Investigating of mining accidents involving trapped mine workers: a human factors-based method for analysis and classification (a case study of an illegal gold mining in banyumas, indonesia)

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Abstract. The number of illegal mining sites in Indonesia is estimated to be around 2.700, with the number of mining accidents reaching 104 in the period 2013-2021. The number of accidents is high and often causes fatalities. This research focuses on reactivating illegal mining in Pancurendang as a source of livelihood for the local community. We focused on analyzing the causes of the trapping of 8 miners in Pancurendang Mine. It revealed more than 110 mining pits, with 30 active mining pits in the mine. The methodology we used was the Human Factor Analysis Classification System (HFACS) framework to process the data. Data collection was conducted by direct observation at the incident site, interviews with miners and the national rescue agency, as well as a comprehensive literature review. Improvements were proposed in a hierarchical analysis based on the HFACS Framework. The analysis showed that the incident was caused by several factors, such as skill-based error, physical environment, absence of supervisor, organizational physics and societal. The results of this study highlight the need for the development of professional mine organizations, safer working environments and responsibility for safety in small-scale gold mining, and provide valuable insights in the development of geotechnical engineering.

1 Introduction

In essence [1] work has a meaning as an economic activity, differences in the meaning of work occur in men and women [2], where men tend to seek value in work compared to seeking security, this is one of the reasons for choosing to work in illegal mines with high income. Occupational health and safety should be a top priority for company management and workers because it is directly related to humans as resources, so as to increase productivity and reduce costs [3]. By providing a safe working environment, it can reduce the risk of accidents and injuries [4].

According to the Indonesian Construction Safety Expert Association on its website pakki.org [5] and the Underground Mine Training Center on its website bdtbt.esdm.go.id,

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mining is a field of work that has a high risk of work accidents and occupational diseases. Therefore, clear and complete OHS provisions and Standard Operating Procedures are required, including artisanal mining as described in Law No. 11 of 1967 [6]. However, according to the Ministry of Energy and Mineral Resources, there are more than 2,700 illegal mining sites spread throughout Indonesia [7]. This is very detrimental to the state, in addition to the absence of Non-Tax Revenue (NTR) obtained, illegal mining is also not in accordance with the Regional Spatial Plan which has an impact on hampering regional development. In addition, illegal mining is very detrimental in terms of the environment, this is indicated by the number of abandoned excavations which only become puddles that cannot be utilized and can pollute the surrounding water levels, where in the samples tested, heavy metals such as manganese, iron, mercury, chromium, cobalt, zinc, arsenic, selenium, cadmium, barium, lead, and thallium were found that exceeded the threshold [8]. In terms of worker health, illegal mining is also very detrimental to miners, where most of them do not care about occupational safety and health.

Based on data from the Ministry of Energy and Mineral Resources, there were 104 accidents from 2013-2021, this number decreased by 28.28% compared to the previous year of 145 incidents [9]. This certainly needs to be of more concern, because accidents in mining often cause fatalities. One of the unlicensed mines is located in Pancurendang Village, Ajibarang District, Banyumas Regency [7]. On July 25, 2023, a tragic incident occurred where 8 miners drowned and were buried in a mining pit at a depth of ± 40 meters [10], [11]. Rescue efforts by the National Search and Rescue Agency (SAR) came to nothing [12]. As a result of the incident, the local government officially closed the mining operation.

It was revealed that the soil structure at illegal mining in Ajibarang was not considered at the time of opening the hole, besides that the space in the hole is very diverse, but dominated by a narrow space measuring less than 1 x 1 meter as seen in Figure 1. The excavation of the hole is also close to the flow of confined aquifer, which is the flow of water in the soil that moves between the high-pressure soil that can be seen in Figure 3. The discharge of stagnant water in the pit is estimated to be very high, this is illustrated in Figure 2 with unsuccessful suction efforts despite using a pump with a power of 30 liters per second. Based on statements from observations of local miners, the death of miners is also indicated to be caused by the presence of uninterrupted high voltage that does not have an automatic breaker in case of a short circuit [13].

The Human Factors Analysis Classification System (HFACS) was used as an analytical tool, which is still relevant in some industries to examine workplace accidents caused by operators and human error. HFACS is a method to investigate an incident through in-depth analysis of operator error and upstream organization [14]. HFACS was chosen because it is able to account for latent and active failures developed into a framework [15], compared to other methods. Thus, through accident investigation [16] preventive measures can be taken and it becomes an important component of the safety management system.

This research is intended to be able to analyze and produce solutions to the illegal mining problem in Pancurendang Village, Ajibarang District, Banyumas Regency. The expected solution is a Standard Operating Procedure that is then used in mining operations, with the aim of mining continuing to run as community mining managed by the people or local management bodies by fulfilling the applicable legality aspects in accordance with the law.

Fig. 1. Mine hole size

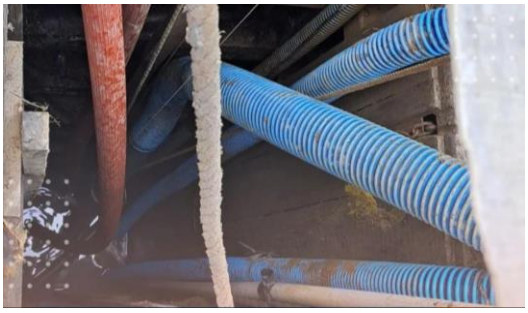

Fig. 2. Mine pit drain process using pump

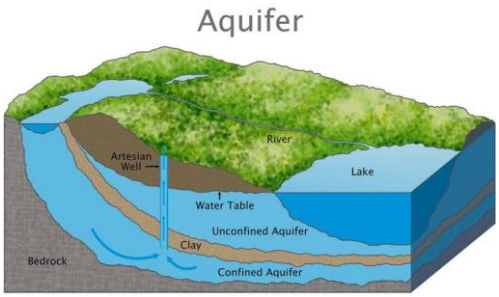

Fig. 3. Aquifer type

Fig. 4. Number of mining accidents in Indonesia (2013-2021)

2 Method

This research methodology explains the stages of research used to solve problems, so that this research is more focused and structured in identifying existing problems.

2.1 Preliminary study

Preliminary studies include HFACS (Human Factors Analysis and Classification System) literature studies and studies of work accidents in the mining sector. Furthermore, by determining the formulation of the problem that mining that does not have a feasibility permit is very high risk of work accidents. The purpose of this research is to identify the root causes of accidents in illegal mines and provide applicable improvement recommendations.

2.2 Data collection

Data collection was carried out by conducting on-site observations and then conducting direct interviews with miners. The questions asked were about causal factors, chronology of an accident related to human factors, and work environment conditions [17]. Other data collected were the results of identification carried out by the Energy and Mineral Resources Office regarding the condition and landscape of the land used for mining as well as the alleged causes of work accidents. Interview results and press releases from SAR related to unsafe conditions and actions taken by miners became supporting data. In addition, literature studies using published official national media became additional data.

2.3 Data processing

From the data collected, it will then be analyzed using the HFACS model framework, [18] this model was chosen because it considers detailed taxonomy to analyze the overall system and not just each individual. The data processing stages include reading the collected incident report data, identifying causes, classifying causes according to the HFACS model for each level. Furthermore, data processing is carried out with a quantitative approach to see the percentage of factors for the occurrence of incidents at each level, and finally by concluding the main causes of accidents.

2.4 Discussion and recommendation

The final result of the analysis is to provide applicable recommendations to prevent similar work accidents from occurring. With improvements and preventive efforts from the factors that have an impact, it can be an objective suggestion for improvement, providing this advice using a top-down approach, starting from the top level to the bottom level, namely direct miners.

3 Result and discussion

3.1 HFACS

HFACS is a method to investigate an incident through in-depth analysis of operator errors and upstream organization [14]. HFACS is able to explain latent and active failures developed into a framework [15]. So that through accident investigation [16] preventive measures can be taken and it becomes a component of the work safety management system.

The Swiss Cheese Model developed [19] is the basis of the HFACS Model which consists of four main levels of human error itself 1) Unsafe Act 2) The Precondition for Unsafe Act 3) Unsafe Supervision 4) Organizational Influence [17]. Because the HFACS model is not yet a perfect model for accident investigation, the HFACS model requires modification [20]. The modification is done by adding level 5) External Factor. The following is an explanation of each level of HFACS:

3.1.1 Unsafe act

Based on Figure 5, the most dominating causal factor of the trapped miners incident is skill-based errors, which are included in the error category in the unsafe acts layer. Skill-based errors account for 40% of the causes of the incident, followed by perceptual errors that fall into the contraventions category with a percentage of 20%. Which means that the main mistakes of miners in committing unsafe acts in the mine are based on skill-based errors and perceptual errors. Examples of actions that can be classified as skill-based errors are miners' lack of knowledge about the potential map of existing mineral resources, as well as the special skills that miners must have in matters such as drilling and excavating arbitrarily. On the other hand, other examples of other action errors that fall under perceptual errors are ignoring the possibility of work accidents and misperceptions in the training of new miners.

This highlights the importance of improving miners' understanding and skills in overcoming skill-based errors and perceptual errors to reduce the incidence of miner entrapment at mining sites.

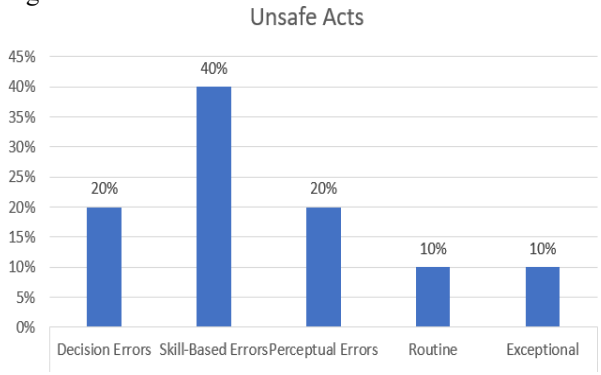

Fig. 5. Percentage of Level 1 Accident Causes Unsafe Acts

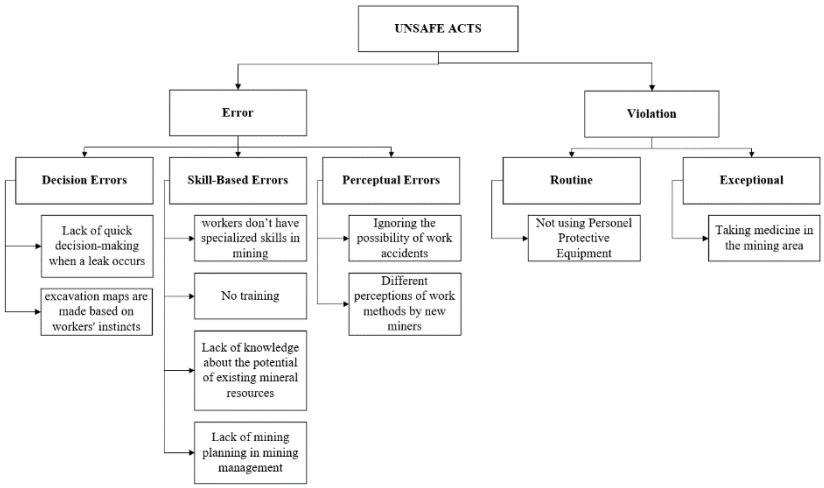

Fig. 6. HFACS Level 1 Unsafe Acts

At this level, recommendations will focus on improving the quality of each individual miner. Efforts for a structured miner recruitment system, specialized skills training for miners, working using complete PPE, mining and OHS education, and OHS cultural awareness must be presented and implemented before miners go directly into mining, to reduce the risk of work accidents and occupational diseases (AOD).

3.1.2 Precondition for Unsafe Act

Based on Figure 7, the most dominant causal factor of the incident is Physical Environment with a percentage of 38%, which is included in Environmental Factors in Precondition for Unsafe Acts. From the results of the identification carried out, there are 6 factors in this physical environment, including the most obvious is the vegetation of land for mining in the form of wet rice fields, besides that the surrounding environment is in the form of hills with a slope level of 15-30% to >70% [21]. From this identification, the land in Pancurendang Village itself has a high level of landslide vulnerability, making it very risky for mining activities to be carried out without prior mitigation.

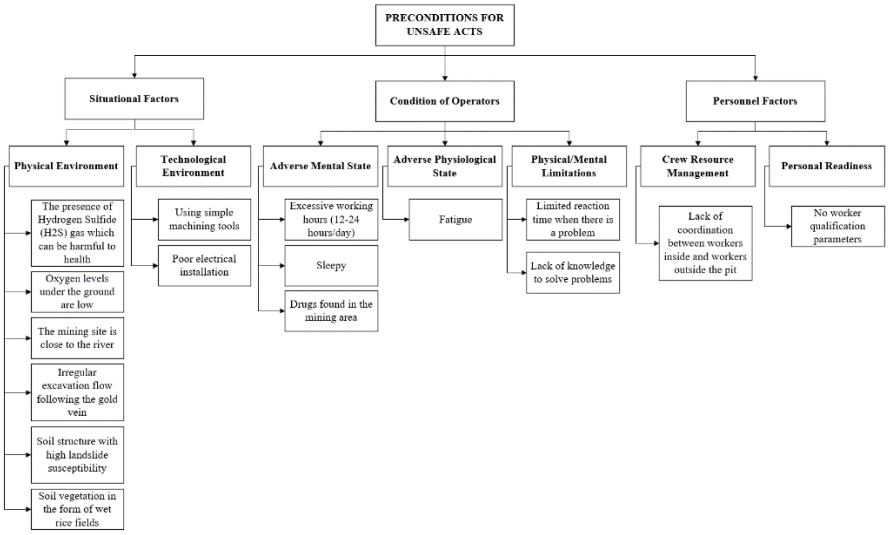

Fig. 7. HFACS Level 2 Precondition For Unsafe Acts

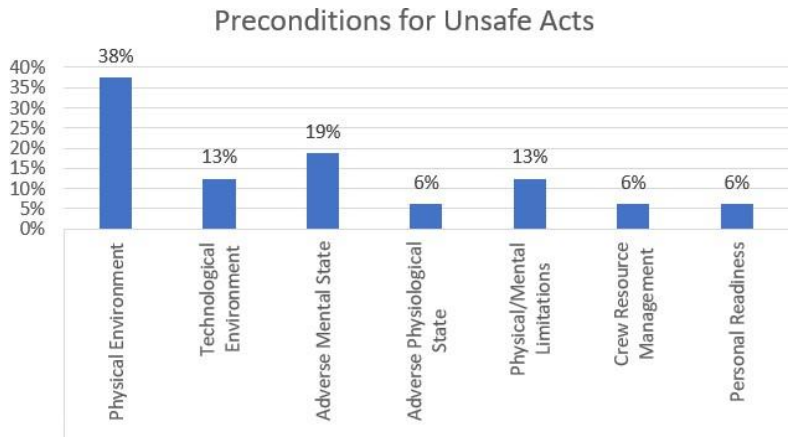

Fig. 8. Percentage of Level 2 Accident Causes Preconditions for Unsafe Acts

Recommendations from this level are more focused on proper installation of utilities and detailed and thorough mapping of the excavation of the mining site, to prevent things like power lines being scattered and dangerous, miners inhaling hydrogen sulfide gas, inadequate oxygen levels, and understanding the soil structure to prevent landslides at the mining site, so that supporting infrastructure can be built effectively and in accordance with the needs of miners.

3.1.3 Unsafe supervision

Based on Figure 9, the causes of the unsafe supervision layer are the absence of adequate supervisors, improper operational planning, and supervisor violations in neglecting to supervise miners' performance and safety. Therefore, the percentage of the Unsafe Supervision layer reaches 100%, which indicates that the absence of supervisors at the site In the absence of supervisors in the mine, it can be said that the control and monitoring duties of all aspects of the project carried out have been significantly neglected, including the safety of miners.

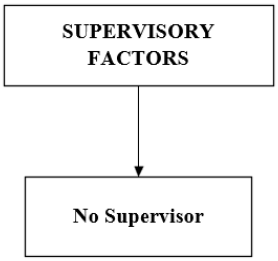

Fig. 9. HFACS Level 3 Unsafe Supervision

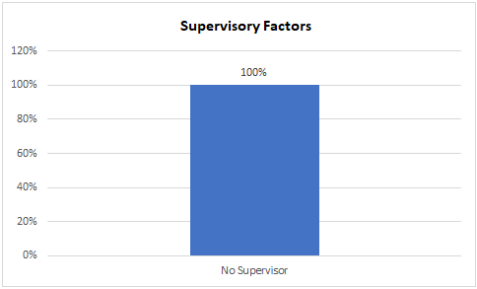

Fig. 10. Percentage of Level 3 Accident Causes Unsafe Supervisor

The recommendation at this level is the establishment of a structured hierarchy that includes supervision of operations and ongoing management. With an organized hierarchical structure, it is easy to implement workforce training, disaster evacuation procedures, and oversight of OHS implementation in mining operations.

Possible solutions include improving the training and assignment of competent supervisors and strengthening adequate operational planning, while ensuring that monitoring miners' performance and safety is a top priority at every stage of a mining project.

3.1.4 Organizational influence

Based on Figure 11, organizational process is the strongest factor affecting accidents at 43%, followed by organizational culture and resource management at 29%. This finding confirms

that the main problem in the mining environment lies in the structure and operational processes of the organization.

It is evident that unclear organizational structures and the absence of official policies have led to mining operations that do not comply with proper procedures and even become illegal. As a result, attention to miners' occupational safety and health is often neglected, while the main focus is more on avoiding investigations and legal actions that may be taken by the authorities.

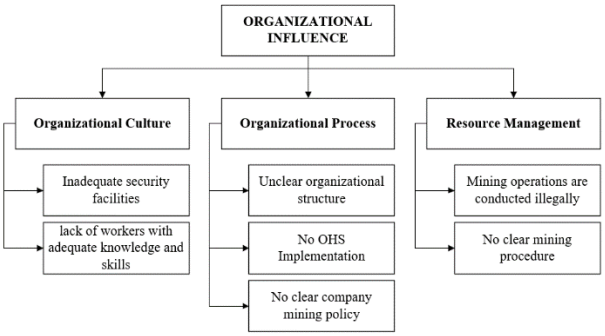

Fig. 11. HFACS Level 4 Organizational Influence

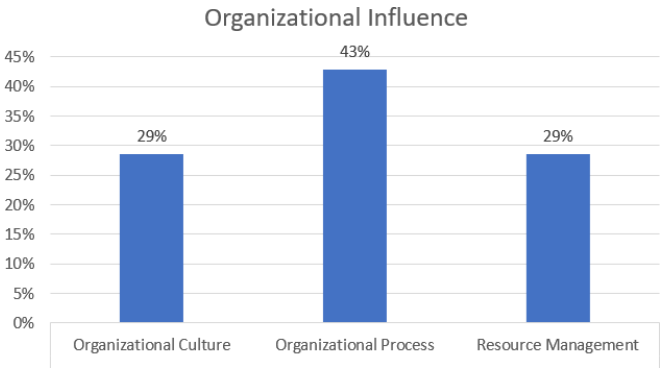

Fig. 12. Percentage of Level 4 Accident Causes Organizational Influence

Organizational factors play an important role in this incident, as the unclear organizational structure makes the division of responsibilities as well as the reporting hierarchy or miners' instructions ill-defined. This vague division of responsibilities meant that there was no person or body to oversee compliance with the miner's OHS safety standards. Miners walking alone in each pit makes communication ineffective as happened in this incident, so responses to disaster situations tend to be slow and not clearly coordinated on how to deal with them. The recommendation is to establish a clear body or individual, in accordance with the license, responsible for the activities of the miners. Although there are different financiers on each

land, they can act as one stakeholder united in one clear organization, so that miners can be gathered into one organization.

3.1.5 External factor

At the 5th additional level based on Figure 13, social factors are the strongest factor influencing the occurrence of accidents at 56% and followed by regulatory factors with a value of 44%. This confirms that social factors greatly influence work accidents in the community gold mining area in Pancurendang village.

The regulatory factor violates Article 4 paragraph 1 of Law No. 3 of 2020 [22] concerning Mineral and Coal Mining because the gold mined is not taxed and controlled by local communities without state intervention, violates Article 5 of Law No. 3 of 2020 [22] concerning Mineral and Coal Mining because the owner of the capital empowers mining for personal gain without considering the national interest, violates Article 35 Paragraph 3 of Law No. 13 of 2003 [23] concerning Labor. 13 of 2003 [23] on Manpower due to capital owners not employing miners by not providing both physical and mental protection, and violating Article 15 paragraph 1 of Law No. 11 of 1967 [24] on Basic Mining Provisions due to capital owners not having mining authorization as they should.

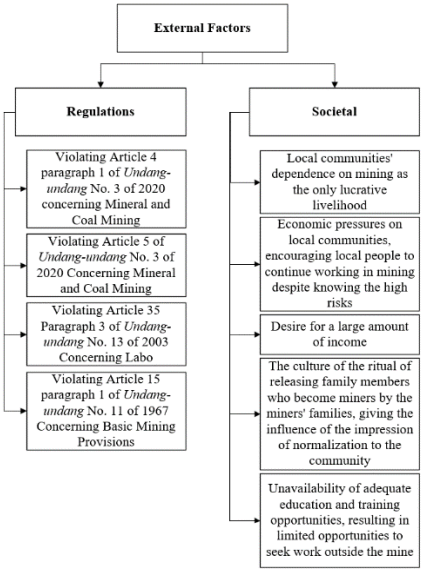

Fig. 13. HFACS Level 5 External Factor

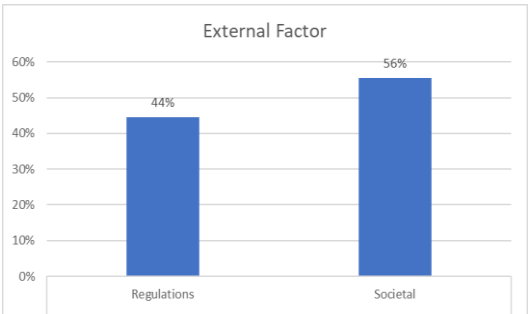

Fig. 14. Percentage of Level 5 Accident Causes External Factor

3.2 Mining excavation plan

At the time of the accident, BASARNAS Banyumas was at the forefront of the rescue process of 8 workers who were trapped in a gold mine pit in Pancurendang Village. From BASARNAS observations during the rescue process, a plan of the pit was produced based on information from one worker who survived the accident. The plan describes the suspected location of water leakage from a confined aquifer from a pit near the main pit.

This artisanal mining pit was built in a community rice field area located near the Tajur River. The soil type in the upper layer tends to be muddy and is a walking land that is very susceptible to landslides because it is close to the river flow. The initial leakage of the Distressed Aquifer started from the excavation of the Dondong Main Hole, the workers in this excavation managed to save themselves but did not provide information about the leakage to miners in other excavations. When the miners in medium Bogor Main Hole.

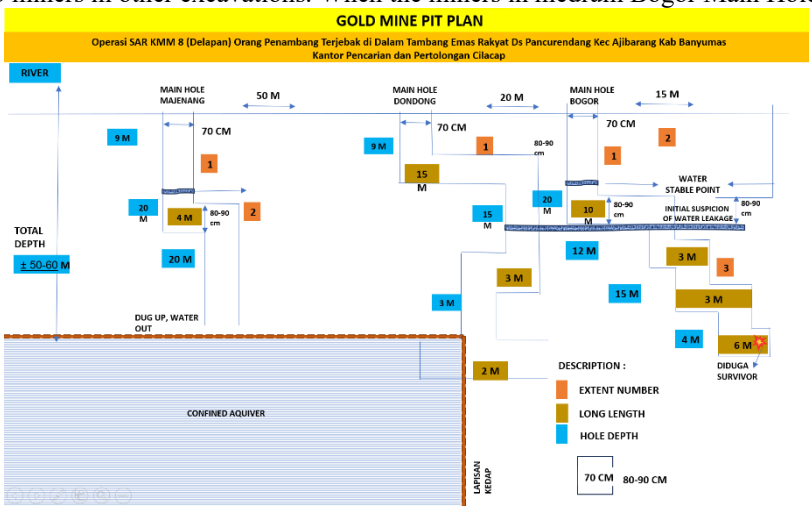

Fig. 15. Plan of People's Gold Mine Pit in Pancurendang Village

3.3 Suggestion

Based on the literature used with the conditions obtained from observations and interviews, suggestions can be made in the form of a hierarchical structure in accordance with how operations run by involving supervisors using an operational system in accordance with established standards. The establishment of a supervisory system that is suggested is also formed by a body that manages mining. The mining management body must be able to adapt to mining operations, this is to maintain the status of mining so that it remains a community mine. The management body can be formed independently from the surrounding community or from the local government. In the management body, there are supervisors who can come from the government or previous miners who have been given training. The supervisor is tasked with overseeing mining operations in accordance with legal SOP's, as well as the implementation of OHS by miners.

Table 1. Solution suggestion

No.	Level	Dominant causes	Contributing factors	Suggestion
1	Unsafe Acts	Skill-Based Errors	• No special mining skills • There is no skill training • Lack of knowledge about the minerals • Lack of mine planning and management	• Establish a recruitment system for new miners (preventive) • Provide development program to improve the miner's skills (corrective)
2	Precondition for Unsafe Act	Physical Environment	• Presence of Hydrogen Sulfide Gas (H2S) that can be harmful • Low oxygen rate underground • Mining site near the river • The mining flow does not follow the gold line • High-risk ground structure • Land vegetationin the form of moist soil	• Use of filter masks for hydrogen sulfide mentoring (preventive) • Availability of better air circulation (preventive) • Analytical approach for mining site before the operation runs (preventive)
3	Unsafe Supervision	Supervisory Factors	• Lack of supervisory system	• Establishment of a proper supervisory system that includes dedicated mine supervisors (preventive) • Establishment of local operational supervisory system (preventive)
4	Organizational Influence	Organizational Process	• Unclear organization structure • Lack of Occupational Safety	• Optimum and effective internal organization

			and Health implementation	coordination (preventive) • Establish a proper organization hierarchy (preventive) • Management training from the mine site owners (preventive)
5	External Factors	Societal	• Dependence of local communities on mining as their only significant source of income • Economic pressure on local communities, encouraging them to continue working in mining, despite knowing the high risks involved • Desire to earn a large amount of income • The culture of ritual release of family members who become miners by the miners' families, giving the impression of normalization to the community • Unavailability of adequate education and training opportunities, resulting in limited opportunities to seek employment outside of mining.	• Conducting socialization to the local community about the negative impacts on the environment, health, and economy (preventive) • Improve supervision and law enforcement against illegal mining (preventive) • Encourage economic development in sectors other than mining for the surrounding community (preventive) • Restoring the environment that has been affected by mining (corrective) • Diversify and optimize natural resources in a sustainable and responsible manner (corrective).

4 Conclusion

From the results of the analysis using the HFACS method, it was found that at the unsafe acts level the biggest factor was skill-based error by 40%, level two precondition for unsafe acts the biggest factor was the physical environment by 38%, at the unsafe supervision level there was no supervisor found so that the percentage reached 100%. The biggest factor in organizational influence is the organizational process at 43%, and society is the most influential factor at level 5, namely external factors with a percentage of 56%.

Based on the percentage amount that has been obtained, the unsafe supervision level is the most dominant factor. This shows that the urgency for supervisors is very high, therefore, the proposed solution is to create a clear hierarchical body by involving supervisors to

supervise operations in accordance with existing Standard Operating Procedures. The structure that is formed must be able to adapt to the operations that run as people's mining runs.

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