Jurnal Rekayasa Sistem Industri
ISSN 2339-1499 (*online*) – ISSN 0216-1036 (*print*)
Volume 15, Number 1, 2026
DOI: 10.26593/jrsi.v15i1.10088.93-105

Integrating Job Safety Analysis and Risk Assessment for Occupational Safety in Task-Based Sulfur Mining Activities

Esti Dwi Rinawiyanti[1*], Argo Hadi Kusumo[2], Fellychita Cindy Irawan[3], Dian Retno Sari Dewi[4]
[1,2,3] *Industrial Engineering Department, Universitas Surabaya, Surabaya, Indonesia*
[4] *Industrial Engineering Department, Universitas Katolik Widya Mandala Surabaya, Surabaya, Indonesia*

Abstract

Purpose: This study aims to identify occupational hazards, assess risk levels, and propose appropriate risk control measures in task-based sulfur mining activities, which are characterised by high-risk environmental and manual work conditions.
Methodology: A mixed qualitative–quantitative approach was employed. Data were collected through direct observation and semi-structured interviews involving five sulfur miners and one company representative at a sulfur mining site in Banyuwangi, Indonesia. Job Safety Analysis (JSA) was used to systematically identify hazards in each work step, while risk levels were evaluated using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method based on likelihood and severity scales adapted from AS/NZS 4360. Risk scoring was validated through iterative discussions with the participants.
Results: A total of 25 potential hazards were identified across key activities, including climbing, sulfur extraction, and material handling. Of these, 21 hazards were classified as medium risk and 4 as low risk. The main hazards include uneven terrain, steep pathways, toxic gas exposure, and manual material handling. Proposed control measures include engineering improvements (e.g., path levelling and guardrails), administrative controls (e.g., training and work procedures), and the use of personal protective equipment.
Conclusion: The integration of JSA and HIRARC effectively provides a structured approach for identifying and assessing risks in dynamic mining environments.
Originality: This study contributes by applying JSA–HIRARC integration in a non-controlled outdoor mining context, highlighting environmental and ergonomic risk factors that are often overlooked in previous studies.

Keywords: hazard identification; HIRARC; Job Safety Analysis (JSA); mining safety; risk assessment

1. Introduction

Occupational health and safety (OHS) play a critical role in protecting workers and improving workplace conditions, particularly in high-risk industries such as mining. Workplace accidents are often associated with unsafe actions and unsafe conditions, which can lead to injuries and negatively affect workers' health and productivity (Yulianti et al., 2023). Mining activities are widely recognized as hazardous occupations due to the high prevalence of workplace accidents and exposure to multiple physical, chemical, and ergonomic hazards (Dartey et al., 2022; Donoghue, 2004; Kyeremateng-Amoah & Clarke, 2015). Mineworkers are frequently exposed to long working hours, physically demanding tasks, and hazardous substances, which contribute to occupational injuries and health problems.

Sulfur mining represents one of the most hazardous forms of small-scale mining activities. Workers are exposed to multiple risk factors, including toxic gases (e.g., sulfur dioxide and hydrogen sulfide), steep and uneven terrain, extreme temperatures, and intensive manual material handling. These conditions not only increase the likelihood of accidents but also pose long-term health risks that may

**Corresponding Author: estidwi@staff.ubaya.ac.id*

Article Submitted January 29th, 2026; Revised April 2nd, 2026; Accepted April 10th, 2026

reduce workers' productivity and income stability. In particular, the dependence of miners' wages on daily output intensifies the impact of occupational hazards, as injuries or illnesses directly affect their livelihoods. In artisanal and small-scale mining, occupational risks are further intensified by labour-intensive processes, limited safety infrastructure, and exposure to environmental hazards such as dust, toxic gases, and heavy physical workloads (Schwartz et al., 2021).

Effective risk management is therefore essential to minimize occupational hazards and improve safety performance. Risk management in occupational safety involves hazard identification, risk assessment based on likelihood and severity, and the implementation of control measures to minimize workplace risks (Garto et al., 2023). In this context, task-based risk assessment approaches are particularly relevant, as they enable detailed identification of hazards at each stage of work activities.

Recent studies have increasingly applied Job Safety Analysis (JSA) and Hazard Identification, Risk Assessment, and Risk Control (HIRARC) to improve workplace safety performance. JSA enables systematic identification of hazards by decomposing work processes into sequential steps, while HIRARC provides a structured framework for evaluating risk levels and determining control strategies. Previous studies have shown that the integration of JSA and HIRARC can support hazard identification and improve risk assessment in industrial settings (Hamdani & Andesta, 2024; Sholichin et al., 2025; Sinaga et al., 2024).

However, existing studies have predominantly focused on controlled environments, such as manufacturing systems and workshop operations, where hazards are relatively stable and predictable (Bimantara et al., 2025; Giovanni et al., 2023). In contrast, outdoor mining environments present significantly higher levels of uncertainty due to environmental variability, including terrain instability, weather conditions, and exposure to hazardous substances. These dynamic conditions create a different risk profile that is not adequately addressed by existing studies.

Furthermore, previous studies have given limited attention to the combined influence of environmental and ergonomic factors in mining contexts (Dartey et al., 2022; Schwartz et al., 2021) despite their significant role in shaping occupational risk in labour-intensive and hazardous work environments. This limitation reveals a gap in the literature regarding the application of integrated risk assessment methods in highly dynamic and hazardous outdoor environments, particularly in sulfur mining activities.

To address this gap, this study applies an integrated JSA–HIRARC approach to sulfur mining activities in Indonesia. This study contributes by extending the application of these methods to a non-controlled, high-risk outdoor environment and by providing context-specific insights into hazard identification, risk assessment, and risk control strategies.

Based on the above background, the objectives of this study are:

1. To identify potential hazards in task-based sulfur mining activities using Job Safety Analysis (JSA);
2. To assess risk levels using the HIRARC method;
3. To propose appropriate risk control measures based on the hierarchy of controls.

To provide a theoretical foundation for achieving these objectives, the following section reviews relevant literature on occupational safety, risk management, and task-based hazard identification methods, particularly the integration of JSA and HIRARC.

2. Literature Review

2.1. Occupational Health and Safety in High-Risk Environments

Occupational health and safety (OHS) is a critical element in protecting workers, particularly in high-risk industries such as mining (International Labour Organisation, 2019). Workplace accidents are generally associated with unsafe conditions and unsafe actions (Yulianti et al., 2023). In mining environments, occupational risks are often intensified by hazardous conditions such as toxic gas exposure, unstable terrain, and physically demanding tasks.

In labour-intensive work environments, occupational risks are closely related to work processes and operational conditions, including human factors and the work environment (Sholichin et al., 2025). In small-scale mining operations, these risks may be further intensified by limited safety infrastructure. These conditions reflect the interaction between environmental and human factors, highlighting the need for more context-specific safety management approaches. Occupational safety and health in mining is influenced by a complex interaction of human, technological, and organisational factors, which collectively contribute to workplace accidents and injuries (Ajith et al., 2022). Previous studies have also highlighted those organisational activities, such as the use of contract labour, may negatively affect occupational safety outcomes due to reduced control over safety implementation (Jackson & Quinlan, 2024).

These studies highlight that occupational risks in high-risk environments are shaped by the interaction between environmental conditions and human factors. However, existing research has not sufficiently addressed how these factors interact in dynamic and labour-intensive outdoor settings, such as sulfur mining, where risk exposure is highly variable and context-specific.

2.2. Risk Management and HIRARC Approach

Risk management involves hazard identification, risk assessment, and the implementation of control measures to minimize workplace risks (Garto et al., 2023). Risk management has developed as a structured and systematic discipline that aims to understand, assess, and manage uncertainty in various operational contexts (Aven, 2016). Risk assessment also involves dealing with uncertainties that may influence decision-making processes in complex work environments (Aven & Zio, 2011).

The HIRARC method is used in occupational safety to identify hazards, assess risks regarding likelihood and severity, and determine appropriate control measures (Ihsan et al., 2016; Sinaga et al., 2024). HIRARC has been applied in various occupational settings to support hazard identification, risk assessment, and the implementation of control measures. The HIRARC method provides a systematic approach for identifying hazards, assessing risk levels based on likelihood and severity, and determining appropriate control measures to reduce workplace risks (Giovanni et al., 2023). The application of risk assessment approaches such as HIRARC has been shown to identify various levels of risk, ranging from low to high, and to support prioritization of control measures in industrial environments (Bimantara et al., 2025). Previous studies have shown that its application can improve safety practices and support the reduction of workplace accident risks in industrial environments (Putra et al., 2025; Sinaga et al., 2024).

Although the HIRARC method has been widely applied in structured industrial environments, its application in dynamic outdoor settings remains limited. This suggests a need to further explore how HIRARC can be adapted to contexts where environmental variability significantly influences risk exposure.

2.3. Job Safety Analysis (JSA) for Task-Based Hazard Identification

JSA is a method used to identify hazards by examining each step of a work process (Aprilliani et al., 2025; Ardinal, 2020). This method enables detailed identification of hazards associated with each stage of work activities and supports the development of preventive measures to reduce risk exposure.

In a task-based approach to hazard identification, as reflected in JSA, work activities are systematically decomposed into sequential steps, allowing hazards to be identified at each step of the work process. This approach emphasises the relationship between specific tasks, worker actions, and environmental conditions, enabling a more precise understanding of how and where hazards occur within a process. By focusing on task-level interactions, JSA can capture operational risks that may not be visible in broader system-level analyses.

Moreover, task-based hazard identification supports the development of targeted and context-specific control measures, as each identified hazard is directly linked to a specific work activity. This makes JSA particularly relevant for analysing labour-intensive processes, where risk exposure is closely associated with manual operations, physical workload, and environmental variability.

JSA has been applied in industrial and construction settings to support hazard identification and improve workplace safety (Ghasemi et al., 2023). This method allows hazards to be identified at each step of the work process, making it suitable for labour-intensive activities involving manual handling. However, its application has mostly been reported in relatively structured work environments, where processes are more stable and predictable.

This highlights the need for further investigation to understand how JSA can be applied in dynamic and non-controlled environments, where work processes are less predictable, and hazard conditions are more variable.

2.4. Integration of JSA and HIRARC

The integration of JSA and HIRARC has been applied to enhance occupational risk assessment. JSA focuses on identifying hazards at the task level, while HIRARC evaluates the associated risks and determines appropriate control measures, resulting in a more comprehensive analysis (Hamdani & Andesta, 2024; Sinaga et al., 2024). In this integration, JSA enables a detailed breakdown of work activities into sequential steps, allowing potential hazards to be identified systematically at each stage of the process. Meanwhile, HIRARC complements this process by providing a structured framework for evaluating the likelihood and severity of identified hazards, thereby supporting the prioritization of appropriate control measures. The combination of these methods creates a more holistic approach by linking task-level hazard identification with risk evaluation and control planning.

Specifically, several studies have reported that integrating JSA and HIRARC can enhance hazard identification and support the development of more effective risk control strategies, particularly in industrial environments (Putra et al., 2025; Sholichin et al., 2025). This integration also allows for a more comprehensive assessment by capturing hazards that may not be identified when using a single method. Furthermore, it improves the alignment between identified hazards and corresponding control measures, thereby strengthening decision-making in occupational safety management. However, this integrated approach has been predominantly applied in structured industrial environments, where work processes are relatively stable and well-defined.

Despite the demonstrated effectiveness of integrating JSA and HIRARC in industrial contexts, limited studies have examined their combined application in dynamic and non-controlled environments, highlighting a gap in their contextual adaptability.

2.5. Comparison with Other Risk Assessment Methods

Other risk assessment methods are also used in occupational safety and engineering contexts. Failure Mode and Effects Analysis (FMEA) is applied to identify potential failure modes and evaluate their effects on system performance (Stamatis, 2023). Hazard and Operability Study (HAZOP), on the other hand, is used to analyse process deviations and identify potential hazards in complex engineered systems (Kletz, 1999). These methods are particularly effective in highly mechanized environments, where risks are associated with system reliability and process interactions.

These approaches are primarily designed for system-oriented risk analysis, where hazards are linked to equipment, processes, and technical failures. However, in task-based and labour-intensive environments such as mining, risks are more closely related to human activities and environmental conditions rather than system failures. In such contexts, hazards often emerge from dynamic work processes, physical workload, and environmental variability, which require a more task-oriented perspective.

Therefore, methods such as JSA and HIRARC are considered more suitable for capturing task-specific hazards and dynamic risk exposure. This comparison indicates that while methods such as FMEA and HAZOP are suitable for system-based risk analysis, task-based approaches such as JSA and HIRARC are more appropriate for analysing risks in labour-intensive and environmentally dynamic activities such as mining.

2.6. Research Gap and Contribution

Even though previous studies have demonstrated that the integration of JSA and HIRARC can improve workplace safety, these studies are generally conducted in industrial environments such as manufacturing and construction (Hamdani & Andesta, 2024; Sinaga et al., 2024). Limited research has explored their application in outdoor and high-risk environments, such as sulfur mining, where hazard variability is significantly higher and less predictable.

This limitation is important because risk characteristics in outdoor environments differ fundamentally from those in controlled industrial settings. In such environments, hazards are influenced by dynamic factors such as terrain conditions, weather variability, and exposure to hazardous substances, which may alter both the likelihood and severity of risks. As a result, methods validated in stable industrial contexts may not fully capture the complexity of risk exposure in these settings.

Furthermore, existing studies primarily focus on hazard identification within structured industrial settings, with limited attention to environmental variability and context-specific risks in outdoor work environments (Ghasemi et al., 2023). This indicates a gap in the literature regarding the application of integrated risk assessment methods in dynamic and hazardous outdoor environments.

In addition, there is limited understanding of how integrated approaches, such as JSA–HIRARC, can be adapted to account for the interaction between environmental and ergonomic risk factors in labour-intensive outdoor activities. This highlights the need for context-specific applications that go beyond conventional industrial settings.

Therefore, this study addresses this gap by applying the JSA–HIRARC approach in sulfur mining activities. The contribution of this study lies in extending the application of these methods to a non-controlled environment and providing context-specific insights into hazard identification, risk assessment, and risk control strategies.

3. Methodology

This study adopts a mixed qualitative–quantitative approach to analyse occupational hazards and risks in sulfur mining activities (Creswell & Creswell, 2018). The mixed-method approach was selected to enable a comprehensive understanding of the research problem by combining qualitative insights from field observations and interviews with quantitative risk assessment using a structured scoring system. This approach allows both contextual interpretation of hazards and systematic evaluation of risk levels.

3.1. Research Setting and Participants

The study was conducted at a sulfur mining area located in East Java, Indonesia. The mining activities are labour-intensive and include climbing, sulfur collection, and material handling, which expose workers to various occupational hazards.

The participants were selected using purposive sampling to ensure that respondents had direct experience with the mining activities under study (Creswell & Creswell, 2018). The participants consisted of five sulfur miners and one company representative. The miners were actively involved in daily mining operations and had practical knowledge of workplace hazards, while the company representative provided managerial perspectives on safety practices and risk control implementation.

3.2. Data Collection Instruments and Procedures

Data were collected using several instruments and procedures as follows:

a. Direct observation: observations were conducted along the mining route, covering all major work activities, including preparation, climbing, sulfur collection, and material handling. An observation checklist was used to systematically identify unsafe conditions, unsafe actions, and environmental hazards encountered during mining activities (Creswell & Creswell, 2018).
b. Semi-structured interviews: semi-structured interview guidelines were used to collect data from miners and the company representative. The interviews focused on identifying experienced hazards, frequency of incidents, and perceived severity of risks. This method allowed in-depth exploration while maintaining consistency across the participants (Kallio et al., 2016).
c. Field documentation: field notes and visual documentation were used to support data accuracy and provide contextual understanding of working conditions (Yin, 2018).

The combination of these data collection methods enables a comprehensive understanding of workplace conditions by integrating observational evidence, participants' experiences, and contextual documentation, thereby strengthening the accuracy and completeness of the collected data.

3.3. Data Analysis Methods

The analysis was conducted at two main stages. First, JSA was used to systematically break down each work activity into sequential steps and identify potential hazards associated with each step (Roughton & Crutchfield, 2015). The analysed work activities include climbing, sulfur collection, and material handling performed by miners.

Second, the HIRARC method was applied to assess risk levels by evaluating the likelihood and consequence of each identified hazard. The integration of JSA and HIRARC enables a comprehensive analysis from hazard identification to risk evaluation and control.

The likelihood scale used in this study was adapted from commonly applied risk matrix approaches in occupational safety, as reflected in standards such as AS/NZS 4360 (Standards Australia & Standards New Zealand, 2004), and was defined according to the observed frequency of incidents (e.g., daily, weekly, or occasional occurrences). The consequence scale was similarly adapted to reflect the severity of potential impacts, ranging from minor injuries to severe or extreme outcomes.

Risk scoring was performed using a semi-quantitative risk matrix by combining likelihood and severity values to determine the risk level of each identified hazard. This approach allows for a systematic classification of risks and supports the prioritisation of appropriate control measures based on their relative significance.

3.4. Validation and Reliability

The scoring process was conducted through discussions with miners and management to incorporate practical experience in the field (Yin, 2018). This approach allows the integration of empirical observations with participants' experiential knowledge, thereby improving the contextual accuracy of the assigned risk ratings.

To improve consistency and reduce subjectivity, the assigned ratings were discussed and validated through iterative consultation among the participants. During this process, differences in judgment regarding likelihood and consequence levels were reviewed and reconciled through collective agreement, ensuring that the final ratings reflected a shared understanding of workplace conditions.

In addition, triangulation was achieved by comparing data obtained from direct observations, interviews, and field documentation. This combination of multiple data sources strengthens the credibility of the findings and reduces potential bias in the assessment process. Overall, this validation procedure enhances the reliability and validity of the risk assessment results.

3.5. Development of Risk Control Measures

Based on the results of hazard identification and risk assessment, risk control recommendations were developed for each identified hazard. Each recommendation was formulated by considering the specific characteristics of the hazard, its associated risk level, and the working conditions in the mining environment (Garto et al., 2023; Giovanni et al., 2023). These recommendations were structured according to the hierarchy of controls, including engineering controls, administrative controls, and personal protective equipment (PPE), to ensure a systematic and prioritised approach to risk mitigation (OSHA, 2023). Engineering controls were proposed to address hazards at the source, administrative controls focused on improving work procedures and worker behaviour, and PPE was recommended as a protective measure where higher-level controls were not feasible (Sinaga et al., 2024).

The proposed measures were further evaluated through discussions with management to assess their feasibility, practicality, and suitability within the operational constraints of the mining context. This evaluation ensured that the recommended controls were not only theoretically appropriate but also applicable in real working conditions.

The application of the above methods resulted in a comprehensive identification of hazards and risk levels, which are presented and analysed in the following section.

4. Results

A hazard is defined as a condition, action, or potential that can cause harm to people, property, processes, or the environment (Supriyadi & Ramdan, 2017). Hazard identification is a systematic process used to identify potential hazards within workplace activities (Ramli, 2010; Supriyadi & Ramdan, 2017). Hazard analysis typically focuses on work activities with higher exposure to potential hazards. These activities can be analysed using the JSA, a technique used to identify hazards before accidents or incidents occur and serves as an important tool in safety management (Roughton & Crutchfield, 2015).

As shown in Figure 1, there are eight stages of miners' work, starting from preparation for climbing to sulfur weighing. Regarding interviews with miners and direct observations along the climbing route, several hazards and potential risks were identified, as listed in Table 1. The identified risks were categorized as inherent risks, referring to risks present before any additional control measures are implemented.

4.1. Risk Analysis

Risk refers to the effect of uncertainty on objectives, while risk management involves coordinated activities to direct and control an organisation's risks. It is described as a structured process that supports decision-making by providing a deeper understanding of risks and their potential impacts (AS/NZS 4360:2004).

In this study, risk analysis was conducted using the HIRARC method (Sholichin et al., 2025) to systematically evaluate the risks associated with each identified hazard. Following hazard identification using the JSA method, risk assessment was performed for each work activity by analysing the likelihood of occurrence and the severity of its consequences.

Figure 1. Eight work stages of miners' activities

Table 1. Hazard identification and inherent risk assessment of sulfur mining activities

Work Stage	Cause of Hazard	Potential Hazard	Inherent Risks		Risk Level
			Likelihood	Consequence	
Preparation of climbing equipment and trolley (1)	Preparation of climbing equipment and trolley	Fingers pinched by the brake handle	4	2	Medium
Journey after preparation to the post (2)	Uneven and slippery road	Slipping and spraining	3	2	Medium
	Tree roots sticking out of the ground	Tripping and falling	4	2	Medium
	Tall trees around	Hit by falling trees	1	4	Low
Climbing from the post to the round hut (3)	Steep and uphill road	Tripping	3	2	Medium
	Uneven road	Slipping and spraining	4	2	Medium
	Cliff without barriers	Falling into a ravine	1	5	Medium
	Tree roots sticking out of the ground	Tripping and falling	3	2	Medium
Climbing from the round hut to the crater (4)	Steep and narrow road	Slipping and spraining	4	2	Medium
	Uneven road	Tripping and falling	3	2	Medium
	Cold air temperature	Hypothermia	1	4	Low
	Landslide-prone cliff	Buried by a landslide	1	4	Low
Journey from the summit to the crater base for sulfur collection (5)	Rocky, uneven road	Tripping and falling	4	2	Medium
	Narrow path	Breathing difficulty	1	4	Low
	Sulfur gas	Eye irritation	3	2	Medium
	Lifting a load too heavy	Back pain	3	2	Medium
Return trip from the crater to the sulfur weighing area (6)	Steep and descending road	Tripping and falling	3	2	Medium
	Uneven, slippery road	Slipping and spraining	3	2	Medium
	Cliff without barriers	Muscle injury	3	2	Medium
Moving sulfur from the trolley to the scale (7)	The trolley moves when the load is lifted	Muscle injury	3	2	Medium
	Body position when lifting sulfur	Back pain	3	2	Medium
Moving sulfur from the scale to the truck (8)	Body position when lifting sulfur	Back pain	3	2	Medium
		Muscle injury	3	2	Medium
	Sulfur dust	Eye irritation	3	2	Medium
	Load too heavy	Hit by a falling load	2	3	Medium

The likelihood scale used in this study was adapted from commonly applied occupational safety risk matrices (Standards Australia & Standards New Zealand, 2004), defined as Rare (1), Unlikely (2), Moderate (3), Likely (4), and Almost Certain (5). The consequence scale was also adapted from AS/NZS 4360 (Standards Australia & Standards New Zealand, 2004) and modified to accurately reflect the specific operational risks associated with sulfur mining activities, ranging from Negligible (1) to Extreme (5). Notably, the term "moderate" refers to the likelihood scale, whereas "medium" is used to describe the resulting risk level classification.

Risk assessment was performed by combining likelihood and consequence values to determine the overall risk rating for each identified hazard. This process enables the classification of risk levels and supports the prioritisation of appropriate control measures. The risk rating framework used in this study is illustrated in Figure 2.

The risk assessment results for each work stage, based on inherent risk conditions, are presented in Table 1. The likelihood and consequence ratings were determined based on miners' experiences and field observations. The results show that, among the 25 identified hazards, four are categorized as low risk and 21 as medium risk.

4.2. Proposed Risk Control Measures

As shown in Table 2, several risk control measures were proposed for each identified hazard based on the risk assessment results. These recommendations were developed by considering the nature of each hazard, its associated risk level, and the specific working conditions in sulfur mining activities. These conditions are characterized by dynamic environmental exposure and labour-intensive tasks.

The proposed measures aim to address both the sources of hazards and the exposure of workers by combining engineering improvements, administrative interventions, and the use of personal protective equipment. This integrated approach ensures that risk reduction is not only reactive but also preventive, targeting hazards at different levels of control.

These recommendations are described as follows:

a. Wear gloves, such as Kevlar gloves, when using a trolley to reduce the risk of impact injuries.
b. Use personal protective equipment (PPE), such as safety shoes with non-slip outsoles, to prevent slips and sprains.
c. Level the climbing route by adding and compacting soil on uneven areas.
d. Regularly inspect and remove hazardous trees along the climbing route while using appropriate PPE.
e. Install guardrails and warning signs in areas with steep ravines.
f. Use PPE such as scarves, earplugs, wool, and thermal clothing to prevent hypothermia.
g. Install retaining walls in landslide-prone areas.
h. Use respirator masks to reduce exposure to sulfur gases.
i. Use safety glasses to prevent eye irritation.
j. Apply correct body posture during lifting activities.
k. Perform stretching and take adequate rest to prevent muscle injuries.
l. Avoid exceeding physical limits during work activities.

		CONSEQUENCES				
		Negligible (1)	Minor (2)	Moderate (3)	Major (4)	Extreme (5)
LIKELIHOOD	Almost Certain (5)	Medium	Medium	High	High	High
	Likely (4)	Low	Medium	High	High	High
	Moderate (3)	Low	Medium	Medium	High	High
	Unlikely (2)	Low	Low	Medium	Medium	Medium
	Rare (1)	Low	Low	Low	Low	Medium
		(1)	(2)	(3)	(4)	(5)

Figure 2. Risk analysis matrix (adapted from AS/NZS 4360:2004)

Table 2. Proposed risk control measures and residual risk assessment

Work Stage	Potential Hazard	Risk Level	Hazard Control Recommendation	Residual Risks Likelihood	Consequence	Risk Level
Preparation of climbing equipment and trolley (1)	Fingers pinched by the brake handle	Medium	a	2	2	Low
Journey after preparation to the post (2)	Slipping and spraining	Medium	b	2	2	Low
	Tripping and falling	Medium	c	2	2	Low
	Hit by falling trees	Low	d	1	3	Low
Climbing from the post to the round hut (3)	Tripping	Medium	c	2	2	Low
	Slipping and spraining	Medium	b	2	2	Low
	Falling into a ravine	Medium	e	1	3	Low
	Tripping and falling	Medium	e	1	3	Low
Climbing from the round hut to the crater (4)	Slipping and spraining	Medium	b	2	2	Low
	Tripping and falling	Medium	c	2	2	Low
	Hypothermia	Low	f	1	3	Low
	Buried by a landslide	Low	g	1	3	Low
Journey from the summit to the crater base for sulfur collection (5)	Tripping and falling	Medium	c	2	2	Low
	Breathing difficulty	Low	h	1	3	Low
	Eye irritation	Medium	i	2	2	Low
	Back pain	Medium	j	2	2	Low
Return trip from the crater to the sulfur weighing area (6)	Tripping and falling	Medium	c	2	2	Low
	Slipping and spraining	Medium	b	2	2	Low
	Muscle injury	Medium	k	2	2	Low
Moving sulfur from the trolley to the scale (7)	Muscle injury	Medium	k	2	2	Low
	Back pain	Medium	j	2	2	Low
Moving sulfur from the scale to the truck (8)	Back pain	Medium	j	2	2	Low
	Muscle injury	Medium	k	2	2	Low
	Eye irritation	Medium	i	2	2	Low
	Hit by a falling load	Medium	l	2	2	Low

These measures reflect different levels of intervention in risk control, ranging from eliminating or reducing hazards at their source to minimizing worker exposure. Engineering controls primarily target environmental and physical hazards, particularly those related to terrain instability and unsafe pathways. Administrative controls focus on improving work practices and reducing ergonomic risks associated with manual handling activities, whereas PPE serves as an additional layer of protection when higher-level controls are not fully feasible.

In terms of the hierarchy of controls (OSHA, 2023), recommendations (c), (d), (e), and (g) are categorized as engineering controls. Recommendations (j), (k), and (l) are identified as administrative controls, while the remaining measures fall under PPE.

4.3. Comparison of Hazard Control Ratings

A comparison was conducted between inherent risk and residual risk levels based on the proposed control measures, as presented in Tables 1 and 2. Initially, among the 25 identified hazards, four were categorized as low risk and 21 as medium risk, as presented in Table 1. After implementing the proposed control measures, all hazards were reduced to a low-risk category, as shown in Table 2. This reduction implies that the recommended control measures are effective in mitigating the identified risks by lowering the likelihood of occurrence, reducing the severity of potential consequences, or both. In particular, engineering controls, such as improving pathways and installing guardrails, directly address environmental hazards, while administrative controls and the use of PPE help reduce exposure and improve worker safety behaviour.

The results also demonstrate that medium-level risks dominate across most work stages in sulfur mining activities, indicating continuous exposure to hazardous conditions. This finding suggests that, even though individual risks may not be classified as high, their cumulative and repetitive nature can still pose significant safety concerns, particularly in labour-intensive and physically demanding work environments.

Furthermore, the comparison between inherent and residual risk highlights the importance of implementing context-specific control measures that are aligned with actual working conditions. This ensures that risk reduction is not only theoretically effective but also practically applicable in dynamic mining environments.

5. Discussion

The findings demonstrate that medium-level risks dominate across work stages, directly supporting the study objective of assessing task-based risk levels in sulfur mining, which indicates continuous exposure to hazardous conditions. These risks are primarily associated with uneven terrain, steep pathways, and manual handling activities. Although high-risk hazards were not identified, the persistent exposure to medium-level risks represents a significant safety concern, as cumulative exposure can substantially increase the likelihood of accidents and long-term physical strain.

The dominance of medium-level risks reflects the inherent characteristics of sulfur mining, which relies heavily on manual labour and is conducted in a dynamic outdoor environment. Unlike controlled industrial settings, mining activities are influenced by environmental variability, including terrain conditions and exposure to hazardous gases. These factors contribute to a higher likelihood of incidents, resulting in a concentration of medium-risk classifications. These findings are consistent with previous research indicating that mining-related hazards are strongly associated with physical workload and exposure to hazardous environments (Dartey et al., 2022). Furthermore, in small-scale mining contexts, the limited implementation of structured safety management systems further increases workers' vulnerability to occupational hazards (Schwartz et al., 2021).

Compared to previous studies conducted at manufacturing and workshop environments, where risks are generally associated with machinery and process-related factors (Garto et al., 2023; Hamdani & Andesta, 2024; Sinaga et al., 2024), this study reveals a different risk pattern. Environmental and ergonomic hazards emerge as the dominant risk factors in sulfur mining activities. This finding highlights the importance of environmental exposure and physical workload in shaping occupational risks in mining contexts.

The application of the proposed control measures resulted in a consistent reduction of all identified hazards to low-risk levels. This outcome confirms the effectiveness of the recommended interventions, particularly those targeting environmental improvements and the use of appropriate personal protective equipment. The effectiveness of these measures can be attributed to their alignment with the hierarchy of controls, where engineering and administrative interventions directly address the primary sources of risk.

From a theoretical perspective, this study extends the application of integrated JSA and HIRARC methods into dynamic and non-controlled environments. While previous research has largely focused on structured industrial systems, this study demonstrates that these methods remain effective when adapted to environments characterised by high variability and uncertainty. This contributes to expanding the applicability of task-based risk assessment frameworks.

From a practical perspective, the findings provide actionable and context-specific recommendations for improving occupational safety in sulfur mining. The proposed control measures are not only effective in reducing risk levels but also feasible to implement, as confirmed through discussions with management. This highlights their potential to support safer and more sustainable mining practices.

Nevertheless, this study has several limitations. First, the relatively small number of participants may limit the generalizability of the findings. Second, the risk assessment relied partly on subjective judgment, although validation efforts were conducted. Third, environmental variables such as weather conditions and gas concentration levels were not quantitatively measured. Future research should incorporate larger samples and objective environmental measurements to enhance the robustness of the analysis.

According to these findings and their implications, the following section summarises the main conclusions of the study and highlights key contributions and recommendations.

6. Conclusion

This study aimed to identify potential hazards, assess risk levels, and propose appropriate risk control measures in sulfur mining activities using the integrated Job Safety Analysis (JSA) and Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach.

The results show that sulfur mining activities involve multiple hazards, particularly those related to uneven terrain, exposure to sulfur gas, and manual material handling. A total of 25 hazards were identified, of which four were categorized as low risk and 21 as medium risk under inherent conditions. These findings suggest that miners are consistently exposed to moderate levels of risk across various work stages.

The application of risk control measures based on the hierarchy of controls demonstrates strong potential to reduce risk levels. Engineering controls, such as levelling climbing routes and installing guardrails, along with administrative controls and the use of PPE, effectively address the primary sources of risk. The comparison between inherent and residual risk levels shows that the proposed measures can reduce all identified hazards to low-risk categories.

Overall, this study confirms that the integration of JSA and HIRARC provides an effective and structured approach for identifying hazards and managing risks in sulfur mining activities. The findings highlight the importance of implementing context-specific safety measures that address environmental and ergonomic risk factors in dynamic outdoor work environments.

While this study provides valuable insights into hazard identification and risk assessment in sulfur mining activities, future research is recommended to validate the proposed risk control measures through field implementation and to incorporate quantitative environmental measurements for more robust risk evaluation.

References

Ajith, M. M., Ghosh, A. K., & Jansz, J. (2022). Contributing effects of individual characteristics, behavioural and job-related factors on occurrence of mining-related injuries: A systematic review. *A Journal of Prevention, Assessment & Rehabilitation (WORK), 71*(1), 87–117. https://doi.org/10.3233/WOR-205227

Aprilliani, C., Frinaldi, A., Lanin, D., Rembrandt, Yasril, A. I., Audia, W., & Febrina, C. (2025). Identifikasi potensi bahaya dengan metode JSA (job safety analisis) pada bengkel las. *Buletin Kesehatan Lingkungan Masyarakat, 44*(4). https://doi.org/10.31983/keslingmas.v44i4.14113

Ardinal, Y. (2020). *Analisa keselamatan kerja: Job safety analysis*. Rhuekamp Indonesia.

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 253*(1), 1–13. https://doi.org/10.1016/j.ejor.2015.12.023

Aven, T., & Zio, E. (2011). Some considerations on the treatment of uncertainties in risk assessment for practical decision making. Reliability Engineering & System Safety, 96(1), 64–74. https://doi.org/10.1016/j.ress.2010.06.001

Bimantara, A., Irianingtyas, R., Chahyadhi, B., & Rahmania, N. E. N. (2025). Analysis of occupational safety and health risk management in metal industry production areas using the hira method. *Nurse and Health: Jurnal Keperawatan, 14(*2), 10–20. https://doi.org/10.36720/nhjk.v14i2.874

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.

Dartey, E., Monney, I., Sarpong, K., & Kuffour, C. (2022). Occupational health hazards among large-scale gold mineworkers in Ghana. *Occupational Diseases and Environmental Medicine, 10*, 149–166. https://doi.org/10.4236/odem.2022.103012

Donoghue, A. M. (2004). Occupational health hazards in mining: An overview. Occupational Medicine, 54(5), 283–289. https://doi.org/10.1093/occmed/kqh072

Garto, T., Syarif, A. A., & Harahap, U. N. (2023). Identifikasi potensi bahaya pada pekerja dengan menggunakan metode job safety analysis (JSA) dan HIRARC di home industri emi craft. *Industrial Engineering System and Management Journal (IESM), 4*(1), 19–31. https://doi.org/10.22303/iesm.4.1.2023.19-31

Ghasemi, F., Doosti-Irani, A., & Aghaei, H. (2023). Applications, shortcomings, and new advances of job safety analysis (JSA): Findings from a systematic review. *Safety and Health at Work, 14*(2), 153–162. https://doi.org/10.1016/j.shaw.2023.03.006

Giovanni, A., Fathimahhayati, L. D., & Pawitra, T. A. (2023). Risk analysis of occupational health and safety using hazard identification, risk assessment and risk control (HIRARC) method (case study in PT Barokah Galangan Perkasa). *IJIEM - Indonesian Journal of Industrial Engineering and Management, 4*(2), 198–211. https://doi.org/10.22441/ijiem.v4i2.20398

Hamdani, M. I., & Andesta, D. (2024). Analisis potensi bahaya menggunakan metode JSA dan HIRARC untuk mengurangi angka kecelakaan kerja pada area workshop fabrikasi PT. ABC. *G-Tech: Jurnal Teknologi Terapan, 8*(2), 887–895. https://doi.org/10.33379/gtech.v8i2.4076

Ihsan, T., Edwin, T., & Irawan, R. O. (2016). Analisis risiko K3 dengan metode HIRARC pada area produksi PT Cahaya Murni Andalas Permai. *Jurnal Kesehatan Masyarakat Andalas (JKMA)*, *10*(2), 179–185. https://doi.org/10.24893/jkma.v10i2.204

International Labour Organisation. (2019). *Safety and health at the heart of the future of work: Building on 100 years of experience.*

Jackson, H., & Quinlan, M. (2024). Contract labour in mining and occupational health and safety: A critical review. *The Economic and Labour Relations Review, 35*(3), 576–613. https://doi.org/10.1017/elr.2024.32

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing, 72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Kletz, T. A. (1999). *Hazop and Hazan: Identifying and assessing process industry hazards* (4th ed.). IChemE.

Kyeremateng-Amoah, E., & Clarke, E. E. (2015). Injuries among artisanal and small-scale gold miners in Ghana. International Journal of Environmental Research and Public Health, 12(9), 10886–10896. https://doi.org/10.3390/ijerph120910886

Nurmawanti, I., Widaningrum, S., & Iqbal, M. (2015). Identifikasi dan pengendalian keselamatan dan kesehatan kerja (K3) dengan menggunakan metode HIRARC untuk memenuhi requirement OHSAS 18001: 2007 (klausul 4.4.6) di PT. Beton Elemenindo Perkasa. *Proceeding of Engineering,* 4568–4575.

U.S. Occupational Safety and Health Administration (OSHA). (2023). Identifying hazard control options: The hierarchy of controls. https://www.osha.gov/sites/default/files/Hierarchy_of_Controls_02.01.23_form_508_2.pdf

Putra, S. M., Wiryajati, I. K., & Adnyani, I. A. S. (2025). Dealing with occupational health and safety practices using JSA with HIRARC method. *International Journal of Informatics and Computation (IJICOM), 7*(1). https://doi.org/10.35842/ijicom

Ramli, S. (2010). *Sistem manajemen keselamatan dan kesehatan kerja OHSAS 18001*. Dian Rakyat.

Roughton, J., & Crutchfield, N. (2015). *Hazard analysis: A guide for voluntary compliance and beyond* (2nd ed.). Butterworth-Heinemann.

Schwartz, F. W., Lee, S., & Darrah, T. H. (2021). Review of the scope of artisanal and small-scale mining worldwide, poverty, and the associated health impacts. *GeoHealth, 5*(1), 1-15. https://doi.org/10.1029/2020GH000325

Sholichin, M. D., Primasanti, Y., Nugrahadi, B., Indtriastiningsi, E., & Trisna, A. O. (2025). Analisa risiko K3 dengan metode job safety analysis (JSA) dan risk assessment pada proses mesin sizing di PC GKBI Medari Sleman. *Jupiter: Publikasi Ilmu Keteknikan Industri, Teknik Elektro Dan Informatika, 3*(2), 40–58. https://doi.org/10.61132/jupiter.v3i2.781

Sinaga, G., Septarini, I. R., & Sembiring, A. C. (2024). Implementasi job safety analysis dan hazard identification risk assessment and determining control untuk meminimalkan bahaya kecelakaan kerja di stasiun rebusan pabrik PTPN III PKS Rambutan (Persero). *Jurnal Ilmiah Teknik Industri Prima (JURITI PRIMA), 7*(2), 7-14. https://doi.org/10.34012/juritiprima.v7i2.5645

Stamatis, D. H. (2023). *Failure mode and effect analysis: FMEA from theory to execution* (2nd ed.). ASQ Quality Press.

Standards Australia, & Standards New Zealand. (2004). *Risk management guidelines: Companion to AS/NZS 4360:2004*. Standards Australia International; Standards New Zealand.

Supriyadi, & Ramdan, F. (2017). Identifikasi bahaya dan penilaian risiko pada divisi boiler menggunakan metode hazard identification risk assessment and risk control (HIRARC). *Journal of Industrial Hygiene and Occupational Health, 1*(2), 161-177. https://doi.org/10.21111/jihoh.v1i1.752

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Yulianti, R., Apriniyadi, M., Hartami, P. N., Suliestyah, S., Palit, C., & Pattiruhu, D. L. (2023). Penerapan keselamatan dan kesehatan kerja (K3) di lingkungan kerja industri. *Jurnal Abdi Masyarakat Indonesia (JAMIN), 5*(2), 129-134. https://doi.org/10.25105/jamin.v5i2.17363