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Identification of safety hazards in Indian underground coal mines

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ABSTRACT

To improve safety the application of effective risk management has become a requirement in the mining industry. The effectiveness of mining risk management essentially depends on the risk assessment process, as the output of the risk assessment process helps the mine management to decide upon the control measures to be employed to mitigate the risks identified in the mine. The application of risk assessment in mines has become important not only for ensuring a safe working environment but, also, it is now a legal requirement. The capability of a risk assessment process depends on the hazard identification phase, as unidentified hazards may lead to unknown and unmanageable risks. Therefore, it is essential to identify all the potential hazards to manage the risks in mines. The object of this study is to identify the safety hazards present in Indian underground coal mines and to build a preliminary database of the identified hazards. Accident data collected from the Directorate General of Mines Safety in India and a public sector coal mining company was studied to identify safety hazards that may probably lead to accidents. The database could help the mine management to improve decision making after analysing and evaluating the safety risks of identified hazards.

1. Introduction

Mining is renowned for being one of the most hazardous sectors in the world due to its complex work environment. Workers in underground coal mines are prone to several risk conditions during their work which may cause loss of life or serious injury which has a direct and indirect cost for employees and employers. Accidents in underground mines can often have serious catastrophic consequences. Over the years, the Directorate General of Mines Safety (DGMS), mining companies, research institutes and academics have made constant efforts to prevent accidents in Indian mines by proposing solutions, such as additional regulations, improved training, advanced technology and reliable equipment. The trend of fatal accidents occurring in Indian underground coal mines is higher than in the USA's and Western Australia's underground coal mines, as shown in Fig. 1 (DGMS, 2017; Department of Mines, Industry Regulation and Safety, 2018; MSHA, 2017). The different fatality rates from 2002 to 2017 are represented in Fig. 2. Fig. 2 reveals that though there is a decreasing trend in the fatal accident frequency rate per lakh man shifts; the death rate per 1000 persons employed and the death rate per million tonnes in Indian coal mines, the current rates are still unsatisfactory. The fact is that underground coal mining is associated with hazards and therefore complete elimination of risks is unavoidable. To regulate the hazards in mines, risk management has been proposed, implemented and mandated by Australian, New Zealand, Canadian, British, American and South African mining industries over the last few decades. The DGMS has made it mandatory to conduct risk assessment and management in all Indian coal mines after the revision of Coal Mines Regulations in November 2017 (CMR, 2017).

Risk management is a systematic approach taken to eliminate or mitigate risk, by identifying hazards and implementing controls at the workplace (DGMS, 2002). In simple terms, risk management is a thorough analysis of what, could cause harm in mining activities, so that one can review the current precautions taken and increase them if required, to prevent harm. Context establishment, risk assessment and risk treatment are the three major processes in the risk management system (ISO, 2018). The output of the risk assessment will be the input for the decision-making process of the industry, so an effective risk assessment is essential for the successful control or elimination of risks in the workplace (Valis & Koucky, 2009). Risk assessment is defined as the overall process of hazard identification, risk analysis, and risk evaluation (ISO, 2009). To identify and assess risk, it is essential to know what hazards are present and what potential harm is associated with the hazard. As hazards are the primary identifiable cause of risks in workplaces, its control will offer an excellent possibility to reduce injuries and accidents. The hazard identification phase is the most crucial step of the risk assessment process, as the leading causes are identified in this step and unless the cause is identified, it cannot be

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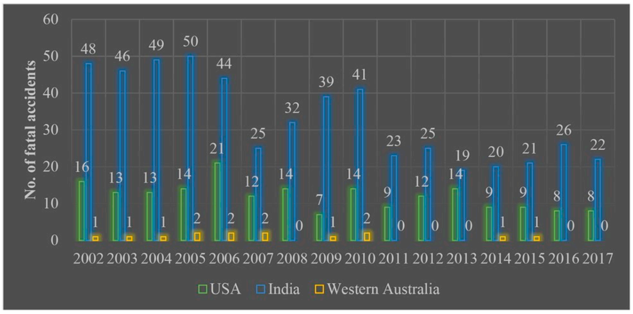

Fig. 1. Comparison of the number of fatal accidents in Indian underground coal mines with the USA and Western Australia.

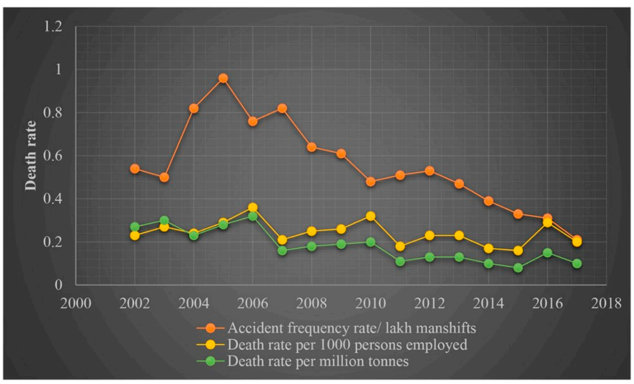

Fig. 2. The trend of different fatality rates in Indian coal mines.

actively managed (Greene & Trieschmann, 1981).

There are two types of approach for hazard identification: (i) an informal approach based on previous data and history (ii) a formal approach based on hazard identification techniques (Henley & Kumamoto, 1996). Ericson (2015) stated that there are over 100 hazard identification techniques in existence and many techniques are not widely practiced. The common hazard identification techniques are presented in Table 1 (Ericson, 2015; Glossop, Loannides, & Gould, 2000; Lees, 2012; McCoy et al., 1999; Mullai, 2006). As most of the hazard identification techniques are generic, they can be used to identify hazards in any workplace. However, hazards may vary from one workplace to another, and that is the reason why skilled expert experience is essential in order to identify all the hazards in a given workplace accurately. The hazard identification process shall consider the entire life cycle of a job and the potential impacts on workers, machines and the environment. To generate a comprehensive list of hazards, the systematic process starts with the objectives of context establishment. The general steps of hazard identification are as follows (AS/NZS, 2004):

- Select the job to be evaluated,
- Divide the job into necessary steps,
- Develop a list of expected hazards associated with each step of the job, and
- Develop a list of risks associated with the identified hazards.

Workplace hazards can be classified as health hazards, safety hazards, biological hazards, chemical hazards, ergonomic hazards, environmental hazards, and economic hazards (SafetyLine, 2014; Tchankova, 2002). Safety hazards are the main hazards in underground coal mines, given that they have an immediate impact and affect all workers equally. Safety hazards in mines may arise from different sources like worker's unsafe actions, unsafe practices, unfit equipment or unsafe working conditions and can take many forms. Therefore, it is essential to identify the sources of the hazards and the scenarios in which they may originate. The safety hazards associated with workers' actions, machines, tools, job procedures and the overall work environment were considered in this study. This paper aims to identify safety hazards present in Indian underground coal mines and to build a preliminary database of identified hazards.

The coal deposits in India are predominantly concentrated in Gondwana sediments occurring mainly in the eastern and central parts of Peninsular India. As of 1.4.2017, the geological exploration carried out by various agencies like the Geological Survey of India, Central Mine Planning and Design Institute, India, proved that there are 315.149 billion tonnes of geological coal reserves at up to 1200 m depth in India. Coal mining is carried out by both opencast and underground mining methods. As of 2016, there are 252 operational underground coal mines, which contribute 7% (64 million tonnes) of the total coal production (Indian Bureau of Mines, 2017). Board-and-pillar and longwall methods are the most commonly employed techniques for coal production in Indian underground coal mines. Most of the underground coal mines are either mechanised or semi-mechanised. The types of machinery commonly used in underground coal mines are load-haul-dumpers, side-discharge-loaders, universal drill machines, handheld drill machines, rope haulage, conveyors, ventilation fans, dewatering pumps, shuttle cars and locomotives (DGMS, 2015). Mine fire, explosion and inundation are the major causes of previous disasters in Indian Underground coal mines.

Table 1
Common hazard identification techniques.

Informal Approach	Formal Approach
Check-Lists	Failure Mode and Effects Analysis
What-If Analysis	Event Tree Analysis
Historical Accident and Incident Records	Fault Tree Analysis
Personal Observation, Interviews	Workplace Risk Assessment and Control (WRAC)
Safety Committee Meetings, Informal Meetings	Job Hazard Analysis
Personal Experience	Bow-Tie Analysis
Brainstorming	Management Oversight Risk Tree
Consultation with Workers	Preliminary Hazard Analysis
Safety Audits	Hierarchical Task Analysis
	Hazard Identification and Ranking (HIRA)
	Hazard and Operability Study
	Hazard Identification (HAZID)

2. Literature survey

Hazard factors related to machinery, humans, the work environment and work methods were the causes identified for the different types of safety risks in underground coal mines (Badri, Nadeau, & Gbodossou, 2012). Ale et al. (2008) studied the accident statistics in the Netherlands and identified fire, explosion, contact with electricity, contact with moving parts and falls as the occupational hazards. After analysing 245 cases in two underground coal mines, Kunar, Bhattacherjee, and Chau (2010) concluded that poor working conditions, material handling, and ground control were the main job-related hazards. Lilić, Obradović, and Cvjetić (2010) stated that the safety in coal mines is based on various interdependent hazards that are classified as dust, gas, noise, vibration, illumination and geotechnical hazards. Khanzode, Maiti, and Ray (2011) listed machinery related, ground fall-related, material related and housekeeping related hazards which were identified in an underground coal mine over 15 months. Yunxiao and Ming (2012) developed a hazard list in coal mines using a systematic hazard identification method. The hazards were identified by categorising the hazard components into three parts, i.e. the hazard element, initiating mechanism, and threat and target. Bahn (2013) presented the list of identified hazards in "Hazard Identification" and "Managing Workplace Hazards" workshops conducted with 77 employees of an underground mining operation in Western Australia. Badri, Nadeau, and Gbodossou (2013) identified the risk elements of all the gold mines in the province of Quebec by studying the previous accident and incident reports, and through interviews and observations in the field. Krause and Krzemień (2014) stated that the impact of methane drainage, electrical equipment, work organization, and ventilation conditions have the most significant influence on the shaping of methane hazards in underground mines. Verma and Chaudhari (2017) presented a list of safety and health hazards identified in underground and opencast manganese mines. Dash, Bhattacharjee, Singh, Aftab, and Sagesh (2017) stated that roof and side fall, explosions, inundation, winding accidents and fire represent the major accidents which occurred in the Indian mining industry between 1901 and 2016. Other notable studies on safety risks in mines by researchers include, among others, roof fall and side fall (Kejriwal, 2002), machinery (Ruff, Coleman, & Martini, 2011), explosion (Grayson, Kinilakodi, & Kecojevic, 2009) and inundation (Luo & Liu, 2010).

A major piece of work for developing the hazard database for the mining industry was performed in Australia (Queensland Government, 2016). The Mineral Industry Safety and Health Centre at the University of Queensland developed online interactive tools RISKGATE (Kirsch, Shi, & Sprott, 2014) and MIRMGate (Kizil & Joy, 2005) for accessing risk controls and hazard-related information, respectively.

3. Method

To achieve the objective of this paper, the authors have collected the accident statistics, incident reports and inspection reports from the DGMS and Coal India Limited. The DGMS is a governing agency under the Ministry of Labour and Employment in India that deals with matters relating to occupational safety, health and the welfare of persons employed in mines and Coal India Limited is a public sector coal mining company. The authors also visited an underground coal mine for ten days in the Orient area, Odisha, India, for data collection and observations. The details of the underground coal mine visited are that the thickness of the seam is 18–24 m and the seam is divided into sections 1, 2, 3 and 4. The thickness of the sections are 2.44 m, 1.61 m, 2.13 m, and 2.20 m respectively. The depth of the working varies from 18 m to 282 m. Mining working is mainly performed by the board-and-pillar method using solid blasting technique. The observations were carried out using the DGMS (2014) accident classification, and International Labour Organization (1994) mines safety checklist that describes the details to be observed in each district of the mine.

The first step of the creation of the safety hazards database was to analyse more than 7000 accident reports of all the coal mining companies collected from 2001 to 2014 as shown in Fig. 3 and the observations done during mine visits. Checklists and the Workplace Risk

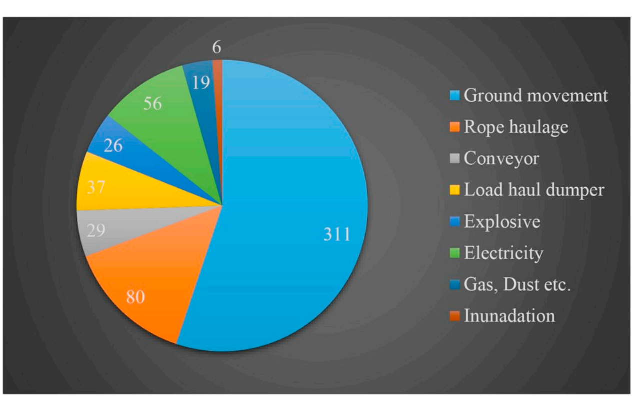

Fig. 3. Cause wise analysis of fatal accidents in coal mines from 2001 to 2014.

Assessment and Control technique were used to identify the mining operation specific safety hazards for the following hazard groups: ground movement, rope haulage system, belt conveyor system, load haul dumper, shot firing and blasting, electricity, dust, gas & other combustible materials, and inundation.

The Workplace Risk Assessment and Control (WRAC) technique is a broad-brush risk ranking approach which allows the employer to concentrate on the highest rank (NSWDPI, 1997; Thompson, 1999). It can be applied in any area of the mine or at a particular time of activity. WRAC is most effective when it is scoped with appropriate detail, including clear objectives and the boundaries of the system have been defined (Joy & Griffiths, 2007). It is a participative approach for identifying multiple potential hazards in a mine, for example, rope haulage accidents due to one or all of the following safety hazards would be identified:

- Improper signalling,
- Deployment of an unauthorised or untrained trammer or clip-man,
- Failure to inspect and maintain haulage road regularly,
- Failure of drawbar,
- Defective rope, rope splicing, rope capel or shackles,
- Lack of proper illumination and whitewash at coupling and uncoupling points.

The Failure Mode and Effects Analysis technique was also used to find the machinery specific hazards for the following hazard groups: the rope haulage system, the belt conveyor system and the load haul dumper. An example of the Failure Mode and Effects Analysis method for rope haulage is represented in Table 2. Specific hazards identified from the literature and after meeting with the mine personnel were also added to the hazard database.

4. Results and discussion

A comprehensive list of safety hazards identified in underground coal mines is represented in Table 3. To the best of their knowledge, the authors have found no research work that identifies safety hazards associated with workers actions, machines, tools, job procedures and overall work environment collectively. This is a preliminary hazard portrait, organised and intended to be a checklist covering all the safety hazards involved in the underground mining operation. From the evidence and findings obtained from the collected reports, the activities that led to multiple fatalities in the past have been selected as the hazard groups. In Table 3, the hazard groups were categorized as the cause of the accident category presented in DGMS (2014) and the associated risks of the identified hazards were also presented. It is practical to categorise a hazard group for the better application of industrial risk assessment techniques in the later stages of the risk assessment process. As it is difficult to identify all the safety hazards in a mine due to changes in the mine environment, emerging factors and unknown phenomena, hazard identification should be treated as a continuous process and the list of hazards should be updated regularly.

From Table 3, it can be observed that a single hazard can result in a number of risks. Therefore, to effectively eliminate or minimise the risk, hazards should be controlled. Depending on the risk level obtained from the other stages of the risk assessment process, the hierarchy of controls can be applied to the hazards with high-risk level. The common forms of control are the complete elimination of the hazard source; replacement of the hazardous work method/equipment/process; engineering methods, such as inserting a barrier between the source and target; providing training, awareness, safe operating procedures and framing rules; providing personal protective equipment to workers; and safe human behaviour.

Table 2
Hazard identification for rope haulage using Failure Mode and Effects Analysis.

Component	Failure Mode	Failure Effect	Recommendations
Rope	Breakage of rope due to wear and tear, rusting or improper splicing	Runaway of tubs, injury to workers	• Rope condition and joints shall be inspected and maintained properly • Improper or damaged ropes shall be replaced immediately • Overloading of tubs shall not be allowed
Drawbar	Failure of drawbar	Runaway of tubs, injury to workers	• Only approved drawbars shall be used • Periodical inspection and maintenance shall be performed • The worn out and defective drawbar shall be replaced immediately
Capel or shackles	Defective Capel or shackles	Runaway of tubs, injury to workers	• Only approved capel shall be used • Periodical inspection and maintenance shall be done • Worn out and defective capel or shackles should be replaced immediately
Track	Defective laying of the track line	Derailment of tubs, injury to workers	• Proper maintenance of haulage track shall be performed
Tubs	Improper maintenance of tubs	Derailment of tubs, injury to workers	• Proper maintenance of tubs shall be performed
Tub buffers	Non-provision or non- functioning	Getting caught between tubs while coupling & uncoupling	• Tub buffers shall be provided and maintained properly

Table 3
Safety hazards database.

Hazard Group	Type of hazard elements	Details of hazard elements	Associated risks
Ground movement (Geo-mechanical)	Human	Rock Mass Rating not determined and Systematic Support Rules not framed properly	Improper support may lead to roof fall
		Poor knowledge of approved Systematic Support Rules	Less than adequate support, injury to workers
		Delay in supporting the freshly exposed roof	Endangering safety of face workers
		Deployment of an unauthorised or untrained support crew	Poor workmanship, injury to support crew
		Poor supervision	Chance of roof or side fall, risk to workers deployed under this individual
	Work methods/ procedural	Improper roof/side testing and dressing	Weak layers may fall on working persons causing injuries
		Less than adequate grout in the column	A fake sense of roof support or deterioration of roof leads to roof fall
		Non-vertical alignment of galleries	Uneven distribution of stresses may lead to roof or side fall, crushed floor and pillars
		More height and width of galleries	Unbalanced stress on roof leads to roof fall, gallery height of more than 3 meters may lead to side fall
	Work environment/ managerial	Poorly supported or unsupported roof/side	Chance of roof/side fall
		Lack of indicators in strata monitoring	No indication of strata deterioration, unexpected falls
		Unavailability of support material	Unsupported workings, chance of roof or side fall
		Poor quality of cement capsules, bearing plates and drill rods	A fake sense of roof support or deterioration of roof leads to roof fall
		Presence of subsidence cracks and fissures on the surface above development panel	Chance of fire, chance of inundation, roof and side fall may occur, injury to workers, loss of property
		Geologically disturbed areas or weak old supports	Roof and side may fall causing injuries to workers, chance of inundation
		Weak roof/side conditions	Roof or side may fall causing injuries to workers
		Water seepage	Roof and sides will become weak causing roof fall or side fall
Rope haulage system (Mechanical)	Human	Deployment of an unauthorised or untrained trammer or clip-man	Injury to trammer or clip-man and other workers
		Overloading of tubs	Breakage of rope, injury to workers
		Lack of precaution while haulage track line crosses the travelling road	Injury to workers while crossing the road
		Failure to inspect and maintain haulage road regularly	Improper road conditions may lead to injury to workers
		Deployment of an unauthorised or untrained operator	Injury to workers
	Machine/tool	Defective or improper clips or lashing chain	Detachment of tub from the rope, injury to workers
		Failure of drawbar	Runaway of tubs, injury to workers
		Defective rope, rope splicing, rope capel or shackles	Breakage of rope, injury to workers
		Failure of sprags	

(*continued on next page*)

Table 3 (*continued*)

Hazard Group	Type of hazard elements	Details of hazard elements	Associated risks
			Sudden movement of tubs, injury to workers
	Work methods/ procedural	Unexpected movement of tubs	Workers get caught between tubs while coupling and uncoupling
		Improper laying and maintenance of track line	Derailment of tubs, injury to workers
		Improper maintenance of tubs and their fittings	Injury to workers, derailment of tubs
		Improper maintenance of engine room	Failure of haulage, injury to workers
		Lack of proper illumination and whitewash at coupling and uncoupling points	Poor illumination may lead to injury to workers
		Improper signalling	Injury to workers
		Failure to display safety labels and code of signals at all stopping places along the roadway	Inadvertent entry of workers may lead to injury
		Improper condition or maintenance of brakes	Failure of haulage brake, injury to workers
		Improper condition or maintenance of the engine	Failure of haulage engine, injury to workers
		Improper condition or maintenance of drum, surge wheel, clutch, and gears	Injury to workers
		Improper condition of automatic catches and buffers	Injury to workers
		Non-functioning of speed limit switch and distance indicator	Non-functioning of speed limit switch and distance indicator may lead to poor judgment by the operator, injury to workers
	Work environment/ managerial	Non-provision of safety buffers	Failure to catch a runaway tub, injury to workers
		Non-provision or improper maintenance of safety appliances like stop blocks, runway switches, backstay, drags, catches, safety hooks, jazz rails, friction rollers, re-railers	Derailment of tubs, the runway of tubs, injury to workers
		Non-provision of guards around all moving parts	Injury to haulage operator
Belt conveyor system (Mechanical)	Human	Deployment of an unauthorised or untrained operator	Injury to operator and others
		Pre-start check not performed by the operator	Injury to operator and others
		Irregular maintenance of a weak or damaged belt joint	Injury to the operator, e.g. friction burns, cuts, abrasion impact with the belt, and drawing-in
		Inadequate cleaning of spillage coal in belt sides, drive heads and tail ends	Injury to operator engaged for cleaning, the chance of fire due to friction
		Inattentive chute opening and improper screen of the chute	Injury to chute operator due to falling of lump while cleaning the chute
		An operator wearing loose clothing	Injury to operator
		Worker crossing the belt to the other side or Inadvertent entry of a worker while the belt is moving	Injury to worker due to falling while crossing
	Machine/tool	Improper condition of belt and belt line	Injury to the operator like friction burns, cuts, abrasion impact with the belt, and drawing-in
		Breaking of coupling or bolts of coupling and non-provision of coupling guard	Injury to workers
		Bearing failure of the drive head	Leads to overheating which may ignite dust or spillage
		Failure of pre-start alarm	Injury to workers
		Failure of pull cord and lockout switches	Injury to workers
		Damaged idlers or rollers	Chance of fire
	Work methods/ procedural	Improper signalling	Injury to workers
		Cleaning belt or checking gear-box and coupling, while the conveyor is in motion	Injury to worker
		Failure to display safety labels and code of signals	Inadvertent entry of workers may lead to injury
		Lack of proper illumination near drive head, discharge and tail end drums	Poor illumination may lead to injury to workers
		Improper shovel for cleaning the coal near tail end drum	Injury to worker
	Work environment/ managerial	Non-provision of guards around drive head, tail end, and tensioning unit	Drawing-in and crushing or injury to the operator while cleaning or maintaining or passing by
		Friction in the running belt due to spillage coal and belt structure	Chance of fire
Load Haul Dumper (Mechanical)	Human	Deployment of an unauthorised or untrained operator	Injury to the operator and other workers
		Pre-start check not performed by the operator	Injury to the operator and others
		Plying of the machine in disturbed or unsafe areas	Flying of coal pieces due to movement of the machine may cause injury to workers
		Workers standing around the machine or unexpected movement of a trailing cable	Injury to workers
	Machine/tool	Front or rear light not working	Injury to operator and others
		Audio-visual alarm or bell not working	Injury to other workers
		Footswitch or deadman switch not working	Injury to other workers
		Improper oil tank condition	Chance of fire, injury to workers
		Bad condition of the tyre	Bursting of the tyre, accidental dislodging of the wheel, injury to the operator

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Table 3 (*continued*)

Hazard Group	Type of hazard elements	Details of hazard elements	Associated risks
		Improper condition of parking or service brakes	Injury to the operator and others
		Improper condition of lift or tilt cylinder	Injury to the operator and others
		Improper canopy or canopy not provided	Injury to the operator
		Bypassed dump valve or dump valve not in order	Operational problem and risk associated with uncontrolled movement of the machine
		Poor condition of the front or rear frame	Injury to the operator
		Pilot switch not in order	Electrocution, chance of fire, injury to the operator and others
		Pressure relief valve not in order	Bursting of oil tank and hoses causing injury to the operator and others
		Temperature switch not in order	Injury to workers
		Poor condition of bucket	Slippage of bucket tip plate during operation, injury to workers
		Oil leakage	Chance of fire
		Improper condition of the engine	Injury to the operator
	Work methods/ procedural	Parking or standing of the machine at a gradient	Unexpected movement of the machine, injury to workers
	Work environment/ managerial	Non-provision of lockout warning tags on the machine	Injury to workers
Shot firing and blasting (Chemical)	Human	Deployment of an unauthorised or untrained blasting crew	Injury to workers present in the blasting zone, chance of misfire
		Not following the blasting card system	Chance of workers entering the blasting zone, injury to workers
		Priming of explosives in unauthorised places	Accidental blasting
		Improper or poorly maintained blasting tools	Accidental blasting
		Carrying of explosives and detonator together	Accidental blasting
		Shot firing from a source other than the exploder	Accidental blasting
		Shot firer engaged in other work	Lack of concentration, accidental blasting
		Improper drilling, cleaning, charging and stemming of shot holes	Blasting projectiles, blown through the shot
		Failure to warn before blasting	Chance of workers entering the blasting zone, injury to workers
		Failure to spray water before and after blasting	Accumulation of coal dust, chance of fire
		Failure to cover the entrance with a fence, in case of misfire	Chance of workers entering the blasted area, injury to workers
		Failure to recover cartridge or detonator, in case of misfire	Accidental blasting
	Work methods/ procedural	Drivage of joining gallery from both ends	Inadvertent entry of workers into the blasting area, blown out and blown through shots
		Multiple operations at face while charging	Chances of injury, accidental blasting
Electricity (Electrical)	Human	Improper maintenance of flameproof features of machinery	Chance of electric fire, explosion
		Improper insulation of electric cables	Chance of fire, short circuit
		Improper permanent cable joints (compounding)	Chance of fire, short circuit
		Improper shutdown procedure	Chance of electrocution
		Improper fencing of installations	Chance of electrocution
		Improper maintenance of electric apparatus of equipment (without proper precaution)	Injury to electrician
		Improper reeling or unreeling of trailing cable	Damage to cable, Uncontrolled runaway of the machine causing injury to operator and others
		Failure to inspect all the electrical parts of the energised machines daily for frayed cords, induction, arcing	Chance of ignition of flammable material in the vicinity, Chance of fire
		Failure to connect plugs or sockets to gate end box	Chance of electrocution
	Machine/tool	Failure of protective devices	Chance of electric shock
		Faulty power cables	Chance of electrocution
		Unsatisfactory flexible trailing cable	Poor installation, the damaged cable may lead to the electrocution
		Improper condition of signalling wires and its clamping	Chance of electrocution
		Improper condition of gate end circuit breaker	Failure to transmit a fault to the tripping mechanism of a switch may lead to electrocution
	Work methods/ procedural	Improper grounding system or earth pit and neutral pit	Chance of electric shock
		Housing of power cable along with signalling cable and lighting cable jointly	Chance of electrocution
	Work environment/ managerial	Failure to display danger boards on all electrical equipment	Inadvertent touching of electrical equipment may lead to electrocution
		Non-intrinsic signalling and telephonic communication circuits	Chance of electrocution
Dust, gas & other combustible material (Geochemical)	Human	Deployment of untrained supervisors	Chance of injury to the individuals deployed under him/her
		Improper monitoring or inspection of gases in sealed off areas and old working areas which are not sealed off	Chances of fire and explosion
		Failure to examine the rate of emission of gas as per statutory norms	Incapability of monitoring the percentage of gases present, chance of fire and explosion

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Table 3 (*continued*)

Hazard Group	Type of hazard elements	Details of hazard elements	Associated risks
		Contrabands	Chances of fire, explosion, injury to workers
		Failure to check speed, amperage and fan drift	Improper ventilation supply, chance of the accumulation of gases
		Failure to clean fallen coal or debris in return airway	Chance of fire
		Failure to clean fallen coal, wood cuttings, oil and greasy waste	Chances of fire
		Improper monitoring of fire stoppings	Chances of fire
	Machine/tool	Inadequate or non-functioning of gas detecting apparatus	Proper detection of gases not possible during early stages which may cause fire and explosion
		Insufficient fan capacity	Inadequate ventilation to the mine working, chance of fire and explosion
		Leakage in ducts	Poor ventilation, accumulation of gases, chance of fire and explosion
		Non-availability or improper condition of auxiliary fans	Accumulation of noxious gases, exposure of workers to accumulated noxious gases, heat stroke, heat exhaustion, non-clearance of post-detonation fumes from working faces, spontaneous heating, chances of fire in old workings
		Improper condition or maintenance of safety lamp	Failure to detect toxic gases, chance of injury to workers
	Work methods/ procedural	Improper sealing of extracted panels	Leakage of ventilation, chances of fire
		Improper sampling of gases by supervisors	Incapability of monitoring the percentage of gases present, chance of fire and explosion
		Non-inter coupling of underground power with the main mine ventilator fans	Chance of spreading accumulated igneous, noxious, toxic, inflammable gases
		Gas cutting and welding work near a dusty area or any unauthorised area	Chances of fire, explosion, injury to workers
		Irregular stone dusting	Chance of fire and explosion
		Irregular ventilation survey	Poor ventilation supply to mine workings
		Obstruction of the return airway or insufficient intake	Inadequate ventilation, accumulation of gases, chance of fire and explosion
		Improper condition or maintenance of main mechanical ventilator	Poor ventilation, accumulation of gases, chance of fire and explosion
		Improper condition or maintenance of stoppings	Failure to prevent the spread of fire to other mine workings
		Non-provision of the interlocking arrangement of auxiliary fans	Poor ventilation in case of failure of other auxiliary fans
		Non-provision of access for the inspection of stoppings, doors, airways and air crossing	Failure to monitor the gases at stoppings, doors, airways and air crossing
		Improper panel size	Chances of fire, spontaneous heating
	Work environment/ managerial	Leakage from sectionalization stoppings	Chance of fire and explosion
		Failure to provide sand, flashback arrester, and water near gas cutting and welding workplace	Fails to prevent the spread of fire, injury to workers
		Stone dust barrier not provided at panel entry	Chance of explosion
		Accumulation of coal dust at the working panel and loading points	Chance of explosion
		Non-provision of explosion proof stoppings where CH_4 exceeds 2%	Chance of explosion
		Presence of surface cracks, fissures, subsidence	Chance of fire
		Inadequate ventilation	Chance of fire and risks associated with fire
		Blind heading	Accumulation of noxious gases, exposure of workers to accumulated noxious gases, heat stroke, heat exhaustion, non-clearance of post-detonation fumes from working faces, spontaneous heating, chance of fire in old workings
		Heat and humidity	Heat stroke, work capacity reduces, the collapse of workers, fatigue, vomiting, nausea, symptoms of shock, headache
		Lengthy ventilation route	Poor ventilation, heat and humidity leads to uncomfortable working conditions for workers
		Lack of dust suppression arrangements	Accumulation of dust, chance of fire and explosion
		Non-provision of a fire-resistant mechanical ventilator, ducts, ventilation doors and air crossings	Chance of fire
		Non-provision or improper maintenance of firefighting equipment	Uncontrolled fire, injury to workers
		Susceptibility of spontaneous heating due to low Cross Point Temperature and high moisture content	Chances of fire, coal seam more susceptible to spontaneous heating
		Shallow depth of cover	Leaking of air from the surface into sealed off areas, special heating
		Huge de-pillared area	Special heating

(*continued on next page*)

Table 3 (*continued*)

Hazard Group	Type of hazard elements	Details of hazard elements	Associated risks
		Geological disturbance affecting the panel	Chance of fire, coal seam more susceptible to spontaneous heating
		Thick seam	Chances of fire
		Improper early fire detection system	Proper detection of fire not possible during early stages which may lead to explosion
Inundation (Environmental)	Work methods/ procedural	Old boreholes which are not sealed effectively	Chance of inundation
		Inaccurate drivage of face	Chance of inundation
		Borehole not marked in the underground plan	Chance of inundation
		Failure to prepare and regularly update water danger plan	Chance of inundation
	Work environment/ managerial	Insufficient number of pumps or failure of pumps	Chance of inundation
		Working near geological disturbance faults, folds, slips, etc.	Chance of inundation
		Presence of surface cracks, fissures, subsidence	Chance of inundation
		Unexpected heavy rains and power failure	Chance of inundation
		Failure of barriers	Chance of inundation
		Non-provision of side drains	Chance of inundation
		Insufficient sump area	Chance of inundation
		Failure of water dams	Chance of inundation
		Presence of old waterlogged areas or abandoned workings	Chance of inundation

5. Conclusion

The hazard identification stage is crucial in the risk assessment process, as unidentified hazards may lead to unmanageable risks and reduce the efficiency of the risk management process. This paper concentrates on the first stage of the risk assessment process in underground coal mines. The other stages of the risk assessment process, i.e., analysis and evaluation of the identified safety hazards and their associated risks should be carried out to improve safety in mines. In this study, checklist, Workplace Risk Assessment and Control, and Failure Mode and Effects Analysis techniques were used to identify the hazards in underground coal mines. Altogether 172 hazard events were identified and categorized into six categories of hazard groups: geo-mechanical (ground movement), mechanical (rope haulage system, belt conveyor system, load haul dumper), chemical (shot firing and blasting), electrical (electricity), geochemical (dust, gas & other combustible materials), and environmental (inundation). The hazard events were further categorized as human, machine/tool, work methods/procedural, and work environment/managerial hazards. The associated risks of the identified hazards were also presented.

The database developed gives mine personnel, researchers and practitioners' access to a comprehensive safety hazard list and their associated risks in the underground coal mines, which in turn may help them to analyse and evaluate the safety risks of identified hazards. Based on the evaluated risk, a hierarchy of controls like engineering, administrative, personal protective equipment or human behaviour may be used to eliminate or control the hazards. This database could be suitable throughout underground mines with some changes in order for them to adapt to the unique environment of each mine.

The comprehensive list provided in this paper is limited to safety hazards only. Thus for future research more in-depth study of safety hazards and other hazards like health, environmental, and issues related to the complexity of operational environment, organisational and human performance could be performed.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Conflict of interest

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