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REVIEW PAPER

Identification and categorization of hazards in the mining industry: A systematic review of the literature

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ABSTRACT

Control of OHS risks in the mining industry has been attracting increasing attention in recent years. Because of their great diversity in a complex system, hazards can be difficult to identify and classify, especially when system components interact. Risk cannot be managed successfully without comprehensive investigation of all its aspects. A coherent and integrated classification for identifying and categorizing all hazards is currently lacking in mining. We propose an integrated system classification of OHS hazards in mining based on our review of 44 studies retrieved using PRISMA. Considering Canadian and international standards, regulations and conventions, new hazard categories are proposed and hazard prevention is discussed from 12 perspectives: physical, chemical, biological, ergonomic, accident and psychosocial risks, as well as policy, legislation, management, design, geography, and uncertainty, with reference to each of the four phases of a typical mine life cycle, the hazards were shown in a portrait. This paper provides suitable categories based on rational data for creating a portrait in order to OHS hazards prevention in life cycle activity in mine.

KEYWORDS

occupational health and safety hazards, mining industry, OHS management, systematic, literature review

1. INTRODUCTION

The mining industry plays a crucial role in the global economy. Mines are currently one of the two sources that provide almost all of the raw materials used throughout the world [1]. In 2010, the nominal value of minerals in global production was approximately four times higher than in 2002. This increase in nominal value was much higher than the gross domestic product of many countries [2].

According to the International Labour Organization, work-related illnesses, injuries and deaths due to accidents or exposure to health hazards exact a heavy annual toll reaching $1.25 trillion in losses, equivalent to 4% of the world's annual gross domestic product [3]. Despite all the efforts to reduce the risks, mines remain the most dangerous workplace, due to the number of people who are exposed to the hazards inherent in this setting [4].

Occupational accidents and illnesses have significant direct impact and longer-term social and economic impact on communities and governments [5]. Direct costs include medical expenses, compensation payments, production down-time, and legal fees. The longer-term costs include lost productivity, accident investigation, remedial training, lower employee morale, increased absenteeism, and so on [6].

Historically, Occupational Health and Safety (OHS) research has treated health and safety separately. Comprehensive consideration of health factors alongside safety factors is a recent development. Although health effects can be investigated from the safety perspective, this complicates prediction [7]. Safety has been focused mostly on accidents (e.g., explosions due to system component failure, falls due to equipment malfunction) and investigation on direct

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cause (e.g., human error, inadequacy of equipment or procedures) with little attention paid to long-term health. However, it is now undeniable that systematic integration of OHS into risk management is financially justified in mining projects [8].

Mining is a complicated and multidisciplinary industry that functions under highly dynamic conditions. Lighting and ventilation must be supplied artificially, a variety of gases released, dusts generated and noises associated with blasting or rock breaking must be controlled, along with numerous ergonomic postures, heavy machinery, vehicles, conveyers and so on [9]. In addition, new hazards can emerge because of technological progress, new interactions between system components, between human behavior and technologies, new expectations or demands associated with social progress [10]. Miners are thus exposed to multifaceted risks, the consequences of which can be work-related disease, injury, disability, or even loss of life. Mining accidents are therefore multifactor risk coupling [11].

Mining processes contain a variety of obvious and hidden health and safety hazards that contribute to risk. In a complex system, the recognition of hazards (sources of danger or risk factors) is not simple. Lack of investigation and imprecise categories contribute to uncertainty. Two types of uncertainty are recognized in safety investigations: system intrinsic changeability and lack of knowledge [12]. The latter can be reduced through study and empirical analysis [13].

With its increased awareness, the mining sector is now more focused on implementation and improvement of risk management. Analysis of risk should cover several aspects such as strategy and policy, human factors, operations, and even unexpected hazards. Recent studies confirm that risk management in the mining field tends to monitor specific risks [14–17]. By spreading itself too thin, research leaves knowledge gaps that hinder accurate risk recognition. Opportunities to create a safer environment for miners can be lost. Inaccurate hazard identification means incomplete risk assessment and hence threats to safety [18]. A hazard must be identified correctly so that if it is avoidable, the probability of it becoming a risk can be reduced, and if it is unavoidable, exposure to it can be controlled.

According to ISO 31000, the first step of risk management is risk identification [19]. Successful risk management usually depends on comprehensive study covering as many aspects of risk as possible. Laws, regulations, and standards generally reflect the importance of the implementation of risk management, and often divide risks into useful categories.

Recognizing hazards within a general framework facilitates identification of knowledge gaps. The aim of this literature review is to provide a helpful resource for researchers, mining engineers and OHS managers who are concerned about risk management/engineering issues and are seeking insight into how best to monitor OHS hazards in the mining sector. This study used the literature review of OHS hazards (section 2), then a general portrait of OHS hazards is created (section 3.2) and in the mineral extraction process (section 3.1.2), and how the portrait could be improved from a management standards perspective (section 3.3). Finally, new categories of OHS hazards and their relevance to each phase of a mining project are proposed (section 3.3.2 and section 4). The final session of this study summarizes the knowledge gaps and mentions our recommendations for future studies.

Other studies have addressed the risks in a scattered way; so, the study of hazards has not been explicitly focused on. At the same time, they are limited by their cross-sectional survey and the lack of traceability in the mining process. Although these studies are a valuable contribution to the literature, they cannot provide a clear and consistent policy and tell us what specific type of risk exists at each specific stage of the mine. This study suggests which potential elements of OHS hazards are important, ignored or missed, by identifying those that are expressed in a comprehensive study. This study can tell us about the changes in hazards over time and finally help us to find solutions.

On the other hand, there are new challenges that change over time and create new gaps. For example changes to the standard-based structure from a compliance-based approach to a risk-based approach [20], evolving with technical challenges [21], humanity challenges such as the absence of evidence regarding mental health hazards, burnout, job stress and lost-time were all related to poor health [22], and the challenges of quality management systems due to modern challenges and pressures affecting [23].

Therefore, this study aims to show which parts of the mining sector need more effort or change, from the point of view of management investment in the field of integrated health and safety.

The purpose of this systematic study is review of the path of identification of health and safety hazards in mines and tracking the anticipated and unanticipated effects of these changes, and to survey how these effects change over time. In addition, studying etiology and/or risk reviews, researcher opinions and policy reviews, are the other objectives, to create a coherent and separated classification (according to mining phases) in order to find accurate identification and identify gaps.

2. MATERIALS AND METHODS

OHS risk management and interpretation of dangerous aberrant events require thorough understanding of mine operating conditions and process control. The focus of this article is the first step of risk management, namely hazard identification, specifically detection, recognition, and classification. For this purpose, we relied on published studies retrieved using the search method known as PRISMA (preferred reporting items for systematic reviews and meta-analyses). The steps are summarized in the flow chart in Fig. 1.

2.1. Literature search

We began by listing OHS hazards found relevant to the management of mining projects, based on their mention in

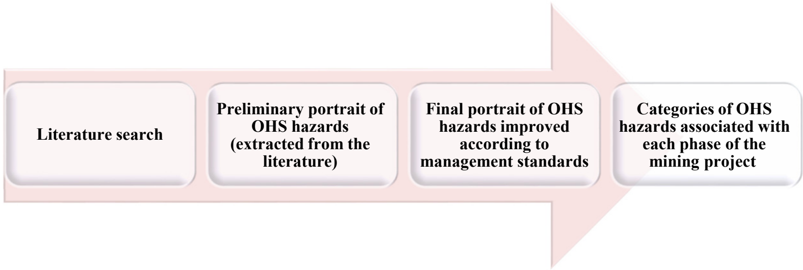

Fig. 1. Process of risk identification and classification

documents retrieved by PRISMA [24], which has built-in quality control of the review process and its replicability [25]. PRISMA generates a summary of article selection, inclusion and exclusion criteria, data analysis procedures, and research approach.

2.1.1. Research strategy. In this study, keywords were chosen by the authors, based on how relevant their various meanings are to OHS hazards in the mining sector to contain all aspects of OHS hazards, and synonym terms have been used for comprehensive research.

The publication time interval was not selected. In fact, we did not set a time limit for the articles, so those published from 1998 to the beginning of 2022 were admissible for our purposes. Applying the Boolean logic operators AND and OR, a set of keywords was combined [26].

Since this study is intended as the groundwork for a more comprehensive project, our immediate goal was to create an initial portrait of OHS and hazards of concern, particularly in the mining sector. Although the relevant databases complement each other, the choice must be based on formal needs [27]. Scopus provides higher citation counts with a pattern of coverage similar to Web of Science, which has lower variety in the source. Google Scholar retrieved documents with more references cited, but the percentage of scholarly journal articles was lower [28]. In addition, development officials state that citation eligibility is obtained through the use of state-of-the-art technology, with a 99% accurate match of reference citations and article citations [29].

For our review, the following set of keywords was used in the Scopus database (Table 1).

2.1.2. Extraction strategy. In this step, the fields of text searched were the title, the abstract, and the keywords, limiting the results to “English language” and “article”, “review” and “conference proceedings”, so the number of papers was 135, all focused on occupational health and safety (OHS), risk, hazard, disease, injury, accident, danger, and the mining sector. One record duplication was recorded, so 134 records were screened. Of these, 44 articles were excluded based on title and abstract screening. In the second step, article content was evaluated to determine if the research criteria were met, which led to the elimination of another 46 publications (Fig. 2). Finally, we recorded 44 papers as studies included in qualitative syntheses.

Table 1. Search protocol in the chosen database and number of publications retrieved

	Terms of the search	Articles
Scopus	(TITLE-ABS-KEY (occupational AND health AND safety) OR TITLE-ABS KEY (ohs) AND TITLE-ABS-KEY (risk) OR TITLE-ABS-KEY (hazard) OR TITLE-ABS-KEY (disease) OR TITLE-ABS-KEY (injury) OR TITLE-ABS-KEY (accident) OR TITLE-ABS-KEY (danger) AND TITLE-ABS-KEY (mining AND sector)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “re”)) AND (LIMIT-TO (LANGUAGE, “English”))	135

Based on the defined inclusion and exclusion criteria, all issues placing emphasis on risks related to worker health and safety were accepted, while subsidiary issues were rejected.

To provide a structured summary including as background, we focused on objectives.

- Subject matter on any type of health or safety hazard
- Occupational risk or hazard
- Mining sector

Exclusion criteria were defined based on:

- Language (language other than English)
- publication status: (book chapter, theses, and unpublished working papers or report
- Specific characteristics: articles not focused exclusively on mining (Promotion of software (simulations), Public health (prevention of diseases and promotion of health-related to general society or public communities), Environmental studies (human interaction with environmental issues), Rock mechanics, mining technology, geological safety, Sampling methods, Biomarkers or tracers, Socio-demographic factors, etc)

The selected papers were analyzed, classified, and documented using Microsoft Excel and Mendeley software was applied as a support tool. The following features were recorded:

- Year of publication
- Type of risk

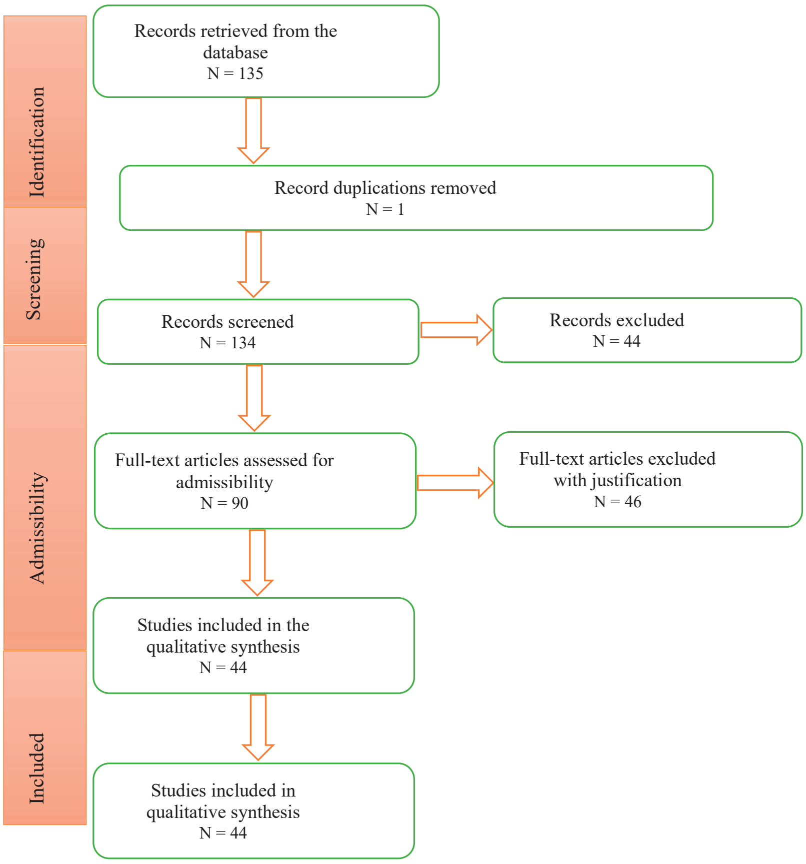

Fig. 2. Flowchart of systematic review based on PRISMA [24]

- Type of problem
- Applied method
- Type of study: article, conference proceeding, or review
- Type of mine: surface, open-pit, open-cast, underground, small-scale mining
- Mining product or type of material extracted: coal, metals (gold, copper, iron, etc.), or non-metals (salt, potash, asbestos, sand, etc.).

In this study, two experts participated. In the first step, the articles were selected and studied by the first author, then the second author reviewed and approved the articles. In the next step, the full-texts were revised by both authors. In cases of disagreement, the problems were solved by discussion and clarification.

In the next step, a number of databases of main organizations were included in this review, in order to reduce the limitation of Scopus and to achieve a coherent classification, in parallel with the PRISMA method for literature review. These included the conventions, the directives and the databases of related global and Canadian organizations' sites (Table 4). Then these results were added to achieve solid categories and integrated portrait.

2.2. Preliminary portrait of OHS hazards described in the literature

The articles were examined fully for elements of interest. According to the authors' proposal, hazards were grouped into eight subject matter categories: management, accident, legislation and regulation, physical agents, chemical agents, ergonomics, psychology, and OHS risk in general, the latter for the articles that discussed several hazards. The specific hazards in this group were later extracted and considered separately.

2.3. Final portrait of OHS hazards matched to management standards

To achieve a comprehensive vision and compensate for deficiencies that may have been overlooked, reference organizations such as the International Labour Organization (ILO), Canadian Centre for Occupational Health and Safety (CCOHS), the Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST), the International Organization for Standardization (ISO), the Occupational Safety and Health Administration of the United States Department of Labor (OSHA), and the Occupational Health and Safety Assessment Series (OHSAS) were used as additional resources to cluster and classify hazards using a common language representing a compromise between different management standards. The categories thus obtained were examined and are discussed below.

In the final step, hazard categories within project phases and overall risk management were discussed in view of the ideas expressed by the authors of the articles and the approaches taken by organizations (mainly Canadian and international regulations and standards) and a portrait of the hazards categories by project phases is presented.

3. RESULTS

According to ISO 45001, work-related injury and illnesses can follow in an OHS management system, and risk management is an iterative cyclic process with clearly defined steps [30]. Since the Plan-Do-Check-Act process is a cycle, incomplete identification or misunderstanding of risks leads to incorrect analysis or even ignoring risks altogether, resulting in a vicious cycle from which it may be difficult to escape.

3.1. Background

3.1.1. Definitions of keywords. The ILO defines an occupational accident as an unexpected and unplanned occurrence regardless of the consequences [31]. Risk is the probability of harm or an adverse health effect as a result of exposure to a hazard [32]. The ISO defines hazard as the potential source or situation that leads to harm, disease or injury [33].

The World Health Organization considers occupational health to encompass the physical, mental and social well-being, general health, and personal development of individual workers [34] An occupational disease is defined as any disorder or health problem that arises from exposure to risk factors associated with work activity. This definition can be completed with two characteristics: the causal relationship between exposure and disease, and the frequency of the average morbidity of the population [35].

Occupational injury is defined as any personal injury, disease, or death resulting from an occupational accident. It may differ from occupational disease because of its origin. Occupational disease arises from exposure to risk factors over a period of time, whereas injury can occur due to an unexpected event or occupational accident [36].

Risk management can be defined as a way of arriving at an acceptable level of safe situations by identifying and reducing potential hazards using risk assessment methods [37]. The CCOHS considers hazard identification to be a part of the process by which the potential of any particular situation, object or substance to cause harm or damage is assessed [38].

3.1.2. Phases of mining projects. The mining industry is recognized as a complex system in which human, organizational, and technological issues evolve at the same time [39]. The life cycle of a mining project can be divided into four main steps: exploration, development, operation, and closure (Fig. 3).

The exploration phase covers the search for raw material. This usually involves teams of specialists including mining engineers, metallurgists, geologists and environmental experts.

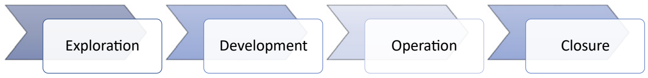

Fig. 3. The life cycle of a mining project (adapted from [40])

The development phase refers to start-up, in which civil, electrical, and mechanical engineers, geologists and other industrial specialists interact and excavation equipment and heavy machinery are used. The principal activities include constructing installations according to design and ensuring that standards are met.

The operation phase begins when the mine starts producing and the project achieves profitability. Mining operations include extraction, processing and transport of ore as well as waste disposal. Maintenance is an important activity during this phase.

The life of a mine comes to an end when the resource becomes exhausted or no longer economically viable to extract. The closure and rehabilitation stage includes shutting down operation, reassigning installations and equipment and restoring the natural surroundings [40].

The co-existence of humans and different types of machinery must be considered in all phases of the mining project, throughout which hazards and uncertainties change. Generally, OHS hazards are present from the beginning to the closure of the project [41].

3.2. Preliminary portrait of OHS hazards based on the literature

The main library databases were included in this review, namely Science Direct, Taylor & Francis, IOS Press, and Springer. In accordance with the types of risk factors, hazards were categorized under the headings management, accident, legislation and regulation, physical agents, chemical agents, ergonomics, psychology, and OHS (Fig. 4). Some documents addressed several types of hazards and therefore fell into more than one category.

Most of the studies were focused primarily on risk management. OHS risks and accidents were enumerated in the second stage. Chemical agents and ergonomics were the least frequently discussed subject matter (Fig. 4).

Type of mines included: underground mining, open-pit mining, smart scale mining (artisanal), multi (i.e., different types of mine) and, general (i.e., not specific mine), shown in Fig. 5.

The type of extracted materials is demonstrated in Fig. 6 and the countries from which the articles come, are shown in Fig. 7.

The number of research articles concerned with OHS has increased significantly in recent years. Figure 8 shows that from 2015 to 2022, numerous authors and practitioners paid specific attention to the OHS field. Considerably fewer studies were published during the years up to 2014. This shift in interest may be due in part to changes in the variety and complexity of OHS hazards over time [42]. The mining industry is a complex socio-technical system that evolves

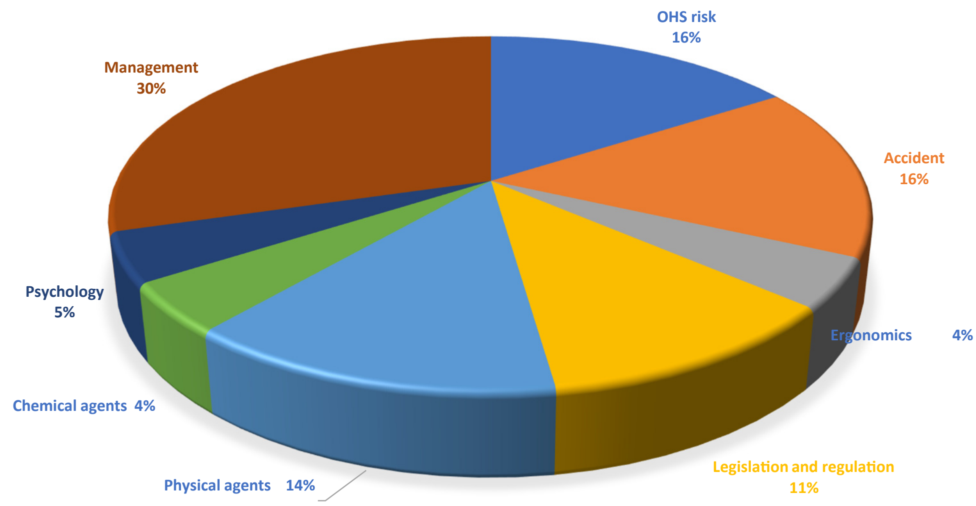

Fig. 4. Subject matter of articles relating to OHS in mining, retrieved from the review of the literature

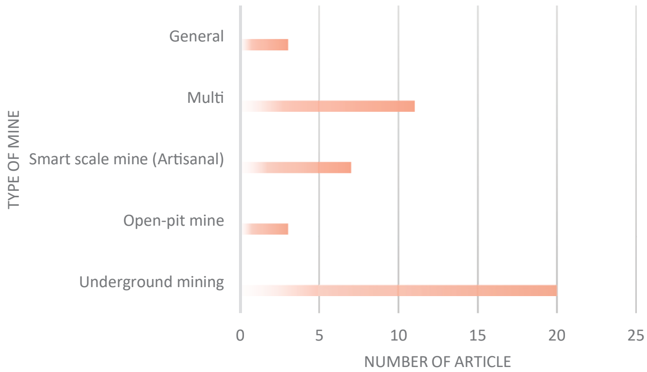

Fig. 5. Analyse based on the type of mine

Fig. 7. Analysis based on countries

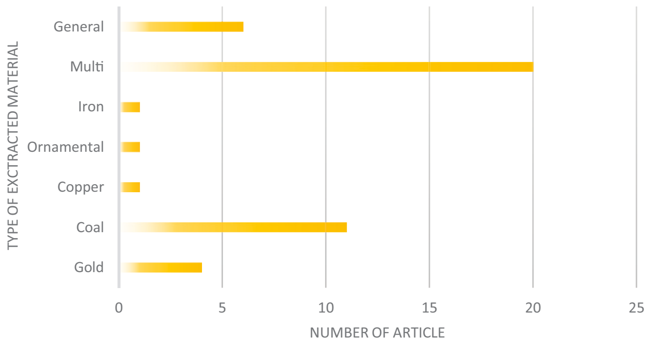

Fig. 6. Analyse based on the type of extracted material

[40], and therefore needs to be surveyed regularly to update the OHS situation (Fig. 8).

Although the search yielded positive results, they are too heterogeneous to allow any judgment of the relative efficiency of the methods used in the studies retrieved, which were mainly questionnaires, observation, and interviews. Articles on OHS risk were often based on multi-aspects surveys, meaning that various types of hazards were investigated. These are summarized in Table 2.

Most articles in the OHS risk category were focused on small-scale mining or artisanal mining. Miners in small-scale mines are generally exposed to dust, heat, humidity, noise, and psychological stress factors. The type of occupational hazards and sources of accidents are also summarized in Table 2.

In addition to the above, risk management [43] and training/education [44] play a significant role in occupational health and safety in small-scale mining. Lu and Lu mention the conditions experienced by women in the small-scale mining sector in the Philippines. These can be grouped as follows:

- Chemical hazards (exposure to dust, e.g., manganese, mercury, cyanide, silica)
- Ergonomics (musculoskeletal disorders, physical trauma, miscarriages due to prolonged standing, stress, or injury)
- Psychological (e.g., sexual harassment and violence, anxiety-related stress)
- Social and political issues
- Policy issues [45]

The initial survey detected a total of 135 citations in the Scopus database. Finally, 90 full texts were selected and

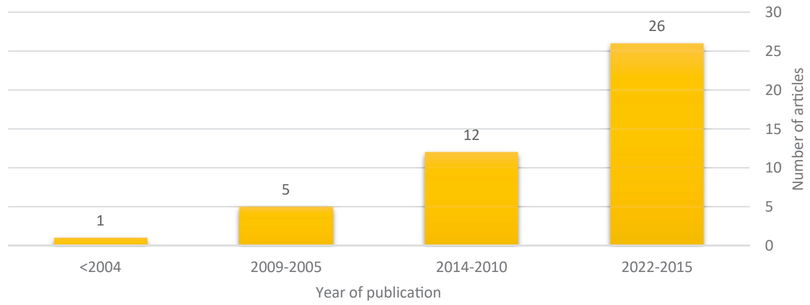

Fig. 8. Distribution of articles relating to OHS in mining based on year of publication

Table 2. Hazards mentioned in articles on OHS risks

Hazard category	Specific agent	Source of hazard
Chemical agent	Cyanide	Extraction of gold and silver from ore
	Mercury	Recovery of gold
	Lead and silica	Substances in ores
	Dust	From blasting (dynamite, soil)
	Methane	Underground
	Smoke	Diesel motors
Physical agent	Noise	Blasting, hammering, drilling
	Lighting	Artificial
	Heat stress	Depth underground
Biological	Soil-borne and water-borne infections	Environment
	Fungal infections	Dampness
	Mosquito bites	Outdoor atmosphere, bushes
Ergonomic	Prolonged crouching and bending	Tasks, work methods
	Prolonged handling of tools	Tasks, work methods
	Carrying heavy loads	Tasks, work methods
	Repetitive muscular trauma	Tasks, work methods
	Awkward working postures	Work setting, methods
Accident	Fire outbreaks	Gasoline and diesel
	Falls from heights	Work setting
	Falling rocks	Work setting
	Flooding	Waterways, spring melt, rain
	Electrocution	Power lines, water infiltration
	Abrasives from the rotating parts	Machinery
	Drawing-in or trapping hazards	
	Cutting and shearing	Machinery
Psychological	Post-traumatic stress	Accidents, military service
	Violence	Social or political unrest

evaluated, some of which were then excluded because they did not meet the chosen criteria. At least 44 studies on OHS risk in mines were identified (Fig. 2). Their content is summarized in Table 3.

3.3. Finalized portrait of OHS hazards matched with management standards

3.3.1. Integration and classification of hazards and proposed new categories. We began by reviewing hazard categorization according to different managerial standards. The proposed categories are presented in Table 4.

Managerial standards as well as general issues of concern in the mining industry are the subject of 10 documents retrieved by our searches. Some of these standards are applied on a global scale, while others are peculiar to mines in Canada. Using these documents and their lists of references, the portrait of OHS hazards in mining (Table 4) was enriched.

Managerial standards and other categories thus helped us obtain a more detailed portrait by clarifying aspects of mining hazards that are expressed elsewhere in vague terms.

The various types of hazards in the mining sector can be presented in an Ishikawa diagram, which shows specific hazards independently of the mining life cycle and integrates their interrelationships, the results of the literature review, standards, and phases of a mining project. These will be discussed throughout the following sections.

3.3.2. Categories of OHS hazards and relationship to the phases of a mining project. Based on the literature review, regulations, standards, and reference organizations, we

Table 3. Preliminary portrait of OHS hazards mentioned in published studies

Authors	Type of hazard	Type of problem	Applied method of research	Periodical	Type of study
Leung AMR et al. [59]	OHS risk	Occupational health and safety hazards	Observational and qualitative study	Acta Medica Philippina	Research
Lu J [45]		Female workers	Survey secondary data	Journal of International Women's Studies	Review
Küçük F et al. [106]		Accident cause	Survey	Turkish Thoracic Journal	Research
Sanmiquel L et al. [107]		Accident	Feyer and Williamson's analysis	Journal of Safety Research	Research
M.A. Hermanus [108]		OHS hazards	System thinking	The Journal of The Southern African Institute of Mining and Metallurgy	Review
Donoghue A [109]		OHS hazards	Classification	Occupational Medicine	Review
Elenge M et al. [50]		Identification of hazards	Observation and analysis of tasks	International Journal of Occupational Medicine and Environmental Health	Research
Nowrouzi-Kia B et al. [22, 110]	Accident	Time lost to injuries	Literature review	Work/Occupational Medicine	Review
Spada M et al. [67]		Accident prediction	Bayesian analysis	Accident Analysis & Prevention	Research
Domínguez CR et al. [111]		Risk assessment	Decision matrix risk assessment (DMRA)	Journal of Sustainable Mining	Research
Oraee S et al. [68]		Risk assessment	Fuzzy FMEA	SME Annual Meeting and Exhibit and CMA 113rd National Western Mining	Conference proceeding
Janjuhah HT et al. [112]		Risk assessment	Decision-matrix risk assessment (DMRA) approach	Sustainability (Switzerland)	Research
Pollard J et al. [66]		Maintenance-related injuries	MSHA reports	Journal of Quality in Maintenance Engineering	Research
Mensah SK et al. [113]	Management	OHS risk management	Interview, data collection	Environmental Challenges	Research
Rudakov M et al. [23]		Risk-based thinking	Fine and Kinny's/Checklist SWOP (strengths, weaknesses, opportunities, threats)	Sustainability (Switzerland)	Research
Nelson BP et al. [44]		Knowledge on OHS programs and interventions	Literature review	Annals of Global Health	Review
Sanmiquel L et al. [114]		Occupational safety management	Questionnaire	Work	Research
Lu Y, Taksa L et al. [85]		Safety behaviors	Questionnaire	safety science	Research
Badri A et al. [98]		Management of mining projects	Observation	Journal of Loss Prevention in the Process Industries	Review
Devine S et al. [115]		Perceptions of occupational health and safety issues	Observation and question	Health Promotion Journal of Australia	Research
R.C.W. Webber-Youngman et al. [116]		Safety training	Virtual reality (VR)	Journal of the Southern African Institute of Mining and Metallurgy	Research
Haas EJ et al. [117]		Safety climate	Survey development	Mining, Metallurgy, and Exploration	Research
Bahn S [86]		Safety culture	Interview and Workrelated injury statistics collected data	Employee Relations	Research
Tilbury T et al. [118]		Musculoskeletal disorders training and culture	Survey of practice guidance	Work	Research

(continued)

Table 3. Continued

Authors	Type of hazard	Type of problem	Applied method of research	Periodical	Type of study
Hermanus M, et al. [119]		Statutory worker health and safety representatives and structures	Interview	Journal of the Southern African Institute of Mining and Metallurgy	Research
Bascompta M et al. [120]		safety culture maturity	Questionnaire-based on Fleming and Parker maturity model	Work	Research
Arntz-Gray J et al. [80]	Legislation and regulation	Regulatory non-compliance	Survey and questionnaires	Safety Science	Research
Altınöz H et al. [81]		Non-enforcement of regulations	Survey	Turkish Thoracic Journal	Research
Lu JL et al. [43]		Legislative of mining-related diseases and injuries	Literature review	Acta Medica Philippina	Review
Kowal B et al [99].		Formal and legal considerations	The survey included qualitative methods involving IDI	Inzynieria Mineralna	Research
Bealko S et al. [4]		Policy	Survey	Journal of Safety Research	Research
Nunfam VF et al. [51]	Physical agent	Heat stress	Questionnaires and temperature data loggers	International Journal of Biometeorology	Research
Mocek P. [47]		Noise	Hearing screening	IOP Conference Series: Earth and Environmental Science	Conference proceedings
Roberts B et al. [121]		Noise	Survey of cross-sectional measurements (MHSA)	International Journal of Audiology	Research
Peiffer J et al. [122]		Heat stress	Measuring core temperature, hydration status, perceived exertion, mood, and fatigue	Annals of Occupational Hygiene	Research
Dekker J. et al. [123]		Noise	407 questions on noise compliance audit tool	The Journal of The Southern African Institute of Mining and Metallurgy	Conference proceedings
Spencer E [124]		Noise	Survey of noise exposure	Mining Engineering	Research
Tello L [55]	Chemical agent	Coal dust, pneumoconiosis	Survey	Procedia Engineering	Conference proceedings
Lkhasuren O et al. [56]		Lung disease	Survey	International Journal of Occupational and Environmental Health	Research
Molek-Winiarska D et al. [125]	Psychology	work-related stress	Job content questionnaire, general health questionnaire (GHQ-28) Experimental manipulation (40h of MBSR training)	International Journal of Occupational Safety and Ergonomics	Research
Stewart JM et al. [126]		Resistance to changing behavior	Survey, interview and review of MOSH documentation	Journal of the Southern African Institute of Mining and Metallurgy/ Journal of the Southern African Institute of Mining and Metallurgy	Research
Pelders J et al. [63]	Ergonomic	Shift cycle	Interview, health and safety executive (HSE), fatigue and risk index calculator	Journal of the Southern African Institute of Mining and Metallurgy	Research
Pelders J et al. [62]		Fatigue	Questionnaire	Safety and Health at Work	Research

Table 4. Summary of managerial standards relevant to characterizing hazard management in mining

Standard	Issue	Scope
Canadian Center of Occupational Health and Safety (CCOHS) [127]	Occupational health and safety	OHS general requirements
CNESST (Commission des normes, de l'équité, de la santé et de la sécurité du travail, Québec, Canada) [128]	Eliminate health and safety hazards at the source	OHS legislation and standards in mining
ISO - IEC 31010:2009 [129]	Risk management, risk assessment techniques	Systemic techniques of risk assessment
ISO 13849-1:2012 [130, 131]	Safety of machinery, safety-related parts of control systems, Part 1: General principles for design	Integration of safety-related parts of control systems (SRP/CS), including the design of software
ISO 12100:2010 [131]	Safety of machinery, general principles for design, risk assessment and risk reduction	Safety in the design of machinery
OHSAS 18001 [132]	Occupational health and safety management systems	Requirements for an occupational health and safety management system (OHSMS)
ILO -C176 - Safety and Health in Mines Convention [133]	Safety and health in mines	Hazards and risks faced in the mining industry, recognizing the value of aiming to prevent all fatalities, injuries and ill-health
C148 - Working Environment (Air Pollution, Noise and Vibration) Convention [134]	Occupational health and safety in the working environment	Working environment: atmospheric pollution, noise, and vibration
OSHA-Directive 89/391/EEC - OSH [135]	Responsibility of workers and employers for safety and health in the workplace	Human psychology and behavior

defined a category and then grouped the OHS hazards in terms of the source into a re-defined zone, to facilitate their study and identification of their source.

In this section, we propose a more complete categorization, one that considers changes in mining hazards over time, with reference to the Ishikawa diagram. The purpose of this section is to integrate safety and health into OHS management with consideration of each phase of a mining project.

Physical hazards. These hazards arise from materials, energies or activities that have an impact on physical safety, for example, dust, indoor air quality, temperature, noise, vibration, radiation, and so on [46]. Physical hazards can have an operational or inherently environmental origin. Operational sources such as machines, tools, explosions, vehicles and so on [47, 48], vibration arising from vehicles and tools [49], as may lighting [50]. Inherent environmental sources include the temperature in underground mines, sunlight in open-pit mines [51], work at height or underground in mineshafts, radioactivity in materials or UV sunlight in open-pit mines [52]. These kinds of hazard are present during the development, operational, and closure phases of a mine.

Chemical hazards. Chemical material is defined as any element, compound, or mixture of elements and/or compounds that can have adverse effects on health [53]. This hazard can be derived from materials or elements found or used inside the mine or from the equipment used, notably diesel-operated vehicles or machinery [54]. It is dependent on the type of mine (coal dust, arsenic, nickel, crystalline silica, etc.) [55–57] and is to be expected during the development, operation, and closure stages.

Biological hazards. Bacteria, viruses, insects, plants, birds, animals, and humans are ever-present sources of hazards with a wide range of effects including skin irritation, infection, cancer, and so on [58]. These hazards depend on the mining environment and the regional flora and fauna and change seasonally or with temperature changes. Examples are soil-borne or waterborne bacterial infections, fungal infections, and mosquito bites [59]. Biological hazards are more present in the operation and closure phases but can arise during the development stage.

Ergonomic hazards. Ergonomics has been defined in the past as matching the job to the worker and the product to the user, and includes workplace design and characterization of bodily postures [60]. Nowadays, ergonomics is divided into three fields: physical ergonomics, organizational ergonomics, and cognitive ergonomics. The focus of physical ergonomics is the human body, whereas the aim of organizational ergonomics is to optimize the work environment to increase the productivity of teamwork and communications to boost output and enhance product quality, and cognitive ergonomics is the study and evaluation of mental function, memorization, interrelationships, perception, response, and rational reasoning [61]. Therefore, as long as humans are present throughout the life of a mine, ergonomic hazards will remain, whether the fitting of tools or equipment, fatigue [62] or human error in shift work is at issue [63]. Normally, ergonomic hazards exist throughout the four stages of the mining project life cycle.

Accident hazards. These are workplace conditions or work processes that lead to aberrant events that cause injury or death [64]. Accidents can have multiple causes, which may occur sequentially subject to a hierarchy of several parameters, or be the outcome of a combination of factors and latent conditions (epidemiological), or tight couplings and complex interactions (systemic) [65] Common sources of mining accidents include roadways used for haulage, tractors, heavy equipment, powered supports, chain conveyors, shearer loaders, machinery tools, materials and their handling devices, welders, electrical sources, technical sources, as well as maintenance process [66]. Most risk assessment methods are applicable to these types of hazards, and complex software and algorithms have been devised recently to predict [67], assess, and evaluate [68, 69] accidents in mines. The accident hazard is observed more in the operation and development phases and to a lesser extent in the closure phase.

Psychosocial hazards. Any disturbance of the psychological well-being of workers, who rely on safe organization and management of the work environment and on economic and social stability, is a hazard in mining [70]. The origins of psychosocial hazards can be found in job content [71], workload, work scheduling, process control, equipment, the environment, organizational culture and function, worker interactions and roles in the organization, career development, personal relationships, and the interface between work and home [72]. Since exploration, development, operation and closure all necessarily involve people, psychosocial hazards will accompany the mining project at all stages.

Policy hazard. The general intentions, prospective plans or action programs of a system implemented to improve OHS performance carry a policy hazard, which is any deviation from the intended approach [73]. Policy reflects the goal of the program, and determines the allocation of resources, participation, responsibilities, and so on [74]. Deviations from policy include holes in the responsibilities of supervisors, managers, or workers, lack of clarity in the plan, inadequate training or meetings, and so on [75]. These can originate from national policies, regional culture, individual behavior, organizational atmosphere, safety culture [4], and so on. OHS policy hazards arise more frequently in the operation and closure phases than in the development phase of a typical mining project.

Legislation and regulation hazard. Fundamental rights, and the responsibilities of the employer, the supervisor, and the worker, as defined by an act, statute or similar legislation, or in-house regulations, all carry a risk [76]. Regulations that define the application and enforcement of legislation are key features of an organization. Laws and policies are an inseparable part of risk management in a complex system, since they define the scope of the rules relevant to each activity of an organization [77]. OHS law includes four main categories of standards: prospective, general duties, performance-based, systemic process-based [78]. Standards (or norms) and legislation are potential hazards since they may be inadequate or poorly fitted to the work setting. Vague or indefinite wording, incompleteness, inapplicability to specific situations, and non-exclusiveness can all lead to non-compliance [79, 80]. In addition, national and international rules and regulations that are not enforced can undermine executive power in projects [81]. Other deviations from regulations in mines can result from: 1. Being uniformly prescriptive, 2. Pre-existing problems between regulatory agencies (state and regional administrations), 3. Division of mines in terms of ownership, objectives, and pricing [82]. This hazard can be seen in the development and operation phases and even in closure.

Management hazard. OHS-related decision-making processes are based on criteria and standards designed to provide methodical assessment and improvement and thereby prevent workplace incidents and accidents through the management of hazards and risks [83]. Górny defines OHS management systems according to the ISO 45001 PDCA cycle: Plan (intention) comprising establishment of policy and safety goals, assessment of safety, evaluation of practical options, elimination of hazards, and improvement measures to achieve objectives; DO (act and support) or implement; CHECK (verify) by monitoring and reporting, and ACT (correct, improve) to improve OHS performance and management [84]. Management of hazards in mining can change over time depending on the organizational culture and climate, social conditions, industrial relations, policy, technical wherewithal and practice, risk-based thinking, and so on [23, 85–87]. Management hazards can be found during the development, operations, and closure phases.

Design hazard. Design in this context refers to the decisions made regarding the materials and methods of manufacture or construction used to improve the safety of production processes in the workplace [88]. The aim of prevention through design (PtD) is to protect the workers that execute the designs or work with the products of the design [89]. This type of hazard may arise in association with equipment, tools, alarms, structures, facilities, machines, substances, and organization of work or work processes [89]. Miners are more likely to be affected in the two latter stages of the mining life cycle than during the development phase.

Geographical hazard. This category of hazard (flooding, landslides, groundfall, etc.) translates to loss of resources, mortality, and morbidity [90]. Although it is not considered among OHS hazards, it is a source of workplace accidents and anticipating it should be investigated as a management measure, since mine profitability obviously can be affected by tendencies towards geological accidents or extreme weather events. Such tendencies can be investigated for different types of mine (gold, coal, uranium, etc.), whether open-pit or underground, given the soil type and structure, regional climate record, and so on. The latter three stages of the mining life are concerned with this hazard.

Uncertainty. Uncertainty can be defined as a lack of precise knowledge needed to determine reality whether qualitative or quantitative [91]. Uncertainty is reduced throughout the evaluation period (the pre-planning and planning phases) [92]. The sources of uncertainty in mines are very diverse: materials, equipment, tool, machinery, facility design, decision-making, software and hardware, geology, information, laws, and so on, whose effects can be included as a chemical agent, physical agent, ergonomics issue, etc., but they are ignored or over time will be identified as a new category of hazards. In the field of OHS management, despite the variety of its sources, uncertainty and its impact on hazard identification, measurement and management methods have not received very much attention. Uncertainty must be managed and controlled as much as possible in all four phases of a mining project.

4. DISCUSSION

The approach to OHS management should be strategic and designed to identify as many potential hazards as possible, this being the main factor of success for risk reduction [93]. A structural framework is needed to overcome the obstacles [94]. The aim of the present study is to guide the development of reliable tools for identifying hazards that concern the mining industry in particular. We have found the scientific and trade literature to be scant of studies that examine each phase of a typical mining project or consider the multifaceted and complex relationships between the variables underlying the interpretive paradigms of hazard and risk management in this sector.

Work-related hazards historically have been classified in four categories: chemical, psychosocial, physical, and biological [95]. The mining industry must deal with other categories of occupational hazard in addition to these (Fig. 9).

Robello et al. recognize seven groups of risk factors commonly faced by miners: thermal stress, musculoskeletal stress, chemical hazards, whole-body vibration, UV exposure, coal dust, and noise [96]. Rout et al. identified and analyzed 116 hazards and classified them in 11 major groups: 1. mechanical, 2. electrical, 3. heat, 4. vibration, 5. noise, 6. fire and explosion, 7. dust, chemicals, and toxic substances, 8. biological, 9. ergonomic, 10. psychosocial, 11. radiation [97]. Badri et al., in a study of the hazards of risk management, refer to five classes of OHS risk: electrical, physical or chemical, mechanical, human, and methodological [98]. In a similar manner, A.M. Donoghue in 2004 classified occupational health hazards in mining as physical, chemical, biological, psychosocial, or ergonomic [71]. Meanwhile, Kowal et al. noted that harmful factors in mines classified as physical, biological, chemical or psychophysical can cause occupational diseases such as poisoning, infections, and allergies [99].

In a systematic review and summary of the main standards of risk evaluation in the mining industry, four categories were proposed: machine, human factors, environment, and general [100]. Despite the broad scope of these categories, they did not overlap with commonly recognized categories, nor are they specific to any mining project phases. In addition, hazard categories did not fit into this scheme unambiguously. In this article, hazards were specified in the phases of the mining project.

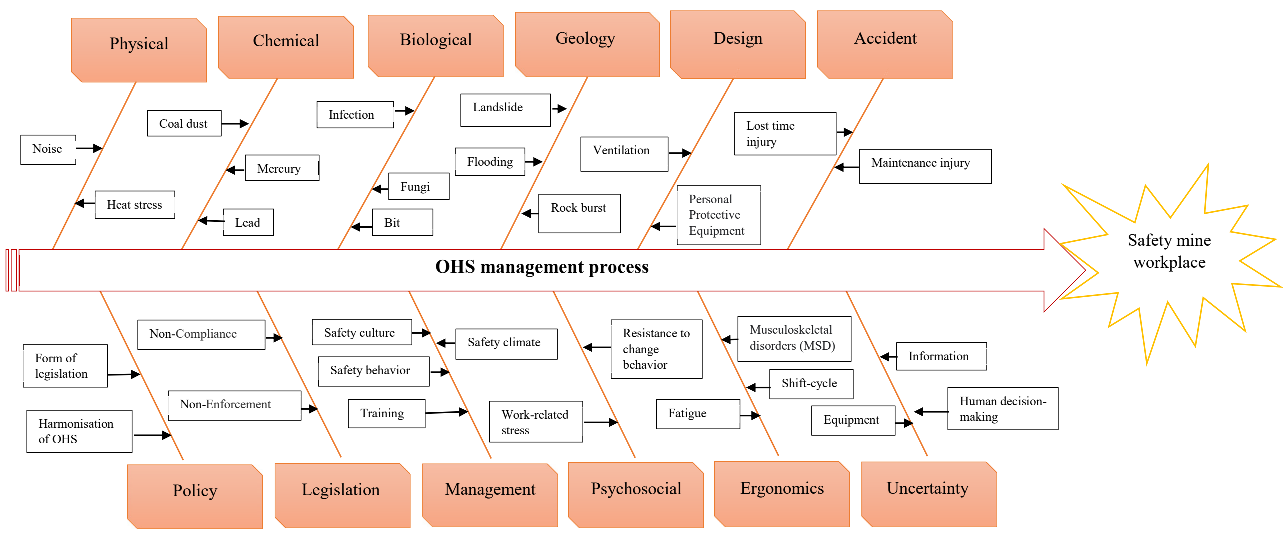

Fig. 9. OHS hazards in the mining industry, their interrelationships within revised categories

The findings of the present review can be used as justification and support for the categorization of hazards. To obtain a more comprehensive model, Canadian and international standards of management were used. In the final step, OHS hazards were classified as described in section 3.3.2, giving the portrait shown in Fig. 10.

In the above portrait, the categories of hazard identified in the literature are shown in relation to each phase of a mining project. Figure 11 shows the relationships between hazards based on their sources. Some are associated with several sources, meaning that these hazards have multiple origins (the origins overlap). In addition, this figure implies that all hazards are embedded in a background of uncertainty, meaning that uncertainty exists in every source or every hazard. With this goal, we can define the source of the hazard in Table 5.

A mine can and usually does change and evolve during its life cycle. In recent years, mining equipment has developed from manual to electrohydraulic and then to intelligent collaborative control [101]. The mining sector is a dynamic system and its management culture can change in terms of preferred technical methods, mode of operation, design, engineering, and so on. The nature of the hazards of concern can change accordingly [102].

To perform professional risk management, a systematic approach and a categorized conceptual structure are necessary, to describe risks clearly and make them easier to manage [103]. A portrait such as we have presented here can provide perspective to guide the implementation of a prevention plan but is preliminary and needs improvement through discussion with workers, specialists in other fields, and using interpretive structural modeling to find other gaps in the model. Uncertainty can be found in each type of hazard and each phase of the mining life cycle, and it can intensify all potential causes of hazards.

4.1. Limitations and knowledge gaps

This survey and categorization of hazards in the mining system provides a useful tool for identifying hazards for the

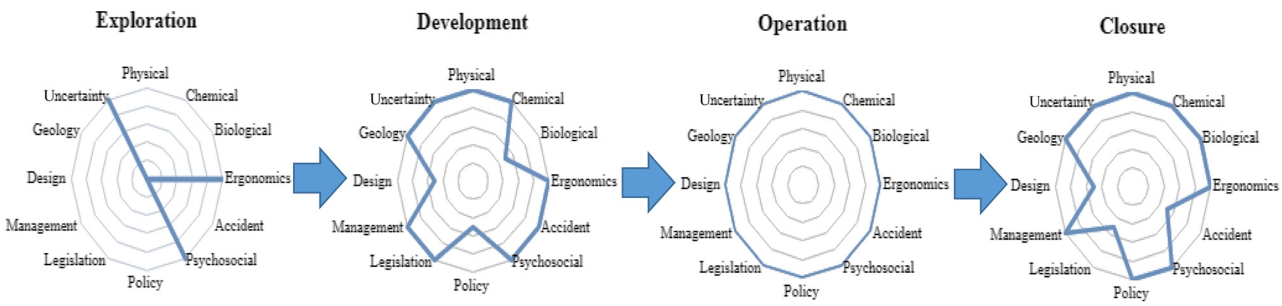

Fig. 10. Preliminary portrait of hazards in the life cycle of a mining project

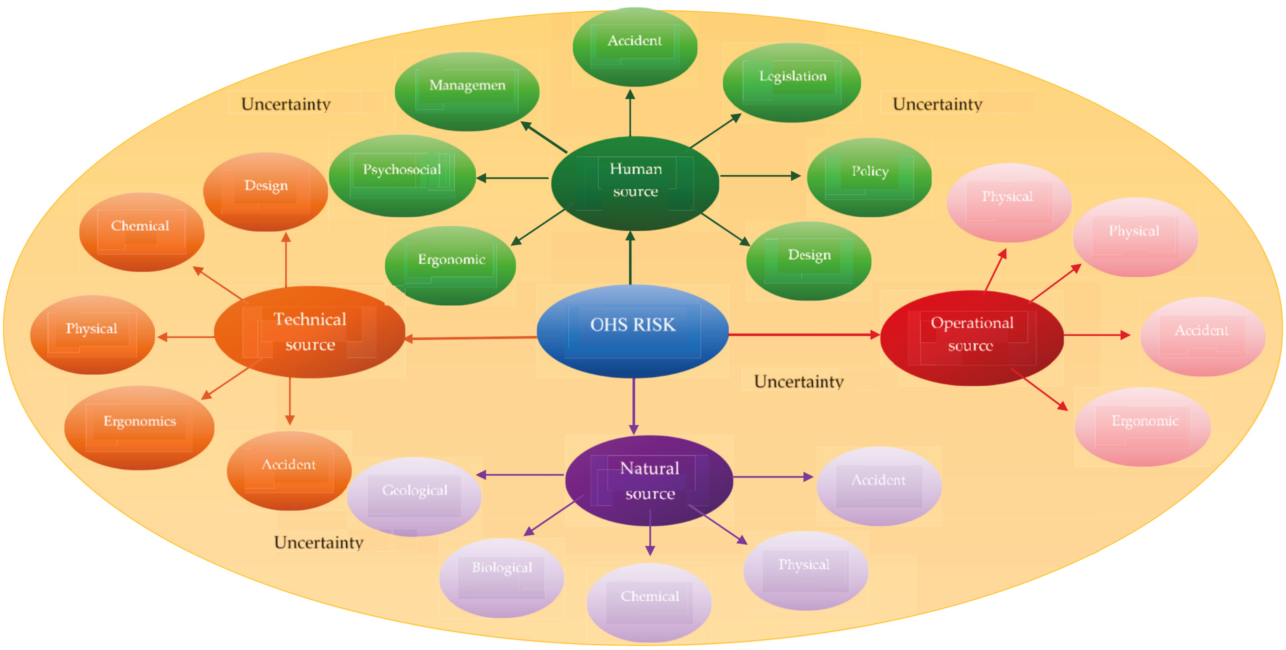

Fig. 11. Sources of hazards and relationships between hazards

Table 5. Zoning of hazards based on source

Source	Definition
Operational	Arising from the type of activity (e.g., cutting, abrasion, drilling, explosion, blasting, transfer operations, crushing, grinding, construction, etc.)
Natural	Attributable to inherent features of the mine setting: Geographic (risk of landslide, earthquake, rockfall, slip fall, flooding, collapse, altitude, etc.) Mined materials (e.g., uranium or other radioactive substance, coal releasing gas or spontaneously igniting, toxic vapors, etc.) Biological factors (fungi, insects, animal damage, tree roots, etc.)
Technical	Arising from the likelihood of device failure over time and hence slowing or stoppage of production [136] Mechanical, electrical, engineering hazards (ventilation design, PPE design, etc.), software, equipment and facility hazards, transportation, maintenance
Human	Responsibility for design defects, decision-making, machine operating, and maintenance [137] Psychological (human error, shift work, mental load, stress), Ergonomic (poorly fitting equipment, etc.) Management, legislation, etc

purposes of OHS management. Heterogeneity was one barrier to the analytical review, and therefore there was no single method to be found most suitable for synthesis of the studies. Another limitation is the range of the review, since all documents examined were scientific articles found in the Scopus database. No other types of literature (e.g., internal government reports, patents, etc.) were considered.

A major potential hazard throughout the life of a mining project is uncertainty, an integral part of any complex system and likely to arise from any component such as information (documentation, risk assessment), engineering and computational activities, maintenance, equipment, and so on. Few of the articles retrieved were investigations focused on uncertainties. Reliability and uncertainty seem to be a research gap needing more study.

Managers and other investigators of risks and uncertainties have, up to quite recently, lacked a conceptual framework to establish the limits of existing knowledge [104]. It is necessary to consider hazards and risks within a conceptual diagram. Quantitative analysis and modeling of the relationship between hazards and their sources and finding the interactions between them can be useful in the quest to achieve a complete portrait to support effective management in the mining industry.

Hazards associated with mining machinery in conjunction with human factors appears to be another research gap [105]. The mining sector is dynamic and undergoes paradigm shifts as new processes are developed to replace older, less efficient or more dangerous processes. Such changes can occur during the life of a project. Whenever technology advances, the hazard portrait needs to be updated as the effects of the changes become apparent (new ergonomics, physical hazards, mental hazards, etc.). Finally, studies of biological hazards, legislation, and policy in the field of OHS risk management also remain limited.

Although few articles mentioned the phase of the mining project, most studies appear to be concerned primarily with operations during the production phase while the development phase needs more attention, and studies of the closure phase are very limited.

5. CONCLUSION

The mining industry, as a high-risk sector, is expected to review its hazards and update its knowledge base in the area of risk identification to inform OHS policy and adapt it to new reality and new criteria of risk assessment or approaches to risk management planning, and at the same time bridge knowledge gaps by benefitting from research conducted in recent years.

This article provides insight into how a hazard and risk conceptual framework could be built to support effective OHS management in the mining sector. It also shows which topics are the most studied as well as some of the research and knowledge gaps that need to be addressed by future research.

This portrait of hazards and risks in mining, derived from studying the scientific literature, proposes a conceptual structure to guide the first steps of new initiatives in OHS management in this sector. The literature review was based on applying the PRISMA model to the identification of hazards in mining, which were therefore classified initially based on a reference organization. In the final step, the categories were completed by integrating Canadian and international standards of management to form a portrait of OHS spanning the life cycle of a mining project. We thus presented mining hazards as an evolving thematic structure and identified some research gaps.

In future works, the researchers should provide more comprehensive research in integrated health and safety management. The present article or similar papers can be a useful guideline to survey the ignored mining hazards in future studies. Due to the complexity of mining risks and the complex relationships between them over time, it is also recommended that researchers focus on methods such as simulation or new risk assessment method to predict and prevent hazards.

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