),
- insufficient training and low employee competence.

Human factors – psychophysical condition of the worker:

- sudden health problems,
- fatigue and exhaustion,
- stress, distraction, lack of focus,
- mental disorders,
- use of alcohol or psychoactive substances.

An inseparable element of the hazard identification process is also the analysis of unsafe behaviors, such as:

- actions inconsistent with regulations or instructions,
- lack of hazard awareness and unfamiliarity with OHS procedures,
- disobeying official instructions,

- overly fast or careless task performance,
- lack of professional experience,
- failure to use PPE,
- violation of organizational and safety procedures.

Accident cause analysis is a valuable and indispensable source of information about existing hazards and their origins. According to the Polish Classification of Activities (PKD), the "Mining and quarrying" section is among the most hazardous sectors of the economy. It is characterized by the highest accident frequency rate (per 1000 employees) and a high average number of work incapacity days per injured person.

In statistical summaries, this section includes the following divisions:

- hard coal and lignite mining,
- extraction of crude petroleum and natural gas,
- metal ore mining,
- other types of mining and quarrying,
- support activities for mining.

An analysis of accident rates in the years 2018-2021 within the entire "Mining and Quarrying" section revealed an average of 2181 occupational accidents per year, including 15.5 fatal, 12 severe, and 2153 minor accidents (Statistic Poland, 2023). The accident figures for individual years are presented in Figure 1.

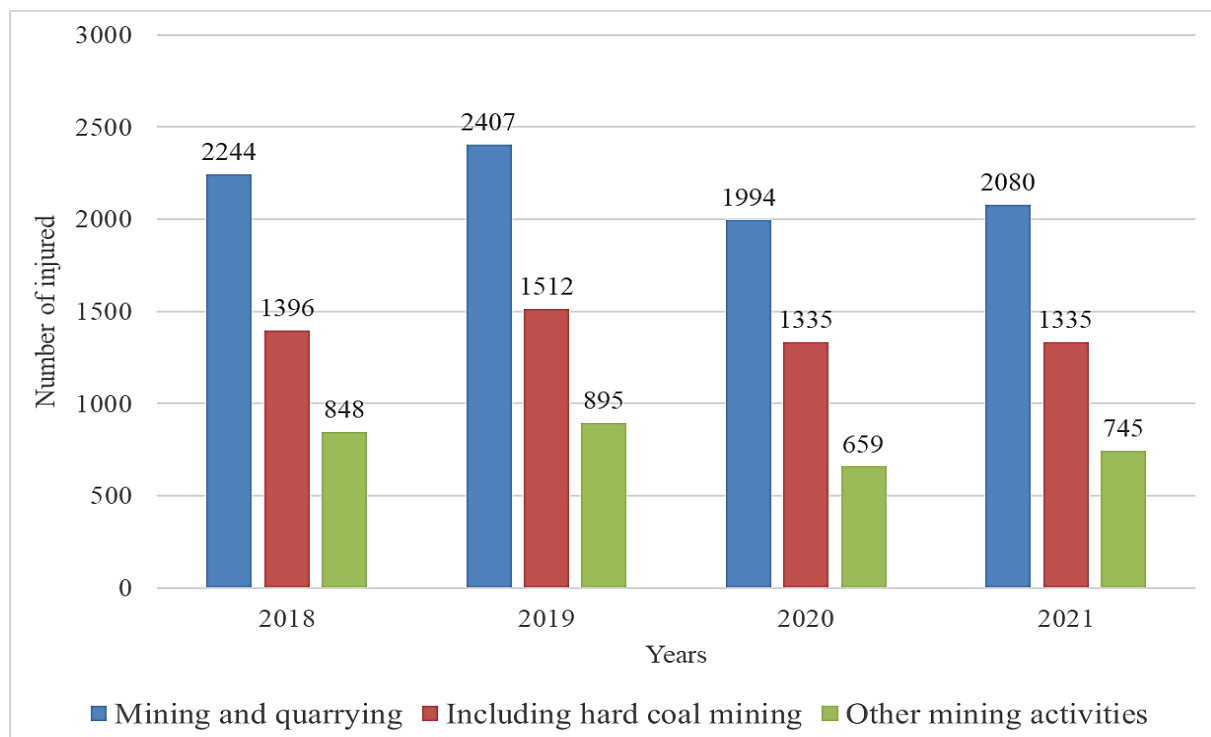


Figure 1. Total number of injured persons in occupational accidents in the mining and quarrying section in the years 2018-2021.

Source: Own study based on GUS data (Statistic Poland, 2023).

In the years 2018-2021, fatal accidents were also recorded in the Mining and Quarrying section, as illustrated in Figure 2.

Among the most common injury-causing events in the total number of occupational accidents in the "Mining and Quarrying" section during the years 2018-2021 were:

- being struck by a moving object,
- collision with or impact against a stationary object,
- physical or mental overload,
- contact with a sharp, rough, or abrasive object.



Figure 2. Fatal accident victims in the mining and quarrying section in the years 2018-2021.

Source: Own study based on GUS data (Statistic Poland, 2023).

Similar incidents also dominated within the "Hard Coal Mining" group. Considering the specific characteristics of the working environment in mining facilities, it can be observed that the most frequent injury-causing events correspond with typical hazards present at mining workplaces. These include, among others: movement in difficult terrain conditions, material transport, work with hand tools, operation of machinery and equipment, presence of transportation systems, exposure to static and dynamic loads, as well as natural hazards.

When comparing data on the most frequent injury-causing events in the "Mining and Quarrying" section with information on the causes of occupational accidents across the national economy in the years 2018-2021 (Statistic Poland, 2023), it is evident that the predominant cause of these accidents was improper employee behavior. This was accompanied by other, less significant contributing factors, which are detailed in Table 1 in relation to specific categories of injury-related events.

The most common events classified as deviations from the normal state in the same section (including the "Hard Coal Mining" group) in the years 2018-2021 were:

- other (unspecified) events,
- slipping, tripping, or falling on the same level,
- being struck by a falling object from above.

Table 1 presents a summary of the most frequent parameters describing the causes, circumstances, and consequences of occupational accidents in the "Mining and Quarrying" section in the years 2018-2021.

It should be emphasized that the data contained in this table reflect the most prevalent accident events, their causes, material agents, as well as the types and locations of injuries occurring within the analyzed economic sector.

In the following years as well, according to data from the Statistical Office (GUS) from 2023 (Statistic Poland, 2023), unsafe employee behaviors remain the leading cause of occupational accidents accounting for over 70% of all incidents. This makes them one of the key elements requiring detailed analysis within the occupational risk assessment process.

Employees in the "Mining and Quarrying" section and its subsections most frequently fall victim to so-called "other" accidents, most commonly involving slipping/tripping and falling on the same level, being struck from above, or slipping and falling from a height.

Table 1.

Causes, circumstances, and consequences of occupational accidents in the mining and quarrying section in the years 2018-2021.

Type of accident	Event causing injury	Cause of accident	Material agent causing injury	Activity at the time of accident	Cause of accident due to activity performed	Material agent related to activity performed	Deviation from normal state	Type of injury	Injured body part
- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -	- 10 -
Total – mining and quarrying (including hard coal mining)	impact by a moving object	<ul style="list-style-type: none"> – improper employee behavior, including: – improper condition of material agent, – lack of or improper use of material agent, – improper or unauthorized employee action 	materials, objects, products, machine parts	movement	<ul style="list-style-type: none"> – improper employee behavior, including: – improper organization (of the workstation), – improper technical or ergonomic condition of material agent 	buildings, structures and their components, surfaces (usually at ground level)	other	cuts and superficial injuries	upper limbs
	collision with / impact against a stationary object	improper employee behavior	buildings, structures and their components, surfaces (usually at ground level)	handling of objects	<ul style="list-style-type: none"> – improper employee behavior, including: – lack of or improper use of material agent, – poor organization of work and workplace – improper condition of material agent 	materials, objects, products, machine parts	slip, trip, fall from height	bone fractures	lower limbs
	physical or mental overload	<ul style="list-style-type: none"> – improper employee behavior, including: – lack of or improper use of material agent, – improper condition of material agent 	buildings, structures and components, surfaces (mainly ground level), materials, objects, products, machine parts	manual transport	<ul style="list-style-type: none"> – improper employee behavior, including: – poor work organization, – lack of or improper use of material agent 	materials, objects, products, machine parts	struck by falling object	dislocations, sprains, strains	head
	contact with a sharp, rough, or abrasive object	improper employee behavior	hand tools without power, materials, objects, products, machine parts	working with hand tools	<ul style="list-style-type: none"> – improper employee behavior, including: – lack of or improper use of material agent, – improper condition of material agent, – poor work organization 	equipment for generating, processing, storing, transmitting and distributing energy	—	—	—

Source: GUS (Statistic Poland, 2023).

In the “Mining and Quarrying” section, an average of 51.8% of occupational accidents in the years 2018-2021 were caused by events classified as "other". In 2018, 2020, and 2021, such events accounted for approximately 49% of all accidents, while in 2019 they represented nearly 58%. The second most frequent cause of accidents in this section was slipping, tripping, or falling on the same level, with an average share of 25.6%. The highest share for this cause was recorded in 2021, accounting for 29.7% of all reported events, whereas in 2019, the share was only 21%. The trend in the proportion of accidents involving this event has shown a year-on-year increase, with the exception of 2019 (Figure 3).

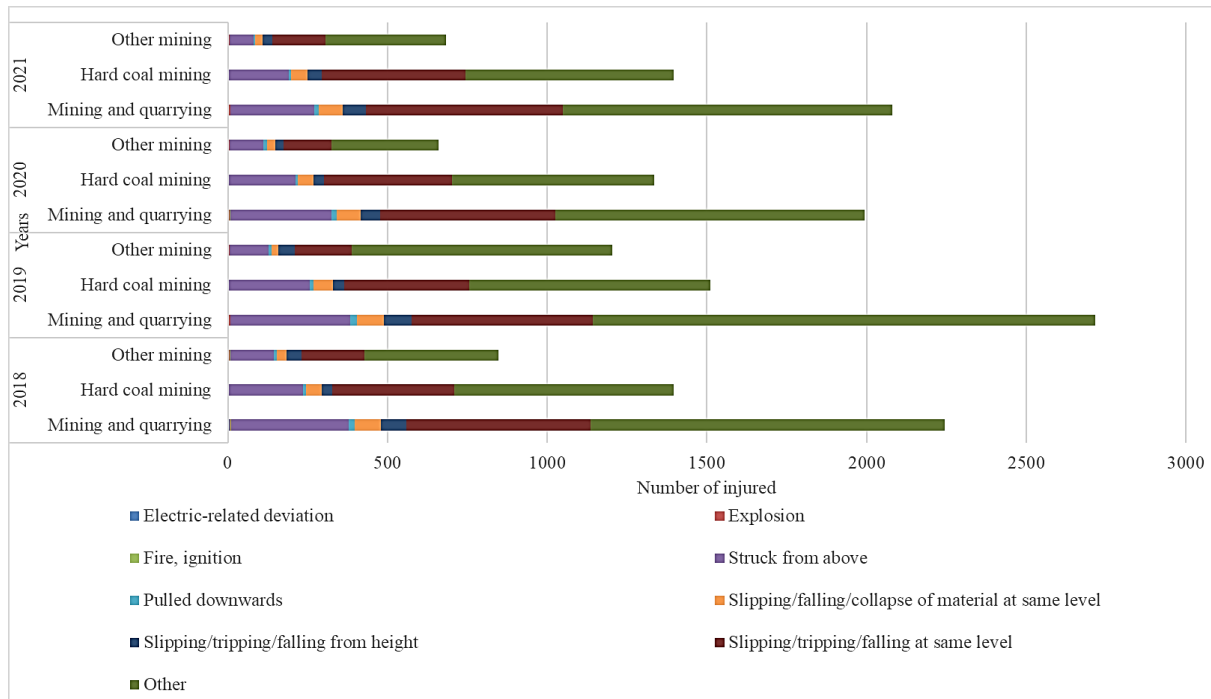


Figure 3. Victims of occupational accidents in the “Mining and Quarrying” section in the years 2018-2021, by events classified as deviations from the normal state.

Source: Own study based on data from Statistics Poland (GUS) (Statistic Poland, 2023).

Among the sources of accidents in hard coal mining, natural hazards must not be overlooked. Some of these particularly those of a catastrophic nature, such as methane explosions or rock bursts can lead to numerous and severe injuries, often with fatal outcomes. According to data from the Central Statistical Office (GUS) (Statistic Poland, 2023), accident rates resulting from natural hazards in the years 2020–2024 are presented in Table 2.

Table 2.

Accident rates resulting from natural hazards in the years 2020-2024

Hazard	Type of Accident			
	Total accidents	Fatal accidents	Serious accidents	Accidents causing temporary work incapacity
Methane	56	16	7	33
Rock Bursts	140	32	4	104
Endogenous Fires	0	0	0	0

Source: Own study based on GUS data (Statistic Poland, 2023).

Polish hard coal mining is characterized by the presence of all natural hazards typical of underground extraction. Among the most accident-prone natural hazards are rock burst hazard and methane hazard. Methane ignitions and explosions, as well as rock bursts and stress relief events that occurred in the years 2020-2024, accounted for the majority of fatal and serious accidents in the Polish mining sector.

The Polish Standard PN-Z-08052:1980 generally defines sources of hazards as follows:

- *hazardous factor* – one whose impact on a worker leads or may lead to injury,
- *harmful factor* – one whose impact may lead to the development of disease.

In addition, the PN-N-18001:2004 standard, now replaced by PN-EN ISO 45001:2024, introduced the concept of a *burdensome factor*, understood as a factor whose impact may cause discomfort or excessive fatigue, but does not result in permanent deterioration of health.

One of the key standardization documents relevant to hazard identification is ISO 12100-1:2012, which outlines the principles of risk assessment in the context of machinery safety. This standard introduces a comprehensive classification of hazards, encompassing mechanical, electrical, thermal, vibration-related, noise-related, and radiation hazards. It also addresses ergonomic hazards and those associated with materials and substances, including chemical, explosive, and biological agents. Additionally, it considers risks stemming from human error, slips, trips, and falls, as well as environmental hazards such as inadequate lighting, extreme temperatures, snow, and strong winds.

Due to the specific nature of mining hazards, the hazard identification process should also include *natural hazards*, defined in Mining Lexicon (Mining Lexicon, 1989), among others, as:

- gas hazard – resulting from the presence of gases, mainly methane and carbon dioxide, in the rock mass,
- fire hazard – related to the presence of fire, fire gases, and smoke in underground workings,
- dust hazard – related to the presence of fine dusts, including coal and silica dust,
- water hazard – sudden inflow of water into the workings from the rock mass or the surface,
- explosion hazard – methane or coal dust explosions.

In addition, the literature (Krause, 2012) lists the following:

- rock bursts,
- roof falls,
- endogenous fires,
- complex and technical hazards.

Other scientific publications (Burtan et al., 2018; Kabiesz, 2001; Krause, 2012; Nowak-Senderowska, 2014; Nyoni et al., 2018; Prusek et al., 2016; Tian et al., 2024; Tubis et al., 2020) also highlight natural hazards that are not explicitly included in legal regulations but nevertheless represent significant risks. These include:

- endogenous hazard – resulting from the spontaneous combustion tendency of coal,
- combined hazards – caused by the interaction of multiple simultaneous hazards,
- gasodynamic hazard – a combination of rock burst and methane hazards.

Occupational hazards in mining are also classified into five primary categories:

- physical,
- chemical,
- biological,
- ergonomic,
- psychosocial.

The most frequently encountered hazards in mining include:

- traumatic hazards (including natural ones),
- ergonomic hazards,
- noise exposure,
- psychosocial hazards.

A three-part classification of hazards is also present in the literature (Burtan et al., 2018):

- natural hazards, originating from the inherent properties of the rock mass:
 - *catastrophic*: methane, coal dust explosion, endogenous fires, rock bursts, gas and rock outbursts, water hazards and their characteristics,
 - *non-catastrophic*: health-threatening dusts, climatic and radiation hazards,
- technical hazards, related to machines, explosives, and exogenous fires,
- human-related hazards, caused by improper employee behavior or poor work organization.

Hazard identification is one of the key stages in the occupational risk assessment process. This stage involves the use of both formal and informal techniques, collectively referred to as hazard characterization (PN-N-18002:2011; Szczepański, 2024). Informal methods include:

- workplace observations,
- employee interviews,
- occupational health and safety committee meetings,
- expert experience,
- consultations with personnel,
- safety audit results.

According to the literature (Burtan, 2016), relying solely on employee knowledge and experience does not ensure complete hazard identification. Therefore, it is essential to use formal methods specifically designed for this purpose. One example is a catalog of 250 potential hazards developed for gold mines, as well as the application of the AHP (Analytic Hierarchy Process) method in occupational risk assessment (Badri et al., 2013).

In conclusion, effective identification and classification of occupational hazards should be based on the use of all available registers, lists, catalogs, and classifications – both those contained in legal regulations and in scientific literature.

2. Materials and methods - methodology

2.1. Groups of occupational hazard factors

Based on the previously indicated sources — including registers, lists, catalogues, and classifications compiled through a review of literature, standards, legal requirements, as well as expert knowledge and practical experience — a classification of factors contributing to the occurrence of occupational hazards in hard coal mining has been proposed. These factors have been divided into four main groups:

- **Natural hazardous factors** – these result from the natural properties of the rock mass and geological processes. In hard coal mining, they include: methane ignitions and explosions, coal dust explosions, seismic tremors, rock bursts, gas and rock outbursts, water inflow, and endogenous fires.
- Technical hazardous factors – these are related to the technical work environment. They include machinery and tools and their usage, installations, extraction and transportation systems, local workplace conditions, operational tasks, and the materials and substances used (including chemical agents).
- **Harmful and burdensome factors** – these lead to deterioration in health or cause temporary health issues. Common examples in mining include: noise, vibrations, radiation (IR, UV, electromagnetic, laser), microclimate, hazardous chemicals, biological agents, as well as static and dynamic loads.
- **Organizational and human factors** – these relate to work organization, compliance with procedures, stressors, and the psychophysical condition of workers. They include, among others: communication errors, fatigue, skill mismatch, lack of concentration, hazard disregard, and non-compliance with safety regulations.

The proposed classification facilitates a structured identification of occupational hazards in hard coal mining, ensuring a comprehensive view of risk factors.

2.2. Characteristics of occupational hazards

According to the definition provided in PN-N-18001:2004, hazard identification is not limited to recognizing hazards but primarily involves determining their characteristic features. As noted in Polish Language Dictionary (Polish Language Dictionary, 2021), "characterization" refers to the description of features defining a person, object, or phenomenon, while a "feature" is an element that distinguishes or defines living beings, objects, actions, states, or phenomena. In the context of hazard characterization, this means defining the features of each identified hazard.

In practical applications, this stage is often omitted in occupational risk assessments—resulting in a lack of documentation and analysis of key hazard attributes. Identifying a hazard merely by confirming its existence is insufficient for properly selecting an appropriate risk

assessment method (PN-EN ISO 45001:2024-02, PN-N-18001:2004; Szczepański, 2024; Tubis et al., 2020; Wróblewski et al., 2028). Skipping this step may result in using an unsuitable method that fails to identify the need for implementing control measures.

Determining the characteristic features of hazards is a critical stage in which a detailed hazard description is developed. Omitting this process may lead to underestimating occupational risks and, consequently, implementing ineffective protective measures. A comprehensive approach that incorporates hazard description enables more reliable and effective risk management.

Both literature and standards indicate that the following aspects should be considered when determining hazard features (Krause, 2012):

- physicochemical data of chemical substances and dusts,
- characteristics of energy types and their values (e.g., reactivity, concentration, voltage, current, kinetic, potential, and electric energy),
- information on work methods and organization (e.g., duration, load, working techniques, posture, task cycles, and repetition),
- hazard effects: injuries, illnesses, occupational ailments,
- statistical data needed to estimate probability (e.g., accident records, frequency, and severity),
- legal requirements and literature sources, including safety data sheets, biological agent profiles, and technical material sheets,
- threshold limit values (e.g., NDS – Maximum Permissible Concentrations, TLV – Threshold Limit Values).

Hazards may be classified according to various criteria, including: cause, nature of impact, effects, measurability, origin (internal/external), and applied preventive measures (Konopko et al., 2013; Krause, 2012). These criteria may simultaneously serve as characteristic features of hazards.

Publications concerning hazard identification focus primarily on two aspects:

- sources of hazards,
- consequences of their impact.

In the hazard characterization process, two types of features are distinguished (Act Geological and Mining Law, 2011):

- features of hazard sources,
- features of hazard consequences.

A feature is defined as a distinguishing or characterizing attribute of living organisms, objects, their actions, conditions, or phenomena (Polish Language Dictionary, 2021). A parameter is defined as a variable that takes on a constant value in a given context to emphasize its significance relative to other variables, or as a characteristic value of a material, process, or device (Polish Language Dictionary, 2021). In the context of hazards, parameters

may be expressed as measurable values (e.g., from physical measurements) or estimated values when precise measurement is not possible.

The explanatory notes of the "Z-10 Workplace Conditions Assessment" form (Statistic Poland, 2023) provide examples of features of mechanical factors that, when in contact with a person, may lead to injury. For instance, mechanical hazards associated with particularly dangerous machines can be described using features such as: kinetic and potential energy (including fluid pressure), shape, dimensions, surface properties, stability, and mechanical strength.

Taking the above into account, it is possible to propose a hazard identification algorithm based on characteristic features and their corresponding parameters (Szczepański, 2024) (Figure 4).

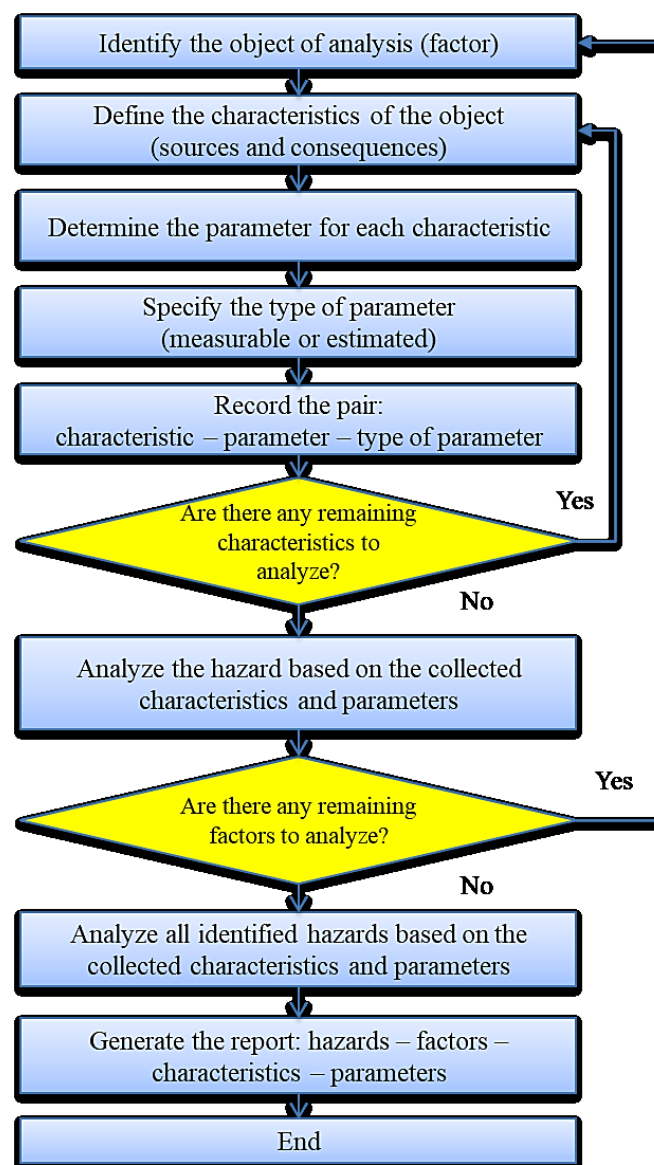


Figure 4. Algorithm for hazard identification considering characteristic features and their parameter.

Both the sources of hazards and their consequences can be described using specific features (Figure 4):

- **Features of hazard sources**, which describe their origin, are assessed based on:
 - physical measurements (e.g., kinetic energy, pressure, noise level),
 - qualitative estimations (e.g., hazard potential).
- **Features of hazard consequences**, which describe their impact on humans, the work environment, or technological processes, are assessed through:
 - probability estimations (e.g., likelihood of injury occurrence),
 - calculated parameters (e.g., risk indicators derived from mathematical models).

The subsequent steps of the algorithm are designed to provide comprehensive information on all identified occupational hazards by analyzing them in terms of underlying factors, characteristic features, and measurable parameters. This structured approach facilitates a systematic identification and classification of hazards, thereby enabling a more accurate assessment of occupational risk. Moreover, the use of characteristic features offers a robust foundation for the development of effective tools for occupational safety management. The implementation of such tools has the potential to significantly reduce the incidence of workplace accidents and enhance overall working conditions in the mining industry.

3. Results

The application of an approach based on characteristic features enables a structured identification and classification of hazards, which contributes to a more precise assessment of occupational risk. It is proposed that the hazard identification process be carried out by developing a detailed characterization of each hazard-inducing factor—taking into account both its sources and potential consequences. Accordingly, the first step in a comprehensive hazard characterization should be to determine its characteristic features, in line with the algorithm presented (Figure 3). These features should describe both the sources and the consequences of hazards in the most precise, exhaustive, and systematic manner possible.

Justification for the use of specific characteristic features of hazards was based on the following premises:

- Consistency with scientific and normative literature

The selection of features was based on an analysis of technical literature and normative documents, including ISO 12100, ISO 45001, and PN-N 18002. A shared aspect of these sources is the emphasis on physical and environmental parameters that directly influence the identifiability of hazards and the magnitude of the associated risk.

- **Measurability and objectivity**
The selected features—such as mass, exposure time, and energy—are characterized by a high degree of measurability and repeatability. This allows their use in both qualitative and quantitative analyses, supporting their practical application in occupational risk assessment.
- **Relevance to hazard impact mechanisms**
The features and their associated parameters directly relate to the mechanisms by which workplace environmental factors can affect the human body (e.g., greater mass results in higher impact force; longer exposure time increases the degree of biological damage). These relationships are reflected in fields such as injury biomechanics, toxicology, and ergonomics.
- **Application in occupational health and safety practice**
In occupational risk assessment methods commonly used in practice—such as the Risk Score method, KIM 1-6, and OWAS—similar characteristic features are used to assess and quantify risk levels. This confirms their practical relevance and applicability in real-world safety systems.
- **Utility in the hazard identification process**
The defined characteristic features included in the hazard classification form a standardized and structured data repository that supports consistent and systematic hazard identification across various work environments. Such a repository may serve as a foundation for both analytical applications and the development of decision support systems based on artificial intelligence.

In this context, the prioritization of features—such as data availability, clarity, and potential for quantitative processing—becomes particularly important. These aspects will be further elaborated in a forthcoming article dedicated to the practical application of the proposed hazard classification and characterization model in the occupational risk assessment process using analytical and digital tools.

Tables 3-6 present an original compilation of characteristic features of the most common hazards encountered in mining, divided into features of hazard sources and features of their consequences (Szczepański, 2024). The adopted classification corresponds to the categories of hazards identified in this study: technical hazardous factors, natural hazardous factors, organizational and human factors, and harmful and burdensome factors.

3.1. Characteristics of Natural Hazardous Factors

The first group of hazards comprises natural hazardous factors. Proposed descriptions of the sources and consequences of hazards within this group are presented in Table 3.

Table 3.
Characteristic features of natural hazardous factors

Type and description of factor	Hazard	Characteristic features of sources
methane	presence in areas with methane hazard	methane-bearing capacity, potential for methane concentration leading to ignition, explosion, or formation of oxygen-deficient mixtures, methane hazard classification (categories I-IV according to legal requirements)
coal dust	presence in areas with coal dust explosion hazard	occurrence of hazardous coal dust, potential for dust explosion, classification of seams or their parts, vertical and horizontal workings into two hazard classes (a and b), according to legal classification
rock bursts	presence in areas with rock burst hazard	susceptibility of rock mass to rock bursts, potential for seismic events (rock bursts) in mine workings, classification according to two hazard levels as defined by legal classification
gas and rock outbursts	presence in areas with gas and rock outburst hazard	methane-bearing capacity, cohesion, desorption index, friability, potential for sudden methane emission or methane and coal outburst, classification of gas and rock outburst hazard (categories I-III), according to legal classification
water	presence in areas with water hazard	hydrogeological conditions, potential for increased water inflow or water ingress with loose material, expressed in three hazard levels I-III), according to legal requirements
endogenous fire	presence in areas with endogenous fire hazard	coal self-ignition susceptibility, activation energy, fire incubation period, quantity and rate of carbon monoxide increase, classification of self-ignition potential in five groups

The characteristic features of consequences such as the number of incidents, types of injuries, number of affected individuals, and injury occurrence frequency which are largely common across all natural hazards, were not included in the table.

3.2. Characteristics of technical hazardous factors

The second group of hazards includes technical hazardous factors. Proposed descriptions of technical hazards and their sources are presented in Table 4.

Table 4.
Characteristic features of technical hazardous factors

Type and description of factor	Hazards	Characteristic features of sources
moving machinery and mechanisms and their components, manual and mechanized tools, transportation of excavated material, rock fragments, rock masses, mining supports	impact by moving objects, machine components, fragments	exposure time, mass, object size, speed of moving object, distance from object, technical condition of equipment, kinetic energy of the object
	entanglement by rotating components	exposure time, mass, object size, speed of rotating object, distance from object, technical condition of equipment, kinetic energy of the object
	crushing by moving object, rock mass, mine collapse	exposure time, mass, speed of moving object, object size, direction of object movement, technical condition of equipment, roof and sidewall condition, kinetic energy of the object
	overturning, falling, rolling, sliding of mining supports, machinery or other objects	exposure time, mass, speed and direction of object movement, object size, technical condition of equipment, kinetic energy of the object
	being covered by transported material	exposure time, mass, speed and direction of object movement, object size, technical condition of equipment, kinetic energy of the object
	impact by hand tools, processed items, assembled or disassembled structures	exposure time, mass, speed and direction of object movement, object size, technical condition of equipment

Cont. table 4.

protruding elements, narrow passages, local height reductions	impact against protruding elements in narrow passages	frequency of exposure, exposure time, size of elements, passage width, passage height, technical condition of workplace
height differences, movement, walking, transport of people, materials, equipment using technical means (e.g., suspended monorails, rail transport, floor-mounted railways, conveyor belts approved for personnel transport), drainage system inspections, sumps	fall from height	frequency of exposure, exposure time, height, technical condition of equipment
	tripping over an obstacle	surface condition, psychophysical state of employee, exposure time
	possibility of falling from transport means (locomotive, suspended tractor, personnel car, cabin), jumping out, collision, derailment, rolling of transport units	frequency of exposure, exposure time, height, speed of transport means, technical condition of equipment
machinery, installations, technological processes	exposure to high pressure (pressurized fluid jets, whipping hoses, fragments propelled by pressurized fluid due to hose rupture)	frequency of exposure, exposure time, pressure, technical condition of equipment and installations
	electric shock, electric arc burns	frequency of exposure, exposure time, electric current intensity, voltage, technical condition of equipment and installations
	high temperature, poisoning due to exogenous fire, underground exogenous fire	exposure time, fire size, fire sources, technical condition of installations
	explosion	frequency of work in explosive atmosphere, exposure time, type and size of explosive hazard zone, technical condition of installations
	hot liquids, hydraulic or pneumatic failure, explosion of pressure vessels, equipment and installations (e.g., tanks, hydraulic accumulators, compressors, pumps)	frequency of exposure, exposure time, quantity of liquid, temperature of liquid, technical condition of installations
	hot surfaces	exposure time, surface temperature, surface area
	low temperature	exposure time, temperature
energy from stress or jamming of supports or rock mass	sudden energy release due to stress or jamming (e.g., support relaxation, conveyor belt release, breaking of jammed pickaxe handle), cable or rope rupture	technical condition of supports and equipment
oxygen, non-breathable atmosphere	oxygen deficiency, mine gases released from rock mass due to mining activities (material decomposition), and operation of diesel-powered machinery	frequency of exposure, exposure time, size of components, passage width, passage height, technical condition of ventilation, ventilation system capacity
lighting	working in areas with inadequate lighting	lighting type (natural/artificial), lighting intensity, lighting color, lighting arrangement, exposure time

The characteristic features of consequences such as the number of incidents, types of injuries, number of affected individuals, and injury occurrence frequency which are largely common across all natural hazards, were not included in the table.

3.3. Characteristic features of harmful and burdensome factors

The third group of hazards comprises harmful/burdensome factors are provided in Table 5. The characteristic features of harmful and burdensome factors are considered together, due to the fact that the distinction between these factors is often unclear, as the features frequently overlap. For practical purposes, the characteristics of sources and effects for both harmful and burdensome factors are analyzed jointly.

Table 5.

Characteristic features of harmful and burdensome factors

Type and description of factor	Hazard	Characteristic features of sources
vibration	exposure to vibration	exposure duration, intensity, route/mode of exposure
noise	exposure to noise	exposure duration, noise level, frequency
radiation (infrared, uv, electromagnetic, visible, laser)	exposure to radiation	radiation type, exposure duration, wavelength, intensity, surface types
radioactive substances	presence in radioactive hazard zones, exposure to ionizing radiation	potential for inhalation or ingestion of short-lived radon decay products or radium isotopes, external gamma radiation emitted from mining sediments and rock formations (radiation hazard classes a and b according to legal classification)
lighting	exposure to inadequate lighting	type of lighting (natural/artificial), intensity, color, arrangement, exposure duration
microclimate	presence in areas with adverse microclimate	air temperature measured by dry bulb thermometer, cooling intensity, microclimatic hazard classification (levels I-III according to legal requirements)
chemical substances	exposure to chemical substances	concentration, exposure duration, hazard classification based on h-statements, physical state, route of exposure, boiling point, process temperature, amount, dust generation potential
biological factors	exposure to biological agents	concentration, exposure duration, classification, toxicity/allergenicity, route of exposure, effects, vaccine availability
static and dynamic loads related to posture	exposure related to body posture	exposure duration, working environment conditions, body posture
manual handling of loads	exposure related to manual transport tasks	load mass, object size, body posture, working conditions
operating transportation equipment	exposure related to operating transport equipment	exposure duration, travel distance, total weight of load and equipment, type and characteristics of equipment, access conditions, working conditions
manual operations	exposure related to manual activities	exposure duration, body posture, object handling method, grip force applied (hand/fingers), working conditions
exertion involving whole-body effort (lifting, pushing, pulling)	exposure to physical loads involving whole-body exertion	exposure duration, body posture, working conditions, symmetry of applied force, force type, force direction
loads associated with movements and relocation	exposure related to movement tasks	exposure duration, movement type (using muscle-powered means, walking, crawling, climbing stairs, ladder use, etc.), movement speed, load weight, carrying method, working conditions

The table does not include characteristics of the effects of each factor. These characteristics include: number of incidents, number and type of injuries, number of errors, number of affected persons and incidence of injuries and are basically consistent for all harmful and troublesome factors.

3.4. Characteristics of organizational and human factors

The final group of hazards, according to the proposed classification, includes organizational and human factors. Proposed descriptions of hazard sources and their consequences for this group are presented in Table 6.

Table 6.

Characteristic features of organizational and human factors

Type and description of factor	Hazard	Characteristic features of sources
stressors – quantitative overload, qualitative overload, quantitative underload, qualitative underload, role conflict, physical working conditions, disruptions, deprivation, tiredness, fatigue, illness, undertaking unacceptable risk	stress	frequency of exposure, duration of exposure, type of work performed, working time, frequency of occurrence
lack, insufficient or incomplete training, incomplete knowledge of methods/ tools/ procedures/ instructions, lack of instruction, or extended periods of inactivity	non-compliance with rules, human error	level of training and skills, competencies, working hours, task difficulty level, frequency of occurrence
misunderstandings, communication errors	aggression by third parties	frequency of exposure, duration of exposure, personal characteristics, type of work performed, frequency of occurrence
psychophysical condition	inappropriate psychophysical condition, fatigue, intoxication, illness	frequency of exposure, duration of exposure, personal characteristics, type of work performed, existing health conditions of employee, frequency of occurrence

The above table does not include columns containing repetitive phrases related to the characteristic features of hazard consequences, as these are common across all listed hazards. These features include: number of illnesses and injuries, type of illnesses and injuries.

For the four distinguished groups of factors, the consequences of their impact exhibit a similar nature—primarily focusing on the type and number of injuries or health issues they may cause. However, it should be noted that certain workplace environmental factors classified as harmful factors may, under specific conditions (e.g., high concentration or intensity), result in consequences typical of another group hazardous factors capable of causing direct injury.

In such cases, the concentration or intensity values of a given factor become critical, as well as the type and severity of the resulting health outcomes, which depend on the extent of the factor's impact on the worker's body. Examples include extremely high noise levels, which can cause immediate hearing damage, or toxic substances, which in large doses may lead to severe injuries or even death.

4. Discussion and conclusions

The proposed classification of characteristic features of factors and hazards occurring in underground coal mining provides a systematic framework for hazard identification and defines the scope of data required for effective hazard information gathering. Both the industrial sector and the specific nature of the process under analysis determine the types of characteristic features and the corresponding parameter values. Integrating characteristic features and their associated parameters into the hazard identification process requires a detailed analysis of each hazard. This approach ensures a comprehensive identification process that reflects the specific operational conditions in underground mining environments.

Adopting such a methodology with clearly defined characteristic features and assigned parameter values emphasizes the necessity of accurate and structured data collection concerning hazards. In subsequent stages of occupational risk assessment, identifying these features and determining the methods for measuring or estimating their parameters becomes crucial. This significantly enhances the effectiveness and credibility of the assessment process, enabling the implementation of targeted preventive and corrective measures tailored to the unique conditions of underground mining operations.

In the proposed classification of factors influencing the occurrence of occupational hazards, natural hazardous factors were identified as the most significant, with their relevance substantiated by statistical data on accident incidence in the mining sector. In current occupational risk assessment practice in mining, evaluations are typically based on estimations of parameters describing the characteristic consequences of hazards (such as the probability of occurrence, type, and severity of injury). However, basing the risk assessment process on the characteristic features of hazard sources enables a more precise estimation of occupational risk and a more effective determination of the necessary preventive measures.

Despite its significant theoretical and structuring value, this study has a validation-related limitation due to the lack of data obtained from direct workplace observations, which could contribute to expanding the repository with new characteristic features of identified hazards. In future research, it would be valuable to consider integrating the proposed hazard classification model with modern digital technologies, such as workplace environment monitoring systems, artificial intelligence (AI) algorithms, and Internet of Things (IoT) solutions. The application of these tools could support the automatic identification of hazards, the dynamic assignment of appropriate characteristic features in real time, and significantly enhance the precision of risk assessment as well as the effectiveness of safety management in the context of future mining operations.

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