Contents lists available at *Dergipark*

Journal of Scientific Reports-C

journal homepage: *https://dergipark.org.tr/en/pub/jsrc*

E-ISSN: 2717-8633 ***Sayı(Number) 7, Ağustos(August) 2024***

ARAŞTIRMA MAKALESİ/RESEARCH ARTICLE

Geliş Tarihi (Receive Date): 23.03.2024 *Kabul Tarihi (Accepted Date): 22.04.2024*

An analysis of coal mining accidents in Türkiye: A decade of incidents

El Hassen Diahah[a]*, Oktay Şahbaz[b]

[a]*Kütahya Dumlupınar University, Faculty of Engineering, Department of Mining Engineering, 43000 Kütahya, Türkiye, ORCID: 0009-0003-6787-6584*

[b]*Kütahya Dumlupınar University, Faculty of Engineering, Department of Mining Engineering, 43000 Kütahya, Türkiye, ORCID: 0000-0003-0945-9048*

Abstract

This article presents the critical issue of coal production accidents in Türkiye within the last decade, providing a comprehensive analysis of these accidents to shed light on the safety and challenges of coal production. Beginning with setting the stage for the inquiry on coal's significance as a primary source of energy, the research compares Türkiye and the USA's coal production sector accident rates and revealing high contrasts changes within the same period. The past decade underground mine accidents examinations identified key contributing factors to these incidents, enriched by insights from leading experts specializing in Occupational Health and Safety (OHS) within the Turkish coal mining sector. Moreover, the analysis of safety measures and regulatory changes over the timespan, revealed the reactive nature of these amendments rather than proactive, which could have served in mitigating these accidents or anticipating the hazards responsible for these tragedies. This study concludes with a discussion of lessons learned from these accidents, proposing a set of forward-thinking suggestions that aim to reduce accident rates, enhance safety protocols, and prevent future tragedies. This investigation not only illuminates the urgent need for proactive and preventive strategies in mine risk management but also calls on decision-makers, industry shareholders, and the global community to put the lives and well of workers in this field above all else. Through the balanced combination of the available methods used in this research, this article aims to contribute deeply to improving coal production safety standards in Türkiye and the world.

Keywords: Accidents, coal mining, occupational health and safety, Türkiye, risk management.

Türkiye'deki kömür madenciliği kazalarının analizi: On yıllık kazalar

Öz

Bu makale, Türkiye'de son on yılda meydana gelen kömür üretim kazalarını ele alarak, bu kazaların kapsamlı bir analizini sunmakta ve kömür üretimindeki güvenlik ve zorluklara ışık tutmaktadır. Kömürün birincil enerji kaynağı olarak öneminin sorgulanmasına zemin hazırlayarak başlayan araştırma, Türkiye ve ABD'nin kömür üretim sektörü kaza oranlarını karşılaştırmakta ve aynı dönemdeki yüksek kontrast değişimlerini ortaya koymaktadır. Son on yılda meydana gelen yeraltı maden kazaları incelenerek, bu kazalara öncülük eden temel faktörler tespit edilmiş ve Türkiye kömür madenciliği sektöründe İş Sağlığı ve Güvenliği (İSG) alanında uzmanlaşmış önde gelen uzmanların görüşleriyle zenginleştirilmiştir. Ayrıca, söz konusu zaman aralığında alınan güvenlik önlemleri ve mevzuat değişikliklerinin analizi, bu kazaların hafifletilmesine veya bu trajedilerden sorumlu tehlikelerin öngörülmesine hizmet edebilecek bu değişiklikleri proaktif olmaktan ziyade reaktif niteliğini ortaya koymuştur. Bu çalışma, kazalardan çıakrılan derslerin tartışılmasıyla sona ermekte ve kaza oranlarını azaltmayı, güvenlik protokollerini geliştirmeyi ve gelecekteki trajedileri önlemeyi amaçlayan bir dizi ileri görüşlü öneri sunmaktadır. Bu araştırma, maden risk yönetiminde proaktif ve önleyici stratejilere duyulan acil ihtiyaca ışık tutmakla kalmayıp, aynı zamanda karar vericileri, sektör paydaşlarını ve küresel toplumu bu alandaki çalışanların hayatlarını ve refahını her şeyin üstünde tutmaya çağırmaktadır. Bu araştırmada kullanılan mevcut yöntemleri dengeli bir şekilde bir araya getirilmesiyle, bu makale Türkiye'de ve dünyada kömür üretimi güvenlik standartlarının iyileştirilmesine derin bir katkı sağlamayı amaçlamaktadır.

Anahtar Kelimeler: Kazalar, kömür madenciliği, iş sağlığı ve Güvenliği, Turkiye, risk yönetimi

1. Introduction

According to the International Labor Organization, nearly 2.3 million individuals, both men and women, globally lose their lives due to work-related accidents or occupational diseases on an annual basis, which equates to an alarming daily average of over 6,000 fatalities. The world witnesses approximately 340 million work-related accidents and around 160 million cases of individuals suffering from occupational illnesses every year, and these statistics, unfortunately, tend to grow [1].

One of the most accident- prone industries is mining, especially coal mining. Coal plays a crucial role in numerous industrial procedures and is a fundamental element in 70% of global steel manufacturing, it holds a crucial position in global electricity production [2]. Currently, coal-fired power stations supply 37% of the world's electricity, and estimations from the International Energy Agency (IEA) indicate that coal will continue providing 22% of the world's electricity in 2040 [3]. Despite its bad reputation due to the hazardous structure of mining and processing, coal is predominantly used to produce electrical power and industrial heating. Türkiye's 2022 total coal reserve estimation is 20.84 billion tons, including 19.32 billion tons of lignite, asphaltite and approximately 1.52 billion tons of hard coal [4], with a total beneficiation, from 800tons traded in the same year, that surpassed 128M $ [5].

The top three countries with the highest fatal occupational accident rate values in the world are India, Russia, and Türkiye, which increased substantially in the last decade. Coal production-related activities, which involve extraction and processing, are one of the riskiest working lines within industries in Türkiye [6, 7, 8]. The occurrence of occupational accidents unfolds at a rate of approximately one incident every 7 minutes, resulting in a tragic loss of an employee's life roughly every eleven hours, with another employee experiencing disability approximately every 6 hours [9].

Analysis of the Social Security Institution (SGK) statistical data between 2001 and 2020 shows that the mining sector in Türkiye has the highest death rate, with an average of 0.81 per 10,000 employees [10]. Moreover, according to the Türkiye Kömür İşletmeleri Kurumu (TKI), the accident severity rate average between 2013-2022 stands at 0.431, which makes it one the riskiest, if not the riskiest, work in terms of accident severity [11].

Thus, minimizing or preventing coal production catastrophic accidents demands a long-term commitment to safety, comprehensive regulations, training, and education, improving community awareness, accountability, investment in hazard detection technologies and risk management & analysis. Immediate actions are essential to protect the well-being of workers and minimize the environmental and social impact of such accidents. This study aims to shed light on the last decade of accidents in the coal production industry, analyzes the root causes of the incidents, and offer recommendations and insights to support the countermeasures that could prevent any similar situations from happening in the future.

2. Overview of major accidents

Türkiye has one of the most severe occupational accidents, which are primarily deadly since the activities in the coal production line are considered significantly hazardous. Historically, officials and non-governmental organizations reported a substantial number of accidents (Table 1) [12, 13].

Table 1. Major coal mining accidents in Türkiye (1992-2012).

Year	Location	Fatalities	Root cause
1992	Kozlu, Zonguldak	263	Firedamp explosion
1995	Sorgun, Yozgat	37	Firedamp explosion
2003	Aşkale, Erzurum	8	Firedamp explosion
2003	Ermenek, Karaman	10	Firedamp explosion
2004	Bayat, Çorum	3	Firedamp explosion
2005	Gediz, Kütahya	18	Firedamp explosion
2006	Dursunbey, Balıkesir	17	Firedamp explosion
2009	M.Kemalpaşa, Bursa	19	Firedamp explosion
2010	Dursunbey, Balıkesir	13	Firedamp explosion
2010	Karadon, Zonguldak	30	Firedamp explosion
2011	Elbistan, K.Maraş	11	Slope failure

As seen in the table, these incidents always leave an enormous number of fatalities which makes a bad reputation for the coal sector.

The total death toll in the twenty years before 2012, sadly reached at least 429. Whether it was a state agency, a public participation, a contractor company, or a private company, unfortunately, all these incidents included the loss of many lives. In comparison with the USA, the mine safety and health administration reported for the same time period 733 deaths [14] (fig. 1).

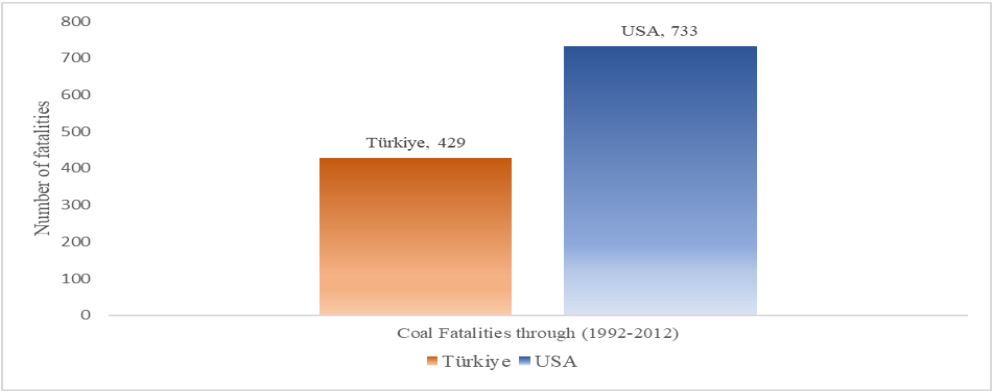

Fig. 1. Coal production fatalities in Türkiye and U.S.A through (1992-2012).

When comparing the coal mining sector in Türkiye with the USA's sector through the last ten years, we can notice a huge difference (fig. 2). For instance, comparing yearly death rates per million tons of coal produced we instantly observe the high death rates among Turkish coal workers for each million tons. These rates reached enormous peak (nearly 5 miners for each million tons), in the year 2014 due to the tragic event of Soma disaster, ranking that year as the highest in terms of occupational fatalities, which have led to increased scrutiny of mining practices and regulations in the country. Besides, we can clearly see that even with the large production values of the USA, which attained double of the Turkish ones in some of the years, the fatality rates are incomparable.

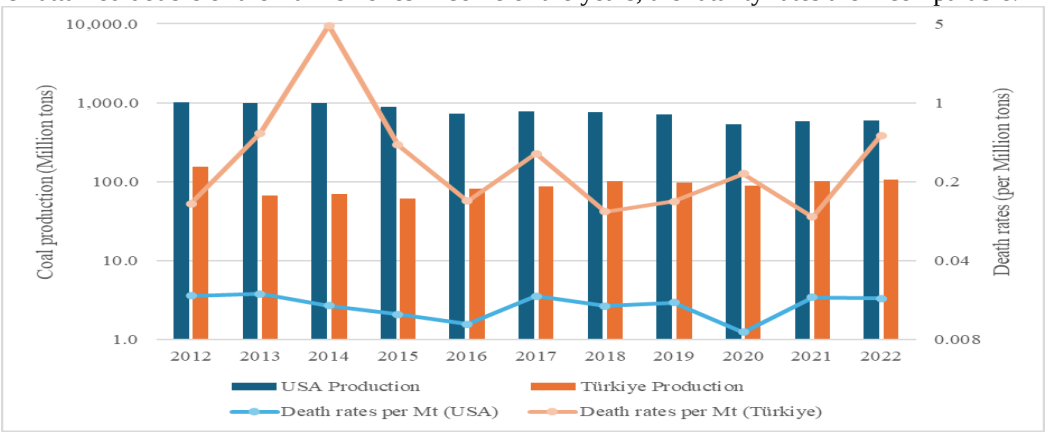

Fig. 2. Türkiye and USA coal production and death toll rates within the last decade [15, 14, 16, 17, 18, 19].

In the same context of comparison, when analyzing the incidence rates (IR) in the two countries within the same time span, we notice a clear difference between the two (fig. 3). We notice an increasing trend toward high numbers in terms of incidence for 200000 working hours in Türkiye's coal production sector. In contrast, the USA's incidence rates trend is miraculously constant and low, given the high production numbers, mentioned earlier.

IR is one of the indicators that can help measure occupational accidents occurrences rates, taking into account several parameters such as the workforce, their total working hours, and the number of accidents that occurred during a specific time period. It is calculated as follows:

$$IR = \frac{Number\ of\ occupational\ accidents}{Total\ exposure\ hours} \times 200{,}000 \quad (1)$$

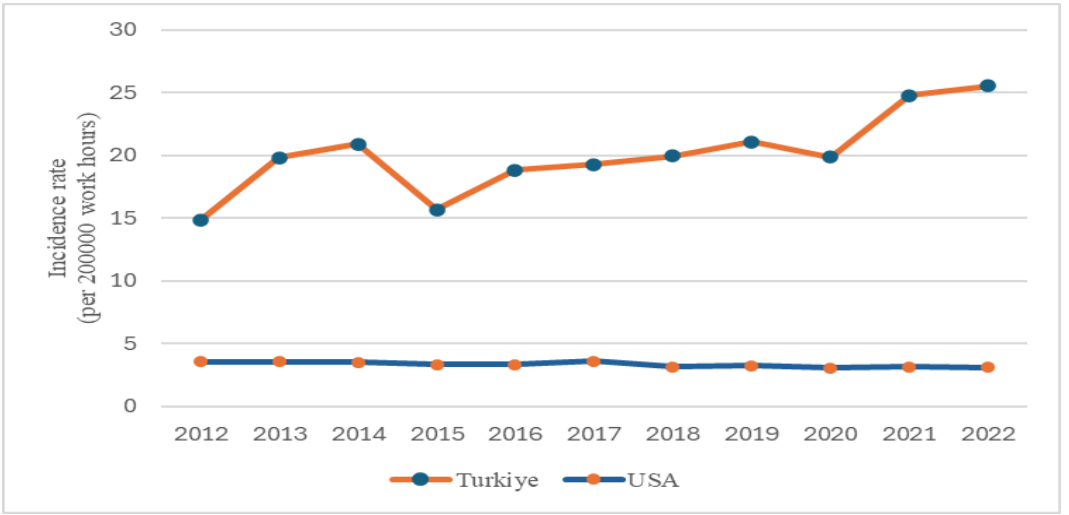

Fig. 3: Incidence rates in Türkiye and U.S.A coal production sector within the last decade.

Today, Türkiye's production of coal, from the last data available, reached 140 million tons, but the price was 54 workers, unfortunately [4]. On the other hand, the USA coal production attained 539 million tons, with a death toll that reached 11 workers [14, 20, 18].

According to statistical reports from the Social Security Institution of Türkiye (SGK) 104,099 coal and lignite production-related workers have been exposed to work accidents or occupational diseases within the last decade (fig. 4) [21].

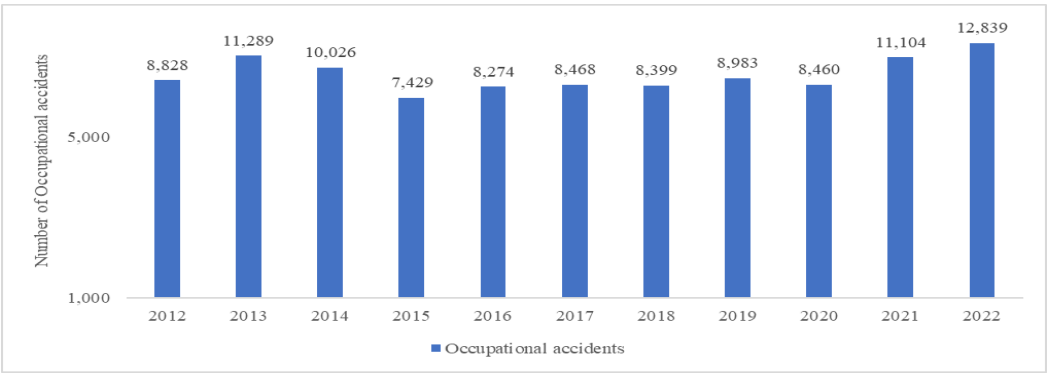

Fig. 4. Insured workers having or exposed to occupational accidents in Türkiye Coal and Lignite production sector within the last decade.

The statistics for sure show a massive increase in the last couple of years, even though the Turkish mining sector has faced criticism over the years for its safety standards which, as we can see, still completely insufficient to cope with the high production levels.

The same statistics reveal frightening numbers of deaths and permanent incapacity among workers that occurred due to work accidents related to coal production activities in the same period (fig. 5) [21].

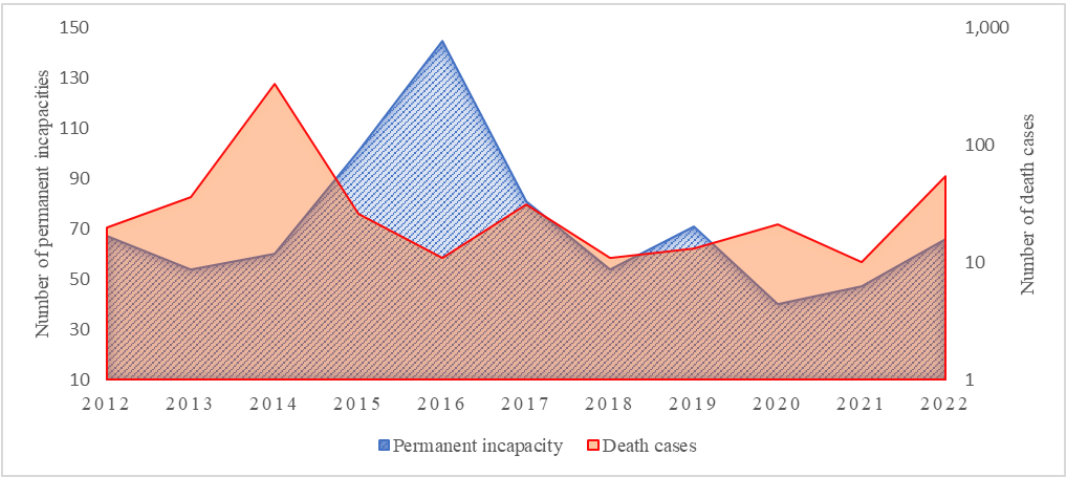

Fig. 5. Insured workers deceased/permanent incapacity due to occupational accidents in Türkiye's Coal and Lignite production sector within the last decade.

These statistics reveal that, unfortunately, 786 workers were permanently incapacitated, and a death toll of 568 among workers in the coal and lignite sector within the same period.

Generally, accidents frequency rates (AFR) and accidents severity rates (ASR) are used to get a deeper understanding and evaluation of the data collected from occupational accidents. To clarify, these rates are used to measure past performance indicating how repeatably and how severe these accidents were withing a defined timeframe. To calculate these rates, the following formulas are used:

$$AFR = \frac{Total\ number\ of\ accidents}{Total\ exposure\ hours} \times 1{,}000{,}000 \quad (2)$$

$$ASR = \frac{Total\ number\ of\ Lost\ workdays}{Total\ exposure\ hours} \times 1{,}000 \quad (3)$$

AFR & ASR show an increasing trend in recent years, except when AFR reach low values 74.04 accidents for every million working hours and 78.37 accidents for every million working hours in 2012 and 2015, respectively (fig. 6). These values are considered to be the lowest within the last decade, yet these values are still very high compared to other countries. The rate has reached its max in 2022 within the last ten years, according to the last data available, with more than 127.64 accidents for every million working hours.

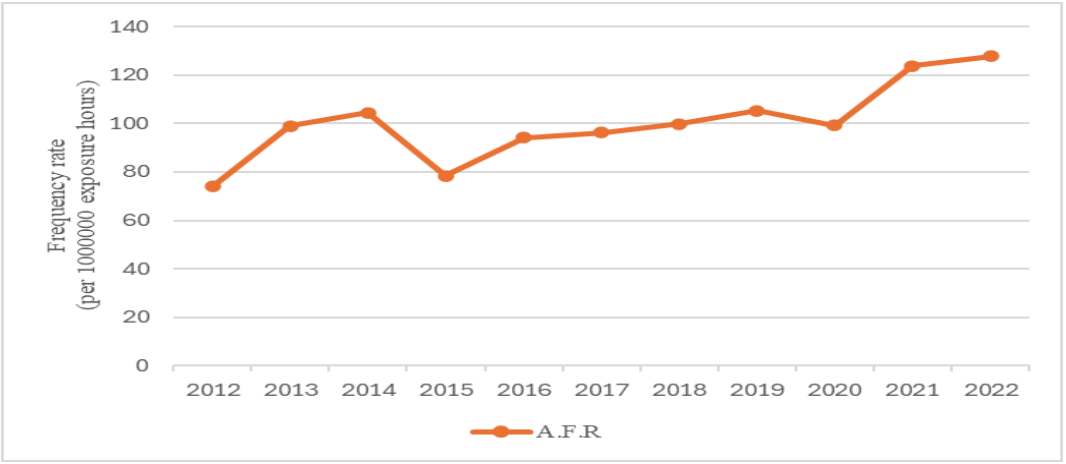

Fig. 6: Coal & lignite mining accidents frequency rates in Türkiye within the last decade.

While ASR reached its lowest, 0.875 lost workday per 1000 working hours, in the year 2018. Which is due to the significant decrease in total days lost within that year. The highest recorded severity rate within the past decade is surely the last two years, with 1.785 and 1.788 lost workday per 1000 working hours in 2021 and 2022, respectively (fig. 7).

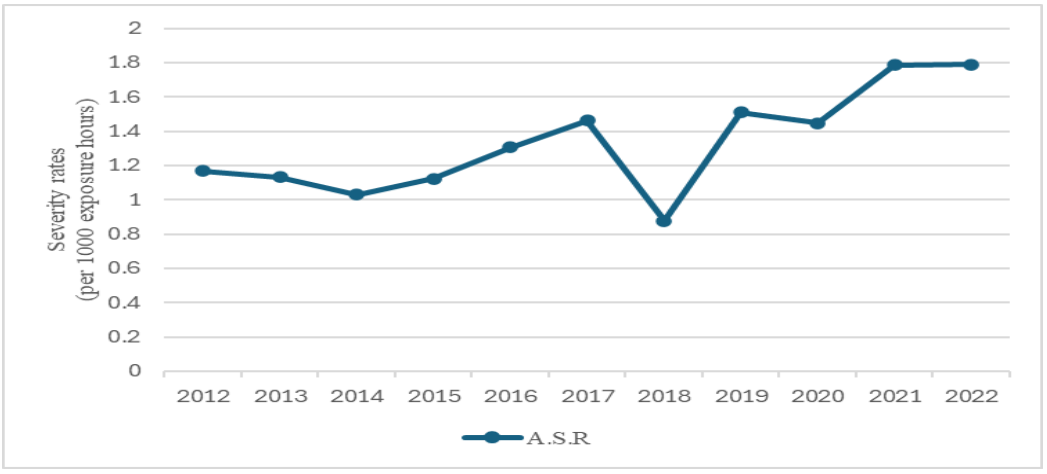

Fig. 7: Coal & lignite mining accidents severity rates in Türkiye within the last decade.

The chronological summary of the deadliest coal accidents in the last decade, with their key details, are as follows (Table 2) [13, 19, 22].

Table 2. Chronological summary of the deadliest coal occupational accidents in the last decade.

Year	Location	Fatalities	Root causes
2012	Soma, Manisa	1	N/A

2013	Kozlu, Zonguldak	8	Sudden Methane discharge.
2014	Soma, Manisa	301	Firedamp explosion/Toxic gasses.
2014	Ermenek, Karaman	18	Flooding.
2017	Kemer, Antalya	2	Firedamp explosion.
2017	Şırnak	7	Landslide
2017	Kilimli- Zonguldak	2	Roof collapse.
2020	Soma - Manisa	3	Roof collapse.
2022	Amasra, Bartin	41	Firedamp explosion.

Moreover, on 13 Sept. 2023, the disaster and emergency presidency (AFAD) reported that at least one person passed and 4 were seriously injured after a coal mine collapse in Armutçuk, Zonguldak, as 4 other workers were still trapped under the rubble.

In addition, it's important to acknowledge the minor incidents, which are not the focus of the present work, however, will be discussed further with insights from the experts and can still significantly impact the health and safety of the workers involved which contribute to the overall safety record of the mining industry.

All of this gives a clear message that lethal coal mine accidents are still in the picture if not treated properly from their root causes. It is vital to note that the previous list has only the major occupational accidents reported in the last decade, however, the number of injuries, traumas, and bad reputation of coal mining especially is immense.

3. Accidents analysis

Coal workers face a range of hazards that make their workplace one of the most dangerous, if not the most dangerous. The spontaneous combustion and high explosion probability properties of coal make it one of the most hazardous earth resources to extract and process.

In underground coal mining, the most frequent accidents occur due to collapses, pillar outbursts, firedamp explosions, gas and dust explosions, blasting and shock waves, roof falls, floodings, transportation and hoisting [23, 9, 24, 25]. Mechanical failure has been a leading contributor to accidents in recent years due to the sensitivity of features. Poor design of features such as tailing dams, ventilation systems, shaft systems, blasting and explosive equipment, and transportation machines could also lead to disasters [26, 27, 28].

On the other hand, preparation plants face other types of hazards, these hazards can be fire hazards, chemical exposure, falling, tripping, slipping, being squeezed under a pile, or hitting a limb while dealing with equipment. Electric shocks, noise and vibration, coal dust which can cause suffocation and skin issues, or skeletal shocks due to carrying high loads [29, 30, 6].

3.1. Factors contributing to accidents

According to a study conducted on research trends in mining accidents between 2015 and 2019, the selected articles were from ten countries, and they managed to identify 57 studies related to mining accidents (fig. 8). Under the theme of “Main causes of mine accidents”, half of these articles were subdivided into sixteen main causes. Along with risk management factors (Safety management, Leadership behavior of supervisors, Unsafe behavior, and Lack of safety training etc.), the statistical results of these research trends show that mechanical failures are the dominant factor in contributing to accidents in the coal mining industry [31].

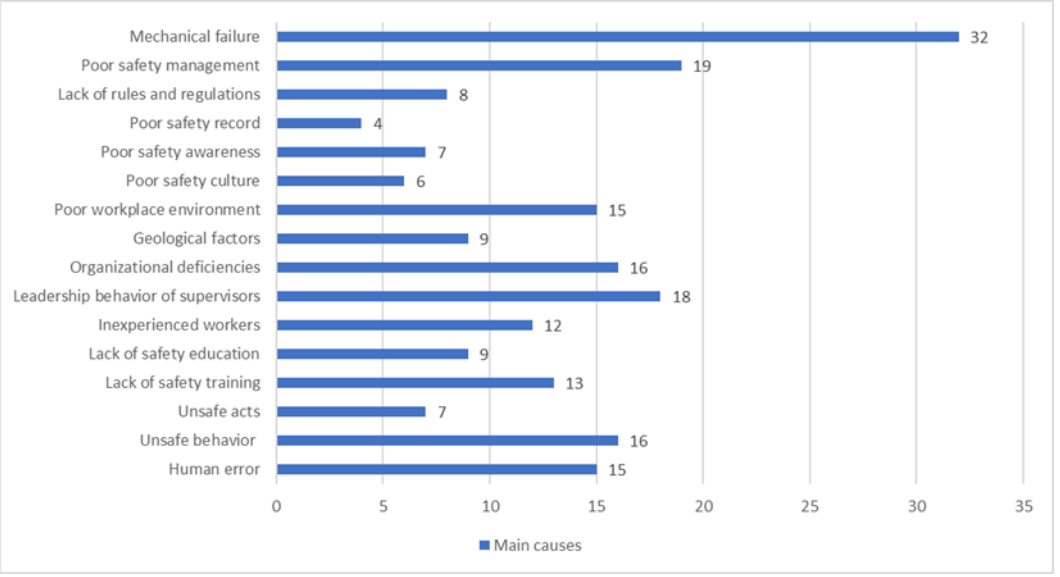

Fig. 8. Main causes of mining accidents in published research (2015-2019).

Investigation on safety culture nowadays is a new area of interest when it comes to accidents prevention by identifying the influence of the cultural factors, such as safety culture. A group of researchers conducted an analysis combining OHS reports from five different countries and more than 900 references, representing a 50-year data set. Their ultimate goal was to respond to the question if/how this concept historically influenced mining accidents. The themes found to be of potential to provide insights into their role in accidents, are subdivided into two main frames (a) Individual and (b) Organization, role in safety culture (Table 3) [32].

Table 3: Key safety culture themes related to main frames (a) Individual (b) Organization.

Individual	Organization
Attitude	Belief
Competence	Safety Culture
Norms	
Patterns	

This analysis identified how the concept of safety culture was framed in the post accidents reports within 50-years of research, which could provide insights on how each of these themes could contribute to understanding and preventing future accidents. For instance, the role of an individual in safety culture is influenced by many factors which consist of the worker's attitude towards safety, how the worker's characteristics add to how he should behave, and his technical competence. On the other hand, the organizational role in safety culture is driven beyond individuals to the larger context of organizational practices. This context is influenced by the commitment from all stakeholders to safety through sharing responsibilities, persuaded by the dominant social practices, and attention.

The chronological summary of the major accidents that occurred during the last decade in Türkiye, shows that firedamp explosions, roofs and wall collapses, ventilation problems, and flooding were the direct reasons that caused these disasters (fig. 9).

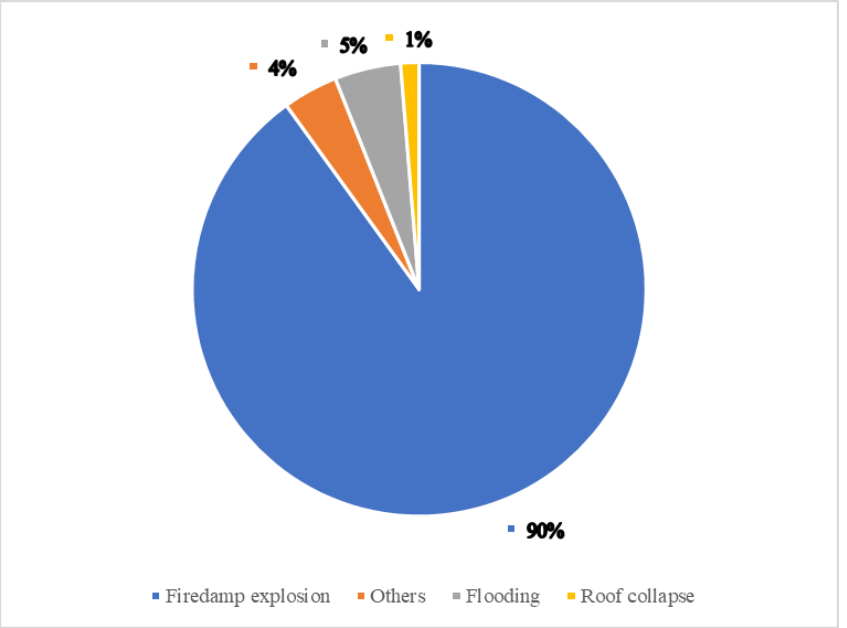

Fig. 9. The proportions on major accidents root causes in the last decade.

When analyzed, the distribution accidents that led to deaths indicate that causes related to gas explosions are the highest in terms of death toll with a percentage of 90%, which is far from other causes due to its presence in the Soma and Amasra disasters.

Methane, emitted throughout the coal mining process, encompasses gases released before, during, and after mining activities, constituting a massive portion of the mine atmosphere. It combines with water vapour, coal or rock dust, and various hazardous gases, creating a complex and potentially perilous mining environment. The origin of these gases spans diverse sources within the mine. Factors such as mineral oxidation, wood degradation, oxygen displacement, and instances like fires and explosions contribute to generating hazardous gases. Among these, methane (CH4) is a primary concern due to its explosive nature and widespread presence in coal mines. Additionally, gases like carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (N2), hydrogen sulfide (H2S), and sulfur dioxide (SO2) pose significant health and safety risks to miners, forming toxic, flammable, or suffocating gas combinations like firedamp and blackdamp (Table 4) [33, 13].

Table 4. Risks for main toxic gases in mines [9, 34].

Gases	Risks
CH4	Explosion, Firedamp and Asphyxiation (Suffocation)
CO	Asphyxia (Suffocation), Explosion
CO2	Suffocation
H2S	Eye and respiratory infections
O2 Shortage	Anoxia (lack of oxygen in the body tissues)
Diesel engines gazes	Respiratory infections, Lung cancer

This investigation, along with many others, attributes a large number of accidents to methane, which can be a key factor in firedamp explosions, with its varying concentrations and conditions creating volatile and potentially catastrophic environments. This gas emanates from diverse sources within the mine, notably ventilation air, pre-mining gas drainage, and post-mining areas. Ventilation air, despite containing lower methane concentrations, significantly contributes to coal mine methane emissions, particularly in gassy coal mines, highlighting its role in the risk profile of mining operations. These reasons can conceal indirect causes as discussed in studies and accidents reports, such as [34]:

- Poor uncertified electrical equipment, wiring and engines.
- Insufficient licensed firefighters, gas detectors, and ventilation in the mine.
- Poor safety plan, safety culture and training.
- Inadequate safety measurements such as gas measurements.
- Poor control and recording of sensors.
- Untrained and unexperienced personnel supervising critical safety posts.

3.2. Expert Insights

We managed to conduct interviews to get a comprehensive view through the insights that were given by the experts and decoding the challenges from different perspectives on preventing coal mining disasters. By connecting our data with insights from experts, which serves as a bridge connecting statistical data of past accidents with the experiential knowledge of those who confront these risks daily, thus offering a more holistic insights on what the statistical data couldn't provide. We asked the experts, from their point of view and experience, three fundamental questions:

- What are the main reasons for occupational deaths in coal mines?
- What are the main reasons for injuries and loss of limbs in coal mines?
- What are the main reasons for minor accidents in coal mines?

OHS experts, MINER 1 and 2, are leading experts in mining safety with several years of experience in the field, were interviewed on the 9th of January 2024. They contributed significantly through supervision of occupational health and safety protocols in the coal company they're working in.

- In response to the first question, MINER 1 stated that, "When fatal work accidents are examined, fortification, ventilation (underground gases), ground water, methane explosion, accidents with mechanical vehicles, falling, blocking, decline, public fall, compressed air hit, accidents while exploding dynamite, wagon crash, rope breaking in descending, etc., accidents caused by electricity or electrical equipment are listed also." While MINER 2, added "Multiple deaths are usually due to fuel explosions, coal dust explosion after ignition, collapses, CO exposure, and falling from heights etc."

They emphasize on the complex nature of coal mining accidents that causes death or multiple death cases. their response highlights the relationship between hazardous environmental factors and dangerous human behavior.

- Going to the second question, MINER 1 answers, "The reasons of work accidents causing limb loss and occupational diseases, along with all the aforementioned reasons, coal dust usually causes occupational diseases, although the risk of occupational disease is low compared to chemical and biological risks because coal is organic."

They both agreed that "Loss of a limb is caused by movement machines and equipment, for example, belt drums, chain conveyor jamming, etc."

MINER 1 adds, "The first precaution, to prevent the formation of dust at the source, it is to prevent dust from coming up during hole drilling, excavation, and blasting." In terms of effective preventive measures for these problems, he remarked, "For this, preventing dust by drilling with wet drilling and preventing dust formation by using wet tightening cartridge. When dust forms for any reason, effective ventilation is provided as a precaution and dust is removed from the environment. As a last precaution, the person's exposure is reduced by using a dust mask, when drilling and blasting, in which workers are mostly exposed to dust, in order to reduce exposure, only the driller and his assistant are present. Transportation and other persons are kept in another section to ensure that they are not exposed to dust." These insights point to the best available precautions from his point of view.

From their point of view, the machinery movement poses a major challenge which requires a high vigilance and safety culture among workers that are exposed to such risk. However, MINER 1 expressed that the main challenge is the prevention of coal dust inhalation which can cause Pneumoconiosis problems. He suggested prevention strategy expresses the complexity of interaction between technological and risk management factors in mining safety. It also highlights the necessity for a holistic safety approach, resonating with present OHS theories that support modern risk management practice.

- Lastly, for the third question, they agreed that "When near miss accidents or accidents with minor injuries are examined, they are usually due to falls due to slippery floor, accidents with hand tools, hit of the air hose, accidents occurring while fortification, accidents while carrying masts, inclined roads, descended stairs. As well as filling the wagon while standing, which can lead to waist injury."

In terms of preventive actions, MINER 1 says, "Following the same logic, precautions are taken with personal protection first at the source, then in the environment and then in the person. When risks arise from the environment, those risks can be removed."

As we can clearly notice that, that these minor accidents usually occur due to the overlooked daily work hazards, which surely include inadequate maintenance, high complexity of routine operations, and minor technical deviations. Their responses highlight the crucial significance of minor accidents as an indicator of potential major risks. The importance of these routine hazards, points to the need for continuous vigilance and regular review of safety standards and operational procedures in the mines.

3.3. Safety Measures and regulatory changes

The aforementioned tragedies come as a part of a pattern of accidents in Türkiye, often attributed to inadequate safety measures and regulatory supervision in the coal production industry. Occupational health and safety act (No. 6331) from Türkiye official newspaper (No. 2833) was accepted and implemented on the 20th of June 2012. Its purpose was to ensure OHS in workplaces and to improve safety conditions by regulating duties, authorities, responsibilities, rights and obligations of employees and employers.

The law came with several definitions, from which it defines the work accident as "Any accident that occurs at the workplace or due to the execution of work , causing death or damaging the integrity of the body mentally or physically", risk as "The possibility of loss , injury or other harmful consequences arising from danger", and Hazard class " the hazard group determined for the workplace, taking in account characteristics of work, substances used at every stage, equipment, production forms and methods, and other work related environment and conditions" [35].

The Ministry of Labor and Social Security published, in the official newspaper (No. 28509) dated 26th of Dec. 2012, an annex listing the workplace hazard classification according to economical activities (Table 5).

Table 5. Hazardous Coal related activities (workplace hazard classes list) [36].

NACE Rev.2 Code	NACE Rev.2 Work Definition	Hazard Class
05.10.01	Hard coal mining	Very Dangerous
05.20.01	Lignite mining	Very Dangerous
19.10.10	Manufacture of coke oven from lignite and peat.	Very Dangerous
19.10.11	Manufacture of coke oven from hard coal	Very Dangerous
19.20.12	Fuel obtained by coal dust pressure	Very Dangerous

Coal related activities have always been considered as one of the most, if not the most, dangerous in workplace hazard classification related to Occupational Health and Safety. Consequently, over the past decade, Türkiye has been engaged in the process of reforming its nation's OHS regulatory system, to harmonize it with the regional and international standards.

- 29th May 2013 the government issued law (No. 6485) concerning participation in OHS development framework convention, which was already adopted by the International Labor Organization ILO [37].
- 19th Sept. 2013, a regulation within the scope of the previous law (No. 6331) on OHS in mining workplaces. This regulation came with some general obligations of employers and employees, protection from explosion and harmful ambient air, rescue, communication and warning systems, health surveillance, employee participation, and minimum health and safety requirements, which was well in this amendment [38].
- 24th Sept. 2014, after the SOMA mine disaster a regulation on amending the OHS in mining workplaces, was published in the Turkish official newspaper number (No. 29129). This amendment brought some additional articles to the previous regulations concerning evacuation and rescue process [39].
- 23rd April 2015, (Law No. 6645) major changes were made in the decision provisioning related to regulatory laws of Occupational Health and Safety decrees, such as providing guidance and consultancy to the employer on issues related to OHS, accountability of employers who exposes employees to fatal work accidents, suspension of workplaces that didn't change conditions after work accidents occurred [40].
- 24th March 2016, the ministry of Labor and Social Security made some changes to OHS regulations in the official newspaper (No. 29663), tackling the enforcement of a tracking and monitoring system of employees during their presence in the workplaces, some new definitions of equipment and materials, and some details concerning escape and rescue plans [41].
- 18th Sept. 2017, another regulatory changes (No. 30244), from the Ministry of Labor and Social Security, was published. These changes were concerning technical materials within the mines that may ignite fires and explosions, dealing with certain rescue and evacuation situations and their alternatives [42].
- 24th May 2018, new regulatory amendments were introduced in the official newspaper number (No. 30430), on the principles of regulations regarding procedure of OHS training of employees. This amendment insists on issues such as OHS training of employees, ensuring their participation by recording and documentation reports of training workshops, emphasizing on the responsibility of employers/sub-employers providing OHS training to their employees. It even defined the minimum training time requirement assigned for each level of hazardous workplaces [43].

From that time until now there was no significate amendment or regulations regarding the occupational health and safety, which causes Turkish mining sector to face criticism over the years for its safety standards. Tragic events like the Amasra, Bartin Province mine explosion in lately, have led to increased scrutiny of mining practices and

regulations in the country. The accidents often lead to calls for improved safety measures, better regulation, and more stringent enforcement of existing laws to protect miners.

4. Lessons learned and recommendations

Preventing or limiting coal-related activities and accidents demands a long-term commitment to safety, comprehensive regulations, training/education, improving community awareness, accountability, investment in hazard detection technologies and risk management strategies to be implemented.

The preventive actions should start from the root of all administrative and regulatory failures. Implementing and rigorously enforcing robust safety regulations specific to coal mining and processing operations. These regulations should address areas such as ventilation, equipment maintenance, hazard identification, and safe work practices. Moreover, according to the analysis, employees working in the coal mining industry were found to be one the topmost exposed to work accidents and fatality numbers in this particular industry cannot be tolerated. Lessons collected from each incident highlight the critical need for a multifaced approach regarding the enhancement of safety standards. Besides, as we can notice clearly from the measures and regulatory changes section, that regulations and amendments are exclusively implemented almost predominantly after the occurrence of a tragedy, such as SOMA, rather than as pre-action mitigation measures which revels a reactive rather than proactive approach in managing risk. Even though it is commonly used in many industries and countries, the reactive approach is increasingly considered as outdated in risk management practices.

Compliance with international occupational health and safety standards such as OHSAS 18001 and recent standards such as ISO 31000 & ISO 45001, which describes a more advanced management system than OHSAS 18001, with terms, definitions, roles, and scope defined more clearly. The standard's compliance with other management system standards such ISO 9001 and ISO 14001 will provide a great advantage for organizations. ISO 45001 establishes an organizational context, which describes factors (external and internal) that can affect the organization's overall responsibility for OHS in a positive or negative sense. Moreover, the updated standard emphasis on the planning aspect within this section, specifying that organizations are to precisely plan control measures by delineating risks related with both routine and non-routine activities [44]. Furthermore, performance evaluation is previously mentioned in the ISO 18001, but it was highlighted in the new standard that monitoring & performance documentation should be crucial to organizations [45].

Developing and implementing comprehensive training and education programs for coal miners is imperative. These programs should not only cover the fundamental aspects of identifying risks, safe machinery operation, and effective emergency response but also delve into advanced techniques and evolving industry best practices. Moreover, specialized skill enhancement modules should be incorporated into these programs, focusing on specific roles and responsibilities within the mining environment. A study on the relationship between coal workers subjective wellbeing and unsafe behavior concluded that the wellbeing of miners plays a significant role when in it comes to unsafe behavior in terms of, positive, negative emotions and life satisfaction of miners [46]. An investigation of learning needs in the mining industry concluded that, training interventions prepared in the three considered macro-areas with the aim of increasing knowledge, skills, and attitudes on not only a strictly cognitive and technical scientific level, but also socio-psychological level which have been confirmed to be of crucial significance when it comes to coal mining accidents. This approach translates into a skills development plan, wherein socio-constructivist strategies and methodologies will be implemented, with a particular focus on the proactive engagement of workers in their educational journey [47].

Engaging with local communities to raise awareness about the potential risks associated with coal mining and processing, emphasizing the importance of safety measures and the role of the community in supporting a safe working environment. A study analyzed work accidents and occupational diseases occurring in the mining sector in Türkiye, identified that, in recent years, both governmental authorities and employers have undertaken notable and

promising initiatives aimed at mitigating work-related accidents in the mining sector. Particular attention has been dedicated to increasing safety measures and promoting safety-oriented culture within mining operations. Consequently, a noticeable but modest trend towards a reduction in work-related accidents has been observed. To augment this positive trend, the authors put forth some recommendations designed to increase the decline in work-related accidents [48].

In terms of accountability, the penalty and reward approach which typically refers to a mechanism of consequences and motivations designed to encourage safety and prevent such tragedies especially for coal mining companies. A study from China found that static penalty approach has a clear impact in promptly decreasing safety hazards and enhancing the immediate state of coal-mine safety production. On the other hand, the dynamic penalty strategy proves effective as mitigation measure and to lower safety risks coming from uncertainty [49]. Alternatively, it's of major importance to have the balance between imposing punishment for violations and disobedience of safety regulations while keeping rewards that motivate those who encourage positive safety behaviour. A group of researchers conducted an analysis of coal safe production under a tripartite evolutionary game model to provide ultimately a reference for an effective reward and punishment mechanism. They found that governmental rewards for coal mining enterprises encourage them to adopt safe production methods, simultaneously, the increase in rewards for local governments boosts the probability of strictly implementing coal safety supervision policy. Moreover, punishment of enterprises for unsafe actions and rent-seeking behaviour of local governments, with an increasing number of fines on both, leads to raising the local government's sternness in implementing safety supervision. Furthermore, increasing sales revenue and rent-seeking costs can lead also to the implementation of coal safe production [50].

Investments in state-of-the-art monitoring and sensing technologies to continuously assess conditions in mines, including gas levels, structural stability, and air quality, and remember early detection of potential hazards is critical for accident prevention. A case study on, the use of sensors in occupational health and safety applications, it was remarkably observed that the utilization of sensors in post-accident risk assessments, employing the 5x5 L-type matrix method, resulted in a significant 75% reduction in the probability of work-related accidents [51].

Risk management and risk analysis protocols are vital, preventing coal mining and processing accidents. This requires conducting thorough risk assessments to identify and evaluate potential hazards within the mining and processing operations. Risk analysis is practical approach in the sense that it deals exclusively with potential accidents, which is the opposite to an accident investigation, which is a reactive approach that seeks to determine the causes and circumstances of accidents that have already happened. Integrating risk management and risk analysis into the training and education programs for coal miners. Again, as we mentioned in the training and education preventive measures, this empowers workers to recognize and respond to potential risks effectively [52]. This assessment needs to be integrated in any project plan that involves any level of occupational risks and should encompass geological, mechanical, and operational factors that may pose risks to worker safety. Developing and implementing risk mitigation strategies based on the findings of the risk assessment. This includes engineering controls, administrative measures, personal protective equipment to reduce the likelihood and severity of accidents, continuous monitoring mechanisms to assess the effectiveness of risk mitigation measures and to adapt to evolving risk factors, and strategies for preventing similar incidents in the future, by analyzing root causes to identify the underlying factors and systemic issues that contributed to the incident.

The mentioned recommendations come as part of the commitment that coal mining companies, central government, local communities, and workers in the coal production field, should comply with the ultimate aim to increase vigilance, improve coal labor conditions, and prevent forthcoming tragedies.

5. Conclusion

This study presents an analysis of coal mining accidents in Türkiye, with the main focus on the last decade (2012-2023), which have highly impacted the reputation of the coal sector negatively. It sheds light on major accidents such as Soma mine disaster, towards minor incidents, which remind us to take serious actions towards the prioritization of safety in coal mining and processing operations.

The historical overview on major accidents revealed that coal fatalities is not to be considered as recent issue, shocking numbers in terms of fatalities were presented only in the twenty-years before 2012, more than four-hundred workers, unfortunately, lost their lives. As in the same period, U.S.A's fatality rates were twice more. However, in recent years, even though with the increase of coal production from the U.S.A which triples Türkiye's production, the number of fatalities is less than the one observed in Türkiye. Which questions the application of safety protocols, standards, and the challenges of safety culture.

The analysis of these accidents revealed multiple factors contributing to the list of root causes. It revealed that ninety percent of these incidents were directly caused by firedamp explosions, which has a long history of being the main trigger of these accidents as we seen in the previous years. The rising of gas content in underground mines produces the necessity to increase airflow rates. This points out the need for more adequate and well-designed ventilation systems that should be considered prior to exploitation phase, during mine development stage. Besides, if the need increases production plans should be modified based on the ventilation requirements. In addition, floodings and roof collapses come in minor percentages. Moreover, other direct and indirect causes, as mentioned in multiple sources, for instance, mechanical failures, poor safety management, lack of safety culture and poor design of mechanical parts, contributed to such accidents. It stretches also to other indirect factors that represent the concept of safety culture which can be grouped as organizational and/or personal factors. From this point, we tracked the regulatory changes that may have occurred in response to these accidents. We found that the foremost general nature of these regulations and amendments were reactive rather than the proactive approach, which serves as a pre-occurrence action to prevent such disasters in the future.

Finally, this study discusses a set of future recommendations drawn from the lessons learned of similar situations and investigations, to ensure the fostering of a strong safety mentality that should be adopted by workers in this field, governmental branches, and stakeholders. Again, following these suggestions from the proactive implementation and enforcement of safety regulations, compliance with the safety international standards, enforcement of safety education on companies, raising safety awareness among workers and local communities, investments in monitoring and safety technologies, to the development of risk management practices, can draw the way for a secure and more sustainable environment for all of those working in the coal production industry in Türkiye.

Acknowledgements

This study is a part of a master thesis carried out by El Hassen Diahah at the Mining Engineering Department of Kütahya Dumlupınar University.

References

[1] ILO, "World statistic," Inter. Labor Org., 13 July 2011. [Online]. Available: https://www.ilo.org/moscow/areas-of-work/occupational-safety-and-health/WCMS_249278/lang--en/index.htm#:~:text=The%20ILO%20estimates%20that%20some,of%20work%2Drelated%20illnesses%20annually. [Accessed 27 Oct. 2023].
[2] WCA, "Coal's contribution," World Coal Assoc., [Online]. Available: https://www.worldcoal.org/coal-facts/coals-contribution/. [Accessed 27 Oct. 2023].
[3] IEA, "Global coal production, (2000-2025)," Inter. Energy Agen., 16 Dec. 2022. [Online]. Available: https://www.iea.org/data-and-statistics/charts/global-coal-production-2000-2025. [Accessed 27 Oct. 2023].

[4] MTA, "2022 faaliyet raporu," Maden Tetkik ve Arama Genel Müd., Ankara, Turkiye, 2022.
[5] MTA, "Madencilik sektörüne ait temel ekonomik göstergeler," MTA Genel Müd., Ankara, Turkiye, 2022.
[6] P. E. Fındıkçıoğlu, "Investigation of workplace accidents in coal and mineral processing plants: unsafe acts, safety culture and safety leadership [Ph.D. - Doctoral Program]," 2018. [Online]. Available: https://open.metu.edu.tr/handle/11511/27236. [Accessed 15 Feb. 2023].
[7] K. Koçali, "Sosyal güvenlik kurumu'nun 2012-2020 yillari arasi iş kazalari," Akad. Yaklaş. Dergisi, vol. 12, no. 2, pp. 302-327, 2021.
[8] C. Hüseyin and al., "High-risky sectors in terms of work accidents in Turkey," Int. Journal of Eng. and Dev., vol. 14, no. 1, pp. 45-57, 31 Jan. 2022.
[9] F. Küçük and A. Ilgaz, "Causes of coal mine accidents in the world and Turkey," Turk Thor. Jour., vol. 16, no. 1, pp. 9-14, 2015.
[10] S. Sadid and A. Konuk, "Türkiye madencilik sektörü iş kazalarının yoğunlaşma analizleriyle değerlendirilmesi," AKU Jour. Sci. Eng., vol. 23, no. 2, pp. 487-502, 21 Mar. 2023.
[11] TKI, "Faaliyet Raporu 2022," Türkiye Kömür Işletmeleri Kurumu (TKI), Ankara, Turkiye, 2022.
[12] TMMOB, "Soma faciasi ön raporu," Maden Mühendisleri Odası, Ankara, Turkiye, 2014.
[13] A. E. Dursun, "An analysis and countermeasures of fatal accidents caused by firedamp explosions in underground coal mines in Turkey," Bilim. Maden. Dergisi, vol. 58, no. 4, pp. 299-310, Jun. 2019.
[14] MSHA, "Coal fatalities for 1900 through 2022," Mine Saf. and Health Admin., [Online]. Available: https://arlweb.msha.gov/stats/centurystats/coalstats.asp. [Accessed 12 Dec. 2023].
[15] SGK, "İş kazasi ve meslek hastaliği istatistikleri (4-1/a)," Sosyal Güvenlik Kurumu (SGK), Ankara, Turkiye, 2022.
[16] TÜİK, "Industrial production index," Türkiye İstatistik Kurumu (TÜİK), 11 Dec. 2023. [Online]. Available: https://data.tuik.gov.tr/Bulten/Index?p=Sanayi-%C3%9Cretim-Endeksi-Ekim-2023-49707&dil=1. [Accessed 18 Dec. 2023].
[17] T.C. enerji ve tabii kaynaklar bakanlığı, "Coal," Ministry of Energy and Natural Res., 20 June 2023. [Online]. Available: https://enerji.gov.tr/bilgimerkezi-tabiikaynaklar-komur#:~:text=Maden%20ve%20Petrol%20%C4%B0%C5%9Fleri%20Genel,37%20milyon%20ton%20olarak%20ger%C3%A7ekle%C5%9Fmi%C5%9Ftir. [Accessed 15 04 2024].
[18] MSHA, "Mine injury and worktime reports 2012-2022," Mine Saf. and Health Admin., Arlington, VA, 2023.
[19] TMMOB, "Madencilikte yaşanan iş kazalari raporu (2010-2020)," TMMOB, Maden Mühendisleri Odası, Ankara, Turkiye, 2010-2020.
[20] EIA, "Annual coal report," U.S Energy Info. Admin., 03 Oct. 2023. [Online]. Available: https://www.eia.gov/coal/annual/#:~:text=Highlights%20for%202022,million%20short%20tons%20(MMst). [Accessed 18 Dec. 2023].
[21] SGK, "İş kazasi ve meslek hastaliği istatistikleri," Sosyal Güvenlik Kurumu (SGK), Ankara, Turkiye, 2012-2022.
[22] TBMM, "Amasra maden kazası araştırma komisyonu raporu," TBMM kaza araştırma komisyonu, Ankara, Turkiye, 2022.
[23] H. Chen and al., "Characteristics of direct causes and human factors in major gas explosion accidents in chinese coal mines: case study spanning the years 1980-2010," Journal of Loss Prev. in the Proc. Indust., vol. 26, no. 1, pp. 38-44, Jan. 2013.
[24] H. H. Erdoğan, "A quantitative risk assessment methodology for occupational accidents in underground coal mines: a case of Turkish hard coal enterprises [Ph.D. - Doctoral Program]," 2016. [Online]. Available: https://open.metu.edu.tr/handle/11511/26151. [Accessed 8 Nov. 2023].
[25] Y. Zhu and al., "A statistical analysis of coal mine fires and explosions in china," Proc. Safety & Environ. Protection, vol. 121, p. 357–366, Jan. 2019.
[26] A. Dash and al., "Lessons learnt from Indian inundation disasters: an analysis of case studies," Inter. Journal Disas. Risk Red., vol. 20, pp. 93-102, Dec. 2016.
[27] Y. Zhang and al., "Analysis 320 coal mine accidents using structural equation modeling with unsafe conditions ofthe rules and regulations as exogenous variables," Accid. Anal. Prev., vol. 92, p. 189–201, Jul. 2016.
[28] L. Wang and al., "Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM," Safety Sci., vol. 103, p. 51–61, Mar. 2018.
[29] MSHA, "Injury experience in coal mining, 2012," Mine Saf. and Health Admin., Colorado, USA, 2013.
[30] P. McKennis, "Report of investigation preparation plant fatality (plate press accident)," West Virginia Office of Miners Health, Safety and Training, Oak Hill, USA, 2013.
[31] S. N. Ismail and al., "Research trends in mining accidents study: a systematic literature review," Safety Sci., vol. 143, no. 105438, p. 105438, 2021.
[32] E. J. Tetzlaff and al., "Safety culture: a retrospective analysis of occupational health and safety mining reports," Safety and Health at Work, vol. 12, no. 2, pp. 201-208, 2021.
[33] S. S. and al., "An assessment of mine methane mitigation and utilisation technologies," Prog. in Energy and Comb. Sci., vol. 31, no. 2, p. 123–170, 30 Mar. 2005.
[34] A. E. Dursun, "Statistical analysis of methane explosions in Turkey's underground coal mines and some recommendations for the prevention of these accidents: 2010–2017," Nat. Hazards, vol. 104, p. 329–351, Jul. 2020.
[35] Resmî-Gazete, "30 haziran 2012 tarihli ve 28339 sayılı resmî gazete," 30 June 2012. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2012/06/20120630-1.htm. [Accessed 24 Dec. 2023].
[36] Resmî-Gazete, "26 aralık 2012 tarihli ve 28509 sayılı resmî gazete," 26 Dec. 2012. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2012/12/20121226-11.htm. [Accessed 24 Dec. 2023].
[37] Resmî-Gazete, "29 mayıs 2013 tarihli ve 28661 sayılı resmî gazete," 29 May 2013. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2013/05/20130529-10.htm. [Accessed 24 Dec. 2023].
[38] Resmî-Gazete, "19 eylül 2013 tarihli ve 28770 sayılı resmî gazete," 19 Sept. 2013. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2013/09/20130919-3.htm. [Accessed 24 Dec. 2023].
[39] Resmî-Gazete, "24 eylül 2014 tarihli ve 29129 sayılı resmî gazete," 24 Sept. 2014. [Online]. Available:

https://www.resmigazete.gov.tr/eskiler/2014/09/20140924-2.htm. [Accessed 24 Dec. 2023].
[40] Resmî-Gazete, "23 nisan 2015 tarihli ve 29335 sayılı resmî gazete," 23 April 2015. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2015/04/20150423-3.htm. [Accessed 24 Dec. 2023].
[41] Resmî-Gazete, "24 mart 2016 tarihli ve 29663 sayılı resmî gazete," 24 March 2016. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2016/03/20160324-5.htm. [Accessed 24 Dec. 2023].
[42] Resmî-Gazete, "18 kasım 2017 tarihli ve 30244 sayılı resmî gazete," 18 Nov. 2017. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2017/11/20171118-26.htm. [Accessed 24 Dec. 2023].
[43] Resmî-Gazete, "24 mayıs 2018 tarihli ve 30430 sayılı resmî gazete," 24 May 2018. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2018/05/20180524-1.htm. [Accessed 24 Dec. 2023].
[44] P. C. ISO, "ISO 45001:2018 (F)," Int.l Org. for Stand., Geneva, Switzerland, 2018.
[45] U. M. and al., "Change in occupational health and safety management system: ISO 45001:2018," in 5th Inter. Proj. and Const. Manag. Conference (IPCMC2018), North Cyprus, 2018.
[46] Y. Zhang and al., "Relationship research between subjective well-being and unsafe behavior of coal miners," EURASIA Jour. of Math., Sci. & Tech. Edu., vol. 13, no. 11, pp. 7215-7221, 2017.
[47] S. Miranda and al., "An Investigation of learning needs in the mining industry," Edu. Sci., vol. 13, no. 10, p. 1036, 2023.
[48] N. Bilim and al., "Ülkemizdeki maden sektöründe meydana gelen iş kazası ve meslek hastalıklarının analizi," BEU Journal of Sci., vol. 7, no. 2, pp. 423-432, Nov. 2018.
[49] Q. Liu and al., "Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in china based on system dynamics," Safety Sci., vol. 111, pp. 224-233, 2019.
[50] K. Zhou and al., "Tripartite evolutionary game and simulation analysis of coal mining safe production supervision under the chinese central government's reward and punishment mechanism," Math. Problems in Eng., vol. 2021, p. 17, 2021.
[51] S. Şimşek and al., "İş sağliği ve iş güvenliği uygulamalarinda sensör kullaniminin incelenmesi," İAÜ journal, vol. 12, no. 1, pp. 41-53, 01 Jan. 2020.
[52] M. Rausand., Risk assessment: theory, methods, and applications, vol. Part 2, NJ, USA: John wiley & sons, Inc., 2011.