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Research Article

Risk analysis of gold processing in artisanal and small-scale gold mining in Bolaang Mongondow Regency, North Sulawesi, Indonesia

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Abstract

Gold processing at artisanal and small-scale gold mining (ASGM) in Indonesia is inherently risky due to the high severity and likelihood of accidents causing serious injury. The objectives of this study were to identify hazards, assess risks, and determine risk control measures in the ASGM location at Imandi Village, East Dumoga District, Bolaang Mongondow Regency, North Sulawesi Province. The method used was Hazard Identification Risk Assessment and Risk Control (HIRARC). The determination of work stages and identification of hazards was carried out through observation at 14 ASGM units and interviews with 14 informants consisting of 6 mining workers and 8 ASGM business owners. The risk assessment was carried out by observing and interviewing 8 experts as informants selected from health and environmental scientists, various offices of the Government Bolaang Mongondow Regency, and non-government institutions. The results showed that the stage of gold processing work in ASGM consists of 13 sources of hazards that can pose 16 risks. The obtained risk assessment results showed that 19% were low risk, 31% moderate risk, 25% high risk, and 25% very high risk caused by exposure to mercury through the gold ore burning process with a risk value of 25. The identified risk control measures were PPE (personal protective equipment) 43%, administrative controls 14%, engineering controls 14%, substitution 21%, and elimination 7%. Realistic risk controls that can be applied in ASGM are a combination of administrative controls and PPE.

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Introduction

Artisanal and small-scale gold mining (ASGM) is the largest mercury user in the world, which continues to grow rapidly throughout the world in line with the demand and rising prices of precious metals and the profitability of gold in developing countries (Obiri et al. 2016; Selin et al., 2018). The ASGM sector has contributed greatly to global economic growth both directly and indirectly because it has provided employment for about 14-19 million people and granted about 20%-30% of the earth's gold production

(Basu et al., 2015; Steckling et al., 2017). Likewise, in Indonesia, the number of illegal ASGM continues to grow, with an amount of 2645 locations spread throughout 30 provinces; it is estimated at least 250,000 miners and around 300,000 to 500,000 people are affected by ASGM activities located in remote areas (Grita et al., 2012).

ASGM's business is in a dilemma because it provides instant economic benefits, but at the same time as a trade-off that sacrifices environmental damage and contributes to the safety and health of mining workers (Basu et al., 2015). Profits obtained from the sale of gold become a pull factor for the community to continue doing ASGM business because it is driven by poverty, lack of socio-economic alternatives, and waiting time for the agricultural planting season (Oramah et al., 2015). People working in the mining sector are at high risk; thus, effective control measures are urgently needed to protect workers' health (Bonsu et al., 2017). Accidents at ASGM in developing countries vary in severity depending on the type of risk experienced by miners. Compared to miners in large-scale gold mining, ASGM miners experience a much higher risk of work-related accidents and fatalities (Kyeremateng et al., 2015; Cossa et al., 2021). The Occupational Health and Safety (OHS) risk is further exacerbated because most ASGM is illegal, so it is not covered by binding regulations and programs related to public health protection (Gibb et al., 2014; Zaharani and Salami, 2015).

Based on a global study, working conditions in ASGM are very worrying, causing hazards including dust, chemicals, and noise, as well as ergonomic, psycho-social, environmental, and biological hazards that threaten the safety and health of mining workers and the surrounding environment (Ralph et al., 2018). The results of studies in several countries in Africa, such as Ghana and Congo, confirm the occurrence of work accidents in ASGM caused by materials, use of heavy equipment, tunnel collapses, and exposure to toxic gases resulting in death (Elenge et al., 2013; Calys-Tagoe et al., 2017). Several contributing factors have been reported, including OHS regulations, law enforcement, education, training, functioning infrastructure, and adequate equipment support not experienced by mining workers in ASGM, causing increased work accidents (Wilson et al., 2015; Bansah et al., 2017).

ASGM is inherently risky, but due to research specialization, little research has been done to integrate the identified risks with the natural and social dimensions resulting from gold processing activities (Benedict et al., 2015; Rajaee et al., 2015; Obiri et al., 2016). The global review of OHS confirms that no studies comprehensively discuss occupational health interventions in ASGM (Tsang et al., 2019). In Indonesia, there are often cases of work accidents in ASGM, but they have not been documented scientifically through studies; hence the data are not suitably published. Thus, research is needed, primarily related to risk analysis in the gold processing process in ASGM. The risk analysis can be an alternative solution to overcome occupational health and safety problems in ASGM. Risk analysis is part of the application of OHS, which aims to prevent, manage, and control hazards in the workplace (ILO, 2011). A risk analysis of ASGM activities must be carried out to estimate risks because apart from being a source of livelihood, ASGM activities are also a source of danger that impacts environmental and health damage (Mestanza-Ramón et al., 2022).

This study aimed to identify hazards, assess risks, and determine risk control measures in the ASGM location at Imandi Village, East Dumoga District, Bolaang Mongondow Regency, North Sulawesi Province.

Materials and Methods

The method used was Hazard Identification Risk Assessment and Risk Control (HIRARC) which is the basis of the Occupational Health and Safety Management System (Supriyadi et al., 2015). Risk analysis using the HIRARC method is divided into three stages, hazard identification, risk assessment, and risk control (NIOSH, 2015). Hazard identification was carried out to find out the potential hazards that exist at each stage of work. The source of the hazard can come from materials, tools, or systems (FU, 2021). A risk assessment was carried out to determine the level of risk so that it can determine risk control measures to reduce the impact or consequences of hazards arising from each stage of work through the hierarchy of control (Purnama, 2015).

Determination of work stages and identification of hazards was carried out through observation at all ASGM locations with a total of 14 ASGM units and interviews with 14 informants consisting of 6 mining workers and 8 ASGM business owners in Imandi Village, East Dumoga District, Bolaang Mongondow Regency, North Sulawesi Province. The area of Imandi Village is 20.94 $km^{2,}$ with a population of 4,220 people (BPS, 2020). Mining workers and owners of ASGM businesses live in Imandi Village, within a 10 m to 2 km radius. The type of interview was a semi-structured interview with open-ended questions. A list of core questions for miners included what types of work stages do you do? What are the types of hazards that can occur when processing gold? How do you squeeze amalgam? How do you burn gold ore? What type of PPE is used? The core questions for ASGM business owners included: Why is the gold processing location behind your house? How is the waste disposal in your ASGM? Do you know the impact of using mercury on the environment and human health? What are your efforts to prevent the hazards posed by gold processing? The same question that was asked by both mining workers and mining business owners is what are the stages of gold processing?. The map of the East Dumoga District, which includes the Imandi Village as the research location, can be seen in Figure 1, and the coordinates of the 14 ASGM units in the Imandi Village are presented in Table 1. Once a potential hazard is identified, a risk assessment is conducted based on Australian standards/New Zealand risk management standards (SAI Global, 2007). There are two parameters used in the risk assessment, the level of probability of a hazard or the frequency of occurrence of a hazard, and the severity of the hazard. Tables 2, 3, and 4 show the risk assessment scales used.

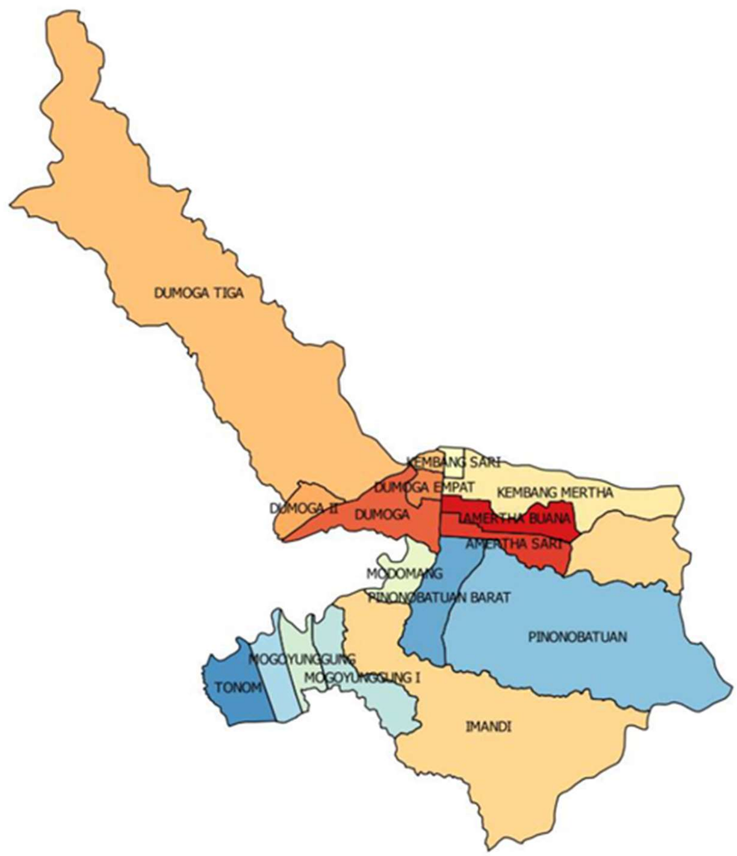

Figure 1 Map of East Dumoga District.

Table 1. The coordinates of the 14 ASGM units.

Unit of ASGM	Coordinates
1	0.583057, 124.070905 (0°34'59.0"N 124°04'15.3"E)
2	0.581984, 124.071658 (0°34'55.1"N 124°04'18.0"E)
3	0.575311, 124.064154 (0°34'31.1"N 124°03'51.0"E)
4	0.581702, 124.069569 (0°34'54.1"N 124°04'10.5"E)
5	0.576850, 124.069269 (0°34'36.7"N 124°04'09.4"E)
6	0.574394, 124.068811 (0°34'27.8"N 124°04'07.7"E)
7	0.574578, 124.071115 (0°34'28.5"N 124°04'16.0"E)
8	0.576233, 124.065856 (0°34'34.4"N 124°03'57.1"E)
9	0.576178, 124.064517 (0°34'34.2"N 124°03'52.3"E)
10	0.573663, 124.072376 (0°34'25.2"N 124°04'20.6"E)
11	0.577033, 124.072731 (0°34'37.3"N 124°04'21.8"E)
12	0.574662, 124.076420 (0°34'28.8"N 124°04'35.1"E)
13	0.578767, 124.075160 (0°34'43.6"N 124°04'30.6"E)
14	0.580530, 124.077244 (0°34'49.9"N 124°04'38.1"E)

Table 2. The likelihood level scale on the AS/NZS 4360: 2004 standard.

Level	Criteria	Description
1	Rare	Almost never happened
2	Unlikely	Rarely happening
3	Possible	Can happen every once in a while
4	Likely	Often occur
5	Almost Certain	Can happen any time

Source: Likelihood criteria adopted from standard AS/NZS 4360: 2004.

Table 3. The severity level scale on the AS/NZS 4360: 2004 standard.

Level	Criteria	Description
1	Insignificant	No injury and/or no disease caused and/or no effect on the environment, small financial loss
2	Minor	Minor injury and/or illness with mild symptoms and/or small effect on the environment, small financial loss
3	Moderate	Moderate injury and/or chronic illness requires medical treatment and/or moderate effect on the environment, sizeable financial loss
4	Major	Serious injury and/or chronic illness require medical treatment and/or serious and long-term environmental damage, big loss, production disruption
5	Catastrophic	Fatal and/or chronic diseases require serious medical treatment and/or very serious and long-term environmental damage, huge losses and very broad impacts, cessation of all activities

Source: Severity criteria adopted from standard AS/NZS 4360: 2004.

Table 4. Matrix of risk assessment on AS/NZS 4360: 2004 standard.

Likelihood	Severity				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	M	H	VH	VH	VH
Likely (4)	L	M	H	VH	VH
Possible (3)	L	M	H	VH	VH
Unlikely (2)	L	L	M	H	VH
Rare (1)	L	L	M	H	H

Source: Risk assessment matrix adopted from AS/NZS 4360: 2004 standard.

The risk assessment was carried out by observation by the researcher and interviews with eight experts as informants selected from university faculty members in the health field and environmental field, the Government of Bolaang Mongondow Regency consisting of the environment office, health office, trade and energy mineral resources office, and non-government institution. The core question to the experts is how likely and how severe is the risk to mining workers at each stage of work? Each expert assessed the likelihood and severity of each potential hazard that had been identified in the previous stage. Then, the average likelihood and severity level were calculated using the formulas in equation (1) and equation (2) so that the level of risk at each stage of work can be obtained by multiplying the average likelihood and the average severity level. The results of the average likelihood and average severity were rounded to make it easier to calculate the level of risk. The level of risk is described through a risk assessment matrix based on the AS/NZS 4360: 2004 standard, as shown in Table 4, with four levels, low (L), medium (M), high (H), and very high (VH). The results of the risk rating become the main consideration for prioritizing the actions needed to manage the risks at each stage of work. The risk with a very high (VH) rating becomes a priority for immediate risk control action (NIOSH, 2015).

$$\text{Average Likelihood Level} = \frac{\Sigma \text{ Likelihood Level}}{\text{Number of Respondents}} \quad \ldots\ldots (1)$$

$$\text{Average Severity Level} = \frac{\Sigma \text{ Severity Level}}{\text{Number of Respondents}} \quad \ldots\ldots (2)$$

Immediate action was taken through the Risk Control Hierarchy, which is sorted by decreasing effectiveness, starting from elimination (physically removing the hazard), substitution replacing the hazard), engineering controls (isolating people from hazard), administrative controls changing the way people work), and PPE (protect the worker with personal protective equipment) (NIOSH, 2015). Risk control measures should always start with the highest risk order (Wijaya et al., 2015; FU, 2021).

Results and Discussion

Hazard identification

Summary of interview with the miners

The main purpose of interviewing mining workers is to find out the hazards posed by each stage of gold processing work directly from them. A summary of the results of interviews with mining workers is presented in Table 5.

Table 5. Summary of the interview results of mining workers.

Theme of questions	Informant	Resumes and quotes from the interview
Stages of work	Miners 1, 2, 3, 4, 5, and 6	The stages of work consist of crushing, grinding, washing and waste disposal, squeezing, and burning
Stages of work performed	Miners 1, 3, 4, 5, and 6	Performed all stages of work, such as crushing, grinding, washing, squeezing, and burning
	Miner 2	“I rarely do squeezing”
Type of hazards or risks	Miner 1	“Crushed by a stone crusher machine”
	Miner 2	“My eyes are exposed to dust”
	Miner 3	“Inhaled dust during the crushing process”
	Miner 4	“Slipped and fell down”
	Miner 5	“Exposed to noise from crusher and trommel machines”
	Miner 6	“My hands pinched in the crusher machine”
Way to squeeze amalgam	Miners 1, 2, 3, 4, 5, and 6	Manually using a filter cloth, by hand, and without using gloves
Way to burning gold ore	Miners 1, 2, and 4	Fire temperature around 300°C with compressor and without wearing a mask
	Miners 3 and 6	With a very hot fire, the mouth and nose are covered with clothes, and not wearing glasses
	Miner 5	“Using fire, sometimes I am wearing a mask, and the facility has a chimney”
Type of PPE used	Miners 2, 3, and 4	Without using PPE at all
	Miner 6	“Sometimes I am wearing a mask during the burning ore process only”
	Miners 1 and 5	Wearing gloves, boots, and glasses

Based on the results of interviews with the miners in Table 5, all informants stated that the stages of gold processing work carried out consisted of crushing, grinding, washing and waste disposal, squeezing, and burning. The same work stages were also confirmed by the ASGM owners, as stated in Table 6. Therefore, the essence of the stages of gold processing work in ASGM is summarized into five stages: stone crushing, grinding, washing and waste disposal, squeezing, and burning (Lusantono and Hantari, 2020).

1. Stone Crushing Stage
   Ores from the mine are pounded until crushed using a stone crusher into smaller sizes, such as grains with an average of 50 mm.
2. Grinding Stage
   The grained ores are put into a trommel along with water to be grounded for the first 4 hours. Furthermore, for the amalgamation process, 300 mL of mercury is poured into the trommel, and one trommel is able to process around 40 kg of ore, then be grounded for the second 4 hours; the total grinding process lasts for 8 hours. The grinding process also serves to separate gold ore from other impurities.
3. Washing and waste disposal stage
   The amalgam is washed to clean off the soil by spraying water into the trommel and separating the water and silt from the wet amalgam that settles under the trommel due to differences in specific gravity. Amalgam is collected in a bucket to be filtered. Some of the water and liquid waste suspected of containing residual mercury from the washing stage is discharged directly into the river and partly collected into settling ponds. An amalgam is an alloy of mercury with other metals, in this case, a metal alloy of gold and mercury (Au-Hg), and amalgamation is the art of making or forming amalgams.

4. Squeezing stage
   The washed amalgam is then squeezed with a filter cloth by hand. The result of squeezing is a liquid containing residual mercury, and gold which also contains residual mercury is left in the filter cloth to be burned. Liquids containing residual mercury are collected for reuse in further gold processing.
5. Burning stage
   The amalgam-burning process is carried out using a retort. The purpose of the burning process is to remove the remaining mercury that is still left in the amalgam. The residual mercury in the amalgam will evaporate into the air.

Generally, the informants perform all stages of work. The hazards identified by each informant were different, including being crushed by a stone crusher machine. The crushing stage allows the stone to hit the limbs and cause bruising to mining workers (Elenge et al., 2013). The eyes of miners are exposed to dust; however, based on observation, stone flakes can enter the eye. Although the likelihood is unlikely, the severity leads to fatal accidents, resulting in eye trauma. If there is damage to the cornea, the scar resulting loss of vision because it blocks or distorts light entering the eyes (Wilson, 2012). Dust gets into the eyes, causing eye irritation (Islam et al., 2022). The miner slipped, fell down during the washing process, and had their hands pinched in the crusher machine. Burning gold ore using fire at very high temperatures can pose a fatal occupational accident hazard for mining workers. Previous research indicated that injuries in ASGM were caused using machines or tools at 46.1%, slips and falls at 32.2%, and less than 2% burns (Nakua et al., 2019). The identified sources of safety hazards found from this study were stones, dust, crushing machines, water, and fire which can cause work accidents and affect the upper and lower limbs of mining workers (Stojadinovic et al., 2012). This finding proved that the prevalence of work injuries in mining workers is higher at the stone-crushing stage because it has more high-risk activities and is done repeatedly (Islam et al., 2022). Based on observation, hazards are divided into three main groups, namely safety hazards, as mentioned above, health hazards, and environmental hazards (Singo et al., 2022). Specifically for health hazards, the researchers divided them into two groups, namely non-mercury hazards and mercury hazards. Health hazards identified from the interview with mining workers were inhaling dust during the crushing process, which can cause respiratory problems, and exposure to noise from crusher and trommel machines which causes hearing disorders (Habybadady et al., 2018; Wang et al., 2020). However, based on the condition of ASGM facilities and the work patterns of mining workers, other health hazards identified in this study were pain in the legs, back, waist, and shoulders resulting in ergonomic and musculoskeletal disorders (Ralph, 2018). Referring to the results of the interviews, all the hazards conveyed by the informants were occupational accidents, and none of the informants conveyed the health and environmental hazards caused by mercury. This indicates that mining workers are unaware of the hazards of using mercury in ASGM.

Health hazards due to the use of mercury identified from field observations occur when mining workers squeeze amalgam and burn gold ore. All informants stated that the amalgam squeezing was done manually using a filter cloth by hand and without using gloves. However, due to their ignorance, none of the informants conveyed the dangers of mercury during the squeezing process. In fact, when they do amalgam squeeze, about 1% of metallic mercury absorbed through skin contact will enter the body of the miners through the pores of the skin and then into the blood vessels (Bernhoft, 2012; Rianto et al., 2012). Mercury exposure through the skin does not only cause skin damage but can cause chronic poisoning in low doses that occur slowly over a long time (Do et al., 2017). Mine workers usually do not realize that their bodies have been exposed to mercury because it does not have a direct effect on their bodies. Based on the behaviour and work habits of mining workers without wearing masks when burning gold ore, it exacerbates exposure so that it can be ascertained that they are exposed to mercury vapour, and about 80% of mercury vapour enters the body of miners through inhalation (Bernhoft, 2012; Zaharani and Salami, 2015). Although some ASGM in Imandi uses a chimney, mercury vapour from amalgam combustion can be exposed and harm non-mining communities living around ASGM sites, which can cause neurological disorders (Oliveira et al., 2021; Wijaya et al., 2015).

The informants did not have the awareness to use PPE. This field observation and the results of interviews showed that three informants did not use PPE at all; one informant only occasionally used a mask when burning. The type of mask used was cloth masks, and after being asked further, the purpose of using masks is because they avoid Covid-19. Three informants wore gloves, boots, and glasses that were improvised and not up to standard. The informants highlighted that they do not use PPE because it slows down their work and interferes with their work process. Based on observation, even mining workers do not wear upper clothes when carrying out gold processing activities. This finding is in line with other studies, which reported low awareness of using PPE in ASGM (Long et al., 2015).

Although the mining workers did not disclose environmental hazards, based on observation, an environmental risk was identified: mercury residue in the waste discharged from the washing and disposal processes. Environmental exposure contaminates soil, water, fish, plants, and other food chains. This pollution leads to reduced environmental carrying capacity, leading to reduced production of agriculture, fisheries, and other commodities. Careless disposal of mercury waste from ASGM activities is a major contributor to mercury pollution in the environment because residual mercury enters water and soil (Obiri, 2016). The potential hazards and risks identified from the interview results of informants and observation by the researcher are shown in Table 6.

Table 6. Hazard identification and risk assessment.

Work Stage	Source of Hazards	Risk	L*	S**	RV***	Risk Rating
Crushing	Stones (ores)	Stone flakes hit the limbs	2	2	4	L
		Stone flakes get into the eyes	2	5	10	H
	Dust	Dust gets into the eyes	2	2	4	L
		Inhaled dust	2	3	6	M
	Crusher machine	Legs and hands crushed or pinched	3	4	12	VH
	Crusher engine sound	Exposed to noise	2	2	4	L
	Squat/sitting position during the crushing process	Pain in the legs, back, waist, shoulders, etc.	3	2	6	M
Grinding	Trommel engine sound	Exposed to noise	3	3	9	H
	Water	Slipped on the floor	2	2	4	M
	Mercury	Exposed through the skin	3	2	6	M
		Exposed through inhalation	3	3	9	H
Washing and waste disposal	Water	Slipped on the floor	3	2	6	M
	Mercury	Waste exposed to the environment	5	4	20	VH
Squeezing	Mercury	Exposed through the skin	5	2	10	H
Burning	Fire	Exposed to fire	4	4	16	VH
	Mercury	Exposed to mercury vapor through inhalation	5	5	25	VH

Notes: *Likelihood, **Severity, ***Risk Value.

Summary of interview with the ASGM business owners

The main purpose of interviewing ASGM business owners was to find out their efforts to prevent the hazards posed by gold processing activities. A summary of interview results with ASGM business owners is presented in Table 7. Based on interview results in Table 7, generally, the reason informants carry out gold processing (amalgamation) near their homes in community residential areas is easier to control and flexible to work until evening. The interesting thing is that neighbours and the community surrounding the site are not disturbed by the noise of machines that operate six days per week for more than eight hours a day. The neighbours are mostly mining workers, and the ASGM sites are spread throughout the Imandi Village. They do not know nor are they aware of the dangers of mercury caused by gold processing activities, so the practice of ASGM in residential areas is common in Bolaang Mongondow Regency. All ASGM businesses in the Imandi Village have a settling pond to accommodate waste. Referring to the results of interviews, settling ponds are not made to treat waste or prevent the entry of gold processing waste directly into the soil or rivers. All informants stated that the purpose of making a waste-settling pond was to accommodate the amalgamated sludge containing residual gold for further processing using cyanide. The gold produced from processed waste becomes the profit of the ASGM business owner. Based on this fact, ASGM business owners were interviewed about whether they knew the impact of mercury on the environment and human health. The interview results showed that three informants did not know the impact of mercury, and five informants stated that mercury had no impact on the environment and health. This study showed that ASGM business owners, as well as mining workers, do not have knowledge about the hazards of mercury. Thus, it is not surprising when the informants were asked what efforts had been made to prevent the hazards posed by gold processing, all of them stated that they had not made any efforts. The informants did not provide PPE because the mining workers were customers who rented processing equipment. Another reason is the financial issue because any effort will cost them extra. Use of PPE for example, both mining workers and mining business owners stated that they could not afford to buy PPE because of low earnings (Becker et al., 2021). Interesting interview from Owner 2, who stated that they would comply if there is support for assistance programs from the government, for example, related to the localization of gold processing in one location to facilitate monitoring and control. But unfortunately, until now, the plan has not been implemented because the status of gold mining locations and gold processing businesses in Bolaang Mongondow Regency are all illegal and have not been designated as community mining areas (WPR) according to the provisions of the Law of the Republic of Indonesia number 3 of 2020 concerning amendments to Law No. 4 of 2009 concerning mineral and coal mining 2020.

Table 7. Summary of the interview results of ASGM owners.

Theme of questions	Informant	Summaries and quotes from the interview
Stages of work	Owners 1, 2, 3, 4, 5, 6, 7, and 8	Crushing the stone, grinding the ore, washing and waste disposal, squeezing the amalgam, and burning with high temperature
Gold processing is placed behind the house	Owner 1	“More comfortable because it's close to home.”
	Owner 2	“So it is close to where I live and easy to control because I work until night. Until now, there are no neighbours or people who complain because almost all the people here are miners, so they are used to it.”
	Owners 3, 4, 5, 6, 7, and 8	Easier to control
Waste disposal	Owners 1, 2, 3, 4, 5, 6, 7, and 8	Settlement ponds are made, but some are wasted directly on the ground or in rivers. The settling pond is made to accommodate the waste dregs that still contain gold to be treated with cyanide
The impact of mercury on the environment and health	Owners 2, 5, and 7	Do not know
	Owners 1, 3, 4, 6, and 8	Do not have any impact on the environment and health
Efforts to prevent hazards	Owners 1, 4, 5, and 7	No effort has been made because the mining workers who process the gold only rent the gold processing site
	Owner 3	“There is no obligation from me including to provide PPE”
	Owners 6 and 8	No effort yet because it becomes an additional expense.”
	Owner 2	“So far, no effort has been made. I will obey and support if the government provides assistance or rules. For a long time, the government has said that it will carry out the localization of gold processing in one place, my friends and I strongly agree and are waiting for it, but until now, there has been no follow-up for that program. I agree with localization because it will be easier to monitor and control waste disposal and contribute to government revenue. The miners agree to whatever is regulated by the government. The proposal for the localization program for ASGM gold processing poses a dilemma because the source of gold mining is a protected forest area at Taman Nasional Bogani Nani Wartabone (TNBNW), meaning that the miners are extracting gold illegally. If the government is going to do localization, it means that the government agrees to illegal mining activities.”

Risk assessment

Risk assessment is an effort to calculate the magnitude of risk and determine whether the risk is acceptable or not (Habybabady et al., 2018). The risk assessment results were used to classify risk ratings according to their level, from low risk (L) to very high risk (VH). The risk values and risk ratings are presented in Table 7. The multiplication result between the likelihood (L) and severity (S) of each stage of gold processing work in ASGM produced a risk value (RV). The multiplication result between L and S produced different risk values for each stage of work, which resulted in a different risk rating classification. Based on the identification of hazards presented in Table 7, 13 sources of hazards pose 16 risks, of which 19% are low risk (L), 31% moderate (M), 25% high (H), and 25% very high (VH). The risk with a very high risk (VH) value can cause occupational accidents, environmental pollution, and health problems for mining workers and communities around ASGM. There are two risks that have a very high risk level (VH) that causes occupational accidents, namely, legs and hands crushed or pinched, with a risk value of 12 and exposure to fire, with a risk value of 16. The behaviour of mining workers who ignore and underestimate the use of PPE exacerbates the risk of work accidents. Environmental pollution is generated by waste that is exposed to the environment with a risk value of 20. Health problems are caused by exposure to mercury vapour through inhalation, with the highest VH value of 25. The waste that is stored in the settling pond is ensured to have been infiltrated into the soil and water because it is not designed at all to treat the waste.

The same practice is carried out in all ASGM businesses in East Dumoga Timur District and other areas in Bolaang Mongondow Regency. Environmental pollution occurs because methylmercury (CH_3Hg^+) enters the food chain and ultimately affects human health at the top of the food chain (Soe, 2022). Bolaang Mongondow Regency has 15 sub-districts, and 53.3% is the location of ASGM users of mercury. The results of the river water sample test conducted by the environment office in 2021 indicated that three rivers in Bolaang Mongondow, the Ongkak River, Dumoga River, and Kaiya River contained 0.0006 mg/L mercury (Durado, 2021). This is in line with previous studies conducted in several areas in the Bolaang Mongondow Regency.

The ecological impact of mercury in the Toraut River Basin Bolaang Mongondow showed that the mercury content in river water (<0.00055 mg/L), river sediment (<0.05-1.45 mg/kg), and aquatic plant tissue (<0.001-0.013 mg/kg) (Rantung and Wantasen, 2016). Mercury content in rice plants in four rice fields in Mopuya Village, North Dumoga District, ranged from 0.0 to 0.1 ppm (Suruh et al., 2012). Likewise, mining workers who burn gold ore are certain to be exposed to mercury vapour, considering the unsupportive working conditions and facilities at ASGM, as well as the negligent behaviour of mining workers who are not wearing masks when burning gold ore. Not only that, non-mining communities living around ASGM areas are potentially exposed to mercury because 14 ASGM business units are located in the community resident of Imandi Village. In fact, the mercury vapour released into the atmosphere from the burning of gold ore can expose people living far from the Imandi ASGM area because mercury in the atmosphere can last for a long time up to 10 years and can travel more than 1,000 km (Nakazawa, 2016; Malehase et al., 2017). Moreover, with the same practice in other districts in Bolaang Mongondow Regency as well as neighbouring regencies, non-mining communities outside the Imandi village are likely to have been exposed to mercury vapour. For instance, a mercury content of 0.171 to 2.08 g/g was found in the hair of people living in Lanut Village, Bolaang Mongondow Regency, which is 75 km from Imandi Village (Latuconsina et al., 2018). Thus, the stage of burning gold ore is the most dangerous and risky for mining workers in Imandi Village. Elemental mercury (Hg^0) in liquid form will quickly evaporate, is easily inhaled and absorbed through the lungs, and oxidized in the body fluids of mining workers (Gibb and O'Leary, 2014; Pateda, 2018).

Risk control

The risk assessment results are the basis for carrying out risk control over all risks found at the hazard identification phase. In other words, risk control is a way to overcome the risks identified at each stage of work to be further implemented through the risk control hierarchy approach. Table 8 shows the risk hierarchy control for each work stage. PPE is present at all stages of work; administrative controls at the stages of crushing and burning; engineering controls at the stage of crushing, washing, and waste disposal; substitution at the stages of grinding, washing, and waste disposal, and squeezing; and elimination in the burning stage.

Discussion

Based on the determination of risk control measures in Table 8 covering all control hierarchies, PPE 43%, administrative controls 14%, engineering controls 14%, substitution 21%, and elimination 7%. The hierarchy of control developed in Table 8 can be a reference to be implemented in ASGM as an effective solution to controlling the risk to protect mining workers (Mansdorf, 2019). Priority action for effective risk control should be carried out at the highest VH value. Based on the risk assessment results (Table 7), the risk with the highest risk value (VH = 25) is exposed to mercury vapour through inhalation caused by mercury from the gold ore burning process.

The risk control aspect must be carried out in the stage of burning gold ore using a reusable facepiece respirator to prevent the entry and inhalation of mercury vapour into the body. The reusable facepiece respirator has filtration effectiveness of 0.1 microns: 99%, higher than N95 masks. This type of mask can filter out small particles of harmful gases and can repeatedly be used as long as the face seal is in good condition. At the control hierarchy aspect, it must be carried out in the highest hierarchical order, which is the elimination, so the risk will not pose a hazard to mining workers. Elimination control is in line with the government of Indonesia's commitment to eliminate the use of mercury in ASGM. Even though the elimination is only 7%, it greatly impacts risk control because the source of hazards will be eliminated.

Indeed, if elimination is implemented, mercury as a source of hazard will be eliminated, 100% effective in protecting humans and the environment, but based on facts on the ground, it is not easy to do because eliminating mercury means closing ASGM. If this is forced, it will cause resistance from all stakeholders, especially mining workers, who will be the ones who will be disadvantaged because they will lose their livelihood (NTG, 2018). If elimination is difficult to implement, the second control option is a substitution, which means replacing mercury as an extraction material with other materials or technologies that are safer but economically effective and efficient. The informants revealed that if there is a non-mercury technology that can be effective in extracting gold, they are basically obedient and willing to switch to using the technology as long as it is affordable for them.

Table 8. Risk control and hierarchy of control.

Work Stage	Risk	Risk Control	Hierarchy of Control
Crushing	Stone flakes hit the limbs	Warning signs and labels	Administrative
	Stone flakes get into the eyes	Using a face shield and safety goggles	PPE
	Dust gets into the eyes	Safety Spectacles	
	Inhaled dust	Masker respirator N95	
	Legs and hands crushed or pinched	Safety shoes and impact hand gloves	
	Exposed to noise	Using earplugs	
	Pain in the legs, back, waist, shoulders, etc.	Workplace redesign	Engineering
Grinding	Exposed to noise	Using earplugs	PPE
	Slipped on the floor	Rubber boot and helmet	
	Exposed through the skin	Chemical Resistance Glove	PPE Substitution
	Exposed through inhalation	Reusable facepiece respirator	
Washing and waste disposal	Slipped on the floor	Rubber boot and helmet	PPE
	Waste exposed to the environment	Standardized tailings ponds	Engineering substitution
Squeezing	Exposed through the skin	Chemical Resistance Glove	PPE Substitution
Burning	Exposed to fire	Welding glasses	PPE
		Warning signs and labels	Administrative
	Exposed to mercury vapour through inhalation	Reusable facepiece respirator	Elimination

Unfortunately, until now, no non-mercury technology has been introduced to be applied in Bolaang Mongondow except for cyanide, which is only limited to treating gold residue from the collected waste. The use of cyanide is not a solution because it is also a bad practice. The use of cyanide has been complained about by many mining workers and ASGM business owners because there have been cases of fish and cattle deaths in Bolaang Mongondow that are strongly suspected to be due to the use of cyanide in ASGM.

The habit of mining workers using mercury in ASGM in Bolaang Mongondow Regency is not easy to change because it is related to behaviour practised for decades from generation to generation. Moreover, mercury in Bolaang Mongondow Regency is easy to obtain because it is sold freely at an affordable price and efficient because it can be used repeatedly (Krisnayanti et al., 2012). Mostly, mining workers and ASGM business owners believe that the stones in Bolaang Mongondow can only be extracted optimally, quickly, and suitable with mercury. Based on the experience of informants, ore that has been crushed into grains cannot be dissolved by cyanide, but it will be dissolved more quickly with mercury. In addition, people who are mastering the method of using cyanide safely are limited, and they do not want to share their expertise with others because it is their livelihood. Currently, no government agencies, universities, and non-governmental organizations provide technical assistance to introduce non-mercury technology to mining workers and ASGM business owners due to the status of ASGM practices in Bolaang Mongondow Regency being illegal. Based on this fact, the option of substituting mercury with other materials or technologies will not be implemented in the near future until the Bolaang Mongondow Regency government stipulates the legality of the WPR and ASGM business.

The next risk control option is engineering control to design the workplace at the burning stage so that the dangers of mercury vapour can be controlled so that it is not inhaled by mining workers and is safe even if exposed to the atmosphere. Engineering control measures are not realistic to apply for ASGM in Imandi Village, even to control the second highest VH value to redesign the settling pond according to its function in treating waste. ASGM business owners will definitely not want and cannot finance it because it requires a very high cost. Due to a lack of knowledge about the dangers of mercury, mining workers are comfortable with the conditions of existing facilities, and it is not necessary or an obligation for ASGM business owners to upgrade the workplace to carry out engineering control. ASGM is not a corporation but is a small micro-scale business carried out by individuals is associated with low capital, so engineering control is difficult to apply in ASGM (NIOSH, 2015; Singo et al., 2022).

The fourth risk control option that can be proposed to ASGM in Imandi is administrative control through several approaches, such as making SOPs, hazard signs, communication, training, and socialization related to the hazards of mercury for mine workers and mine business owners (NIOSH, 2015). Based on conditions in Imandi Village and Bolaang Mongondow Regency, mining workers and ASGM business owners are not actors who can be expected and relied on with their initiative and awareness to be able to implement administrative controls. The local government should be the key actor in proactively advocating for the ASGM business owners and mining workers to carry out administrative control efforts. However, this role has not been carried out optimally by the local government, as indicated by the results of interviews where the dangers of mercury, which is the basis of knowledge, have not been understood by mining workers and ASGM business owners. Administrative control is cheap, without any consequential costs incurred by mining workers and ASGM business owners. However, at this time, it has not become an effective risk control option to reduce the hazards of mercury vapour unless it is carried out simultaneously with PPE risk control.

One last hazard control option available is using reusable facepiece respirator PPE for mining workers carrying out the gold ore burning process. It's not easy to change the behaviour of mining workers; it requires extra effort to make them aware that they are disciplined and consistent in using PPE. Although PPE is ineffective because it relies on miner effort, PPE control in the gold ore burning process must be carried out because no more control measures can be taken to reduce the hazards of mercury vapour exposure (Fogler et al., 2021). The main challenge is who will pay for the purchase of PPE because it is impossible to fully charge the mining workers because financiers hire them to work on processing their gold with a profit-sharing system. Although it is difficult, the cost of providing PPE is still possible to be borne by investors and ASGM business owners. As with administrative control, the use of PPE cannot rely on the initiative of mining workers or ASGM business owners, and government support is needed to regulate and supervise ASGM closely.

The behaviour of mine workers and ASGM business owners toward the use of PPE is poor if training and enforcement at the ASGM are not firmly pushed by the government (Nakua et al., 2019). Therefore, the solution can be done is to combine PPE with administrative control, where the government strictly controls the use of PPE while providing socialization, training, and assistance to increase awareness among mining workers and ASGM business owners on the dangers of mercury. Although the risks cannot be controlled properly, the combination of administrative and PPE controls is possible to apply in Imandi Village. This synergistic momentum can be used to encourage mining workers to use full PPE not only to protect against exposure to mercury vapour but also to protect against other hazards from each stage of work, as listed in Table 7.

Conclusion

The identified hazards of gold processing activities in ASGM are divided into three main groups: health, safety, and environmental, consisting of 13 sources of hazards that can pose 16 risks. The obtained risk assessment results show that 19% are low risk, 31% moderate risk, 25% high risk, and 25% very high risk caused by exposure to mercury through the gold ore burning process with a risk value of 25. The identified risk control measures cover all control hierarchies, PPE 43%, administrative controls14%, engineering controls 14%, substitution 21%, and elimination 7%. Realistic risk controls that can be applied in ASGM are a combination of administrative controls and PPE.

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References

Bansah, K., Galecki, G., Quaicoe, I., Dumakor, D.N., Kenneth, J.B., Grzegorz, G., Ishmael, Q. and Kofi, N.D. 2017. Occupational health and safety practices in the artisanal and small-scale gold mining sector in Ghana. *Conference: X International Conference on Mining Techniques* at Kraków-Krynica, Poland.

Basu, N., Clarke, E., Green, A., Tagoe, B.C., Chan, L., Dzodzomenyo, M., Fobil, J., Long, R., Quansah, R. and Neitzel, R.L. 2015. Integrated assessment of artisanal and small-scale gold mining in Ghana-Part 1: Human health review. *International Journal of Environmental Research and Public Health* 12:5143-5147.

Becker, J., Furu, P., Singo, J., Shoko, D., Elbel, J., O'Reilly, S.B. and Muschack, N.S. 2021. Determinants of health and health needs assessment of artisanal and small-scale gold miners in Kadoma, Zimbabwe: A mixed method approach. *Environmental Research* 197:111081, doi:10.1016/j.envres.2021.111081.

Benedict, N.L., Tagoe, B.C., Ovadje, L., Clarke, E., Basu, N. and Robins, T. 2015. Injury profiles associated with artisanal and small-scale gold mining in Tarkwa, Ghana. *International Journal of Environmental Research and Public Health* 12:7922-7937, doi:10.3390/ijerph120707922.

Bernhoft, R.A. 2012. Mercury toxicity and treatment: a review of the literature. *Journal of Environmental and Public Health* 12:1-10.

Bonsu, J., Dyk, W.V., Franzidis, J.P., Petersen, F. and Isafiade, A. 2017. A systemic study of mining accident causality: An analysis of 91 mining accidents from a platinum mine in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy* 117(1):59-66, doi:10.17159/2411-9717/2016/v116n8a10.

BPS (Central Bureau of Statistics). 2020. *East Dumoga District in Figures*. Lolak (ID): BPS Bolaang Mongondow (*in Indonesian*).

Buckle, P. 2005. Ergonomics and musculoskeletal disorders: an overview. *Occupational Medicine* 55:164-167, doi:10.1093/occmed/kqi081.

Calys-Tagoe, B., Clarke, E., Robins, T. and Basu, N. 2017. A comparison of licensed and unlicensed artisanal and small-scale gold miners (ASGM) in terms of socio-demographics, work profiles, and injury rates. *BMC Public Health* 862, doi:10.1186/s12889-017-4876-5.

Cossa, H., Scheidegger, R., Leuenberger, A., Ammann, P., Munguambe, K., Utzinger, J., Macete, E. and Winkler, M.S. 2021. Health studies in the context of artisanal and small-scale mining: a scoping review. *International Journal of Environmental Research and Public Health* 18(4):1-24, doi:10.3390/ijerph18041555.

Do, S.Y., Lee, C.G., Kim, J.Y., Moon, Y.H., Kim, M.S., Bae, I.H. and Song, H.S. 2017. Cases of acute mercury poisoning by mercury vapor exposure during the demolition of a fluorescent lamp factory. *Annals of Occupational and Environmental Medicine*. 29:19, doi:10.1186/s40557-017-0184-x.

Durado, N. 2021. Three Rivers in Bolmong Detected Containing Mercury. manado.tribunnews.com. Bolmong. Downloaded 6 June 2022, https://manado.tribunnews.com/2021/08/20/breaking-news-tiga-sungai-di-bolmong-terdeteksi-mengandung-merkuri (*in Indonesian*).

Elenge, M., Leveque, A. and Brouwer, D.C. 2013. Occupational accidents in artisanal mining in Katanga, DRC. *International Journal of Occupational Medicine and Environmental Health* 26: 265-274.

Fogler, H.S., Steshetz, K., Agarwal, A. and Miletic, M. 2021. Swiss cheese model. University of Michigan. http://umich.edu/~safeche/swiss_cheese.html.

FU (Federation University). 2021. Guideline HIRAC. https://policy.federation.edu.au/corporate_governance/risk_health_and_safety/hazards/ch01.php.

Gibb, H. and O'Leary, K.G. 2014. Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: a comprehensive review. *Environmental Health Perspective* 122(7):667-672, doi:10.1289/ehp.1307864.

Grita, A., Primanti, A., Zaki, K. and Ismawati, Y. 2012. Rapid Assessment of the Socio-economic Impact and Human Rights Aspect of Mercury Use in Artisanal and Small-Scale Gold Mining Hotspots in Indonesia. International SAICM Impementation Project (pp. 46). Denpasar (ID): Bali Fokus.

Habybabady, H.R, Nasibi, S.H., Paridokht, F., Ramrudinasab, F., Behmadi, A. and Khosravi, B. 2018. Effects of dust exposure on the respiratory health symptoms and pulmonary functions of street sweepers. *Malaysian Journal of Medical Sciences* 25(6):76-84, doi:10.21315/mjms2018.25.6.8.

ILO (International Labour Organisation). 2011. *Occupational Health and Safety Management System: A Tool for Continual Improvement*. Geneva [CH]: International Labour Office.

Islam, S., Biswas, P.K., Saha, S., Sayem, A. and Khan, M.M.A. 2022. Assessment of occupational injuries, health, and risk faced by stone-crushing industry workers. *Research Square* 1-16, doi:10.21203/rs.3.rs-1385658/v1.

Krisnayanti, B.D., Anderson, C.W.N., Utomo, W.H., Feng, X., Handayanto, E., Mudarisna, N., Ikram, H. and Khususiah. 2012. Assessment of environmental mercury discharge at a four-year-old artisanal gold mining area on Lombok Island, Indonesia. *Journal of Environmental Monitoring* 4(2):598-607.

Kyeremateng, A.E. and 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, doi:10.3390/ijerph120910886.

Latuconsina, L., Polii, B. and Umboh, J.M.L. 2018. Mercury and its impact on the health of gold miners in Lanut Village, Modayag District, East Bolaang Mongondow Regency, North Sulawesi Province. *Jurnal Kesehatan Masyarakat* 6(1):64-74 (*in Indonesian*).

Long, R.N., Sun, K. and Neitzel, R.L. 2015. Injury risk factors in a small-scale gold mining community in Ghana's Upper East Region. *International Journal of Environmental Research and Public Health* 12:8744-8761, doi:10.3390/ijerph120808744.

Lusantono, O.W. and Hantari, Y.N. 2020. Artisanal and small-scale gold mining in Indonesia: a case study of Tobongon, East Bolaang Mongondow District, North Sulawesi Province. *AIP Conference Proceedings* 2245:090010, doi:10.1063/5.0061071.

Malehase, T., Daso, A.P. and Okonkwo, J.O. 2017. Initiatives to combat mercury use in artisanal small-scale gold mining: A review on issues 332 and challenges. *Environmental Review* 25:218-224, doi:10.1139/er-2016-0042.

Mansdorf, S.Z. 2019. *Handbook of Occupational Safety and Health.* Hoboken (US): John Wiley & Sons.

Mestanza-Ramón, C., Mora-Silva, D., D'Orio, G., Tapia-Segarra, E., Gaibor, I.D., Parra, J.F.E., Velásquez, C.R.C., and Straface, S. 2022. Artisanal and Small-Scale Gold Mining (ASGM): Management and Socioenvironmental Impacts in the Northern Amazon of Ecuador *Sustainability* 14, 6854, doi:10.3390/su14116854.

Nakazawa, K., Nagafuchi, O., Kawakami, T., Inoue,T., Yokota, K., Serikawa, Y., Cyio, B. and Elvince, R. 2016. Human health risk assessment of mercury vapor around the artisanal small-scale gold mining area, Palu city, Central Sulawesi, Indonesia. *Ecotoxicology and Environmental Safety* 124:155-162, doi:10.1016/j.ecoenv.2015.09.042.

Nakua, E.K., Dabo, E.O., Newton, S., Koranteng, A., Otupiri, E., Donkor, P. and Mock, C. 2019. Injury rate and risk factors among small-scale gold miners in Ghana. *BMC Public Health* 19:1368, doi:10.1186/s12889-019-7560-0.

NIOSH (The National Institute for Occupational Safety and Health). 2015. Hierarchy of Controls. www.cdc.gov/niosh/topics/hierarchy.

NTG (Northern Territory Government). 2018. *Guide Six Steps to Risk Management*. Northern (AU): NTWorkSafe, www.worksafe.nt.gov.au.

Obiri, S., Mattah, P.A.D., Mattah, M.M., Armah, F.A., Osae, S., Adu-Kumi, S. and Yeboah, P.O. 2016. Assessing the environmental and socio-economic impacts of artisanal gold mining on the livelihoods of communities in the Tarkwa Nsuaem municipality in Ghana. *International Journal of Environmental Research and Public Health* 13(160):1-15, doi:10.3390/ijerph13020160.

OHSAS (Occupational Health and Safety Assessment Series). 2008. Occupational and Safety Management System-Guideline for The Implementation of OHSAS 18001-2007. London (UK): The OHSAS Project Group Secretariat.

Oliveira, R.A.A., Pinto, B.D., Rebouças, B.H., Andrade, D.C., Vasconcellos, A.C.S. and Basta, P.C. 2021. Neurological impacts of chronic methylmercury exposure in Munduruku indigenous adults: Somatosensory, motor, and cognitive abnormalities. *International Journal of Environmental Research and Public Health* 18:10270, doi:10.3390/ijerph181910270.

Oramah, I.T., Richards, J.P., Summers, R., Garvin, T. and MacGee, T. 2015. Artisanal and small-scale mining in Nigeria: Experiences from Nigeria, Nasarawa and Plateau states. *The Extractive Industries and Society* 2:694-703, doi:10.1016/j.exis.2015.08.009.

Pateda, S.M., Sakakibara, M. and Sera, K. 2018. Lung function assessment as an early biomonitor of mercury-induced health disorders in artisanal and small-scale gold mining areas in Indonesia. *International Journal of Environmental Research dan Public Health* 15(2480):1-12, doi:10.3390/ijerph15112480.

Purnama, D.S. 2015. Analysis of the application of the HIRARC (Hazard Identification Risk Assessment and Risk Control) and HAZOPS (Hazard and Operability Study) methods in the identification of potential hazards and risks in the unloading unit process in PT. Toyota Astra Motor. *Jurnal Pasti* 9(3):311-319 (*in Indonesian*).

Rajaee, M., Obiri, S., Green, A., Long, R., Cobbina, S.J., Nartey, V., Buck, D., Antwi, E. and Basu, N. 2015. Integrated assessment of artisanal and small-scale gold mining in Ghana-Part 2: Natural sciences review. *International Journal of Environmental Research and Public Health* 12:8971-9011, doi:10.3390/ijerph120808971.

Ralph, O., Gilles, N., Fon, N., Luma, H. and Greg, N. 2018. Impact of artisanal gold mining on human health and the environment in the Batouri Gold District, East Cameroon. *Academic Journal of Interdisciplinary Studies* 7(1):25, doi:10.2478/ajis-2018-0003.

Rantung, J.L. and Wantasen, S. 2016. Biomonitoring of the ecological impact of Hg in the Toraut Watershed, Bolaang Mongondow Regency. *Jurnal Eugenia* 22(2):55-61 (*in Indonesian*).

Rianto, S., Setiani, O. and Budiyono. 2012. Analysis of factors related to mercury poisoning in traditional gold miners in Jendi Village, Selogiri District, Wonogiri Regency. *Jurnal Kesehatan Lingkungan Indonesia* 11(1):54-60 (*in Indonesian*).

SAI Global. *Australian Standards Information and Compliance Organization*. 2007. Handbook Risk Management Guidelines Companion to AS/NZS 4360:2004. Sydney (AU): Jointly published by Standards Australia International Ltd, GPO Box 5420, Sydney, NSW 2001 and Standards New Zealand.

Selin, H., Keane, S.E., Wang, S., Selin, N.E., Davis, K. and Bally, D. 2018. Linking science and policy to support the implementation of the Minamata convention on mercury. *Ambio* 47:198-215, doi:10.1007/s13280-017-1003-x.

Singo, J., Isunju, J.B., Moyo, D., Muschack, N.S., O'Reilly, S.B. and Mamuse, A. 2022. Hazards and control measures among artisanal and small-scale gold miners in Zimbabwe. *Annals of Global Health* 88(1):21, doi:10.5334/aogh.3621.

Soe, P.S., Kyaw, W.T., Arizona, K., Ishibashi, Y. and Agusa, T. 2022. Mercury Pollution from Artisanal and Small-Scale Gold Mining in Myanmar and Other Southeast Asian Countries. *International Journal of Environmental Research and Public Health* 19:6290, doi:10.3390/ijerph19106290.

Steckling, N., Tobollik, M., Plass, D., Hornberg, C., Ericson, B., Fuller, R. and O'Reilly, S.B. 2017. Global burden of disease of mercury used in artisanal small-scale gold mining. *Annals of Global Health* 83(2):234-247, doi:10.1016/j.aogh.2016.12.005.

Stojadinovic, S., Svrkota, I., Petrovic, D., Denic, M., Pantovic, R. and Milic V. 2012. Mining injuries in Serbian underground coal mines-A 10-year study. *Injury* 43:2001-2005.

Supriyadi, S., Nalhadi, A. and Rizaal, A. 2015. Hazard identification and OHS risk assessment in maintenance and repair actions using the HIRARC (hazard identification and risk assessment risk control) method at pt. x. *National Seminar on Applied Research,* December 12 2015; Serang (ID). pp 281-286 (*in Indonesian*).

Suruh, R., Gugule, S. and Palapa, T.M. 2012. Identification of heavy metal mercury (Hg) in rice (*Oryza sativa*) in Mopuya Village, North Dumoga District, Bolaang Mongondow Regency. *Jurnal Biologi Lingkungan* (*in Indonesian*).

Tsang, V.W., Lockhart, K., Spiegel, S.J. and Yassi, A. 2019. Occupational health programs for artisanal and small-scale gold mining: A systematic review for the WHO global plan of action for workers' health. *Annals of Global Health* 85(1), doi:10.5334/aogh.2592.

Wang, T.C., Chang, T.Y., Tyler, R., Lin, Y.J., Liang, W.M, Shau, Y.W, Lin, W.Y., Chen, Y.W., Lin, C.D. and Tsai, M.H. 2020. Noise induced hearing loss and tinnitus-New research developments and remaining gaps in disease assessment, treatment, and prevention. *Brain Science* 10:732, doi:10.3390/brainsci10100732.

Wijaya, A., Panjaitan, W.S. and Palit, H.C. 2015. Evaluation of occupational health and safety using the HIRARC method in PT. Charoen Pokphand Indonesia. *Jurnal Tirta* 3(1):29-34 (*in Indonesian*).

Wilson, M.L., Renne, E., Roncoli, C., Baffour, P.A. and Tenkorang, E.Y. 2015. Integrated assessment of artisanal and small-scale gold mining in Ghana-part 3: social sciences and economics. *International Journal of Environmental Research and Public Health* 12(7):8133-8156, doi:10.3390/ijerph120708133.

Wilson, S.L., El Haj, A.J. and Yang Y. 2012. Control of scar tissue formation in the cornea: strategies in clinical and corneal tissue engineering. *Journal of Functional Biomaterials* 3:642-687; doi:10.3390/jfb3030642.

Zaharani, F. and Salami, I.R.S. 2015. Mercury content in urine and hair as an indication of mercury exposure to unlicensed mining workers (PETI) in Pasar Terusan Village, Muara Bulian District, Batanghari Regency, Jambi. *Jurnal Teknik Lingkungan* 21(2):169-179 (*in Indonesian*).