Assessing the Occupational Risks associated with Artisanal and Small-Scale mining- A Case study in Asankrangwa and Kenyasi Areas in Ghana

N.A. Buadee[1], S.K.Y. Gawu[2], and G. Foli[2*]
Departments of [1]Materials and [2]Geological Engineering, College of Engineering
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Corresponding Author: gordon.foli01@gmail.com

Abstract

This study assesses some environmental and safety impacts, causes of accidents and hazards associated with operations at 10 selected Artisanal and Small-scale Mining (ASM) sites in Asankrangwa and Kenyasi areas. The aim is to establish the extent of the environmental and safety impacts and the risks associated with the hazards at the ASM sites and suggest ways to minimise the impacts. Dust and noise monitoring results show that silica dust and noise levels are above the American Conference of Governmental Industrial Hygienist (ACGIH) of occupational exposure limits. Results from questionnaire administration indicate that low levels of risk awareness, use of personal protective equipment, workplace monitoring and incident reporting, are the main challenges associated with the ASM operations. Causes of accidents are in the decreasing order of Pit collapse, Blasting, Flooding, Suffocation and Others. Using a 5x5 risk matrix, initial risk assessment (IRA), based on existing site conditions and residual risk assessment (RRA), based on recommended controls were conducted on 7 hazard types. The IRA scored HIGH (11-17) to EXTREME (18-25) values while the RRA scored MEDIUM (6-10) to LOW (1-5) values which represent average risk drop of about 47%. Fifty percent of the study sites indicate HIGH fatality rates. The causes of incidents are in the reducing order of; Handling of explosives, Digging to expose the ore, Shaft sinking, Ore preparation and beneficiation, Underground mining, Working in a poorly consolidated environment and Tunnelling. Risk Assessment is thus established as a necessary requirement for ASM practice in Ghana.

Introduction

Artisanal and Small-scale Mining (ASM) are projects generally characterised by (1) small groups of personnel; (2) small concessions often without legal mining titles; (3) use of rudimentary tools; (4) relatively low levels of productivity and; (5) low capital investments (PNDC Law 218, 1989; Hentschel *et al* .,2002). The proliferation of foreign nationals into ASM sector in Ghana has led to increased capital injection, use of very sophisticated equipment contrary to prescribed tools for ASM activities and larger concessions. These translate to increase in workforce and environmental impacts such as air, land, water pollutions and socio-economic impacts (Ncube-Phiri *et al*., 2015).

In Ghana, three main classes of ores exploited for gold during ASM operations are (1) sub-surface alluvial deposits of about 3m depth; (2) Deeper level alluvial deposits occurring at about 7-12 m and; (3) Hard rock material mostly from an underground source. All the three categories of orebodies require varying degrees of input for gold recovery. Mining of the first and second ore types have been influenced by the increased use of sophisticated machinery such as bulldozer for digging and rock crushing machines for ore processing. The third ore type requires mechanical and chemical treatment of ores.

The negative impacts and risk associated with the above mentioned deposit types have been a subject of keen interest and debate by stakeholders, due to the negligence of miners to implement appropriate mitigation actions (Amedjoe and Gawu, 2013). These authors also noted that the nature and severity of impacts depend largely on the mining and processing methods being used. For example:

(1) Miners often adopt unplanned extraction designs such as the creation of moonlike landscapes consisting of unstable waste piles without the needed reclamation; (2) Chemicals such as mercury, which is used for gold amalgamation process are leached into nearby streams and rivers and; (3) Blasting, excavation, haulage and crushing of the ore, which also creates large amounts of dust into the air environment.

The activities listed above results in health and safety issues emanating from incidents ranging from near-misses to fatal accidents. Incidents are consequential events that may lead to accidents, while accidents are sudden events that lead to loss of lives and property. For example, Ghana recorded about 300 deaths in 2011 (Aubynn, 2012). Some of the locations and fatalities are: Kenyasi (5), Subriso (10), Dompoase (18), Jacobu (2), Akrokerri (3), Obuasi (8), Dunkwa-on-Offin (124), Kyekyewere (17), Subrisu Fante (17) and Prestea-Huni Valley (3) among others.

These casualties can, however, be reduced through implementation of regulations for the sector. Until the late 1980s, ASM activities in Ghana were only governed by very weak laws (Hilson, 2002). This situation may have been responsible for the high rate of work-related incidents and impacts in the ASM sector. The enactment of PNDC Law 218 and 219 (Adjei *et al.*, 2012) and the Minerals and Mining Act 2006 (Act 703) from 1988 to 2006, were highly welcome moves to strengthen the ASM legal regime in Ghana.

Despite the enactment of the above laws, strict adherence to standard operating procedures for ASM operations has not been followed, while, only very few incidents are officially reported. The non-compliance with these standards has led to unavailability of reliable data or official statistics about accidents, health and safety issues at ASM sites. It is therefore evident that if the sector remains unchecked, increasing incidents and accidents will cost the nation in terms of healthcare and management of disasters. This would result in loss of vital human and other resources, which are very difficult to restore (Adjei *et al.*, 2012).

This study assessed some environmental and safety impacts, causes of accidents and hazards associated with operations at 10 selected ASM sites in Asankrangwa and Kenyasi areas in Ghana. The aim was to establish the extent of the environmental and safety impacts and the risks associated with the hazards at the ASM sites and suggest ways to minimise the impacts.

Study Area

The study area is situated within Asankrangwa and Kenyasi areas, on Lat. 5° 48' N and Long. 2° 26' W and Lat. 7° 0' N and Long. 2° 24' W, respectively in Ghana. The vegetation of the area is the high forest zone type and influenced by the double peak rainfall pattern. A major season spans from March-August and a minor season extends from September-November, while a dry season spans from December to February. Average annual rainfall range from 1600 to 2000 mm (AGL, 2009; GMET 2016). The areas are underlain by the Birimian rocks, which constitutes: (1) metavolcanic rocks; intruded by mafic mineral-rich granitoid, overlain by Tarkwaian rocks and; 2) meta-sedimentary units intruded by felsic mineral-rich granitoid (Perrouty et al., 2012). Placer deposits occur in floodplains and unconsolidated terrains. A geological map of south-western Ghana showing the study areas is presented in Fig. 1.

Methodology

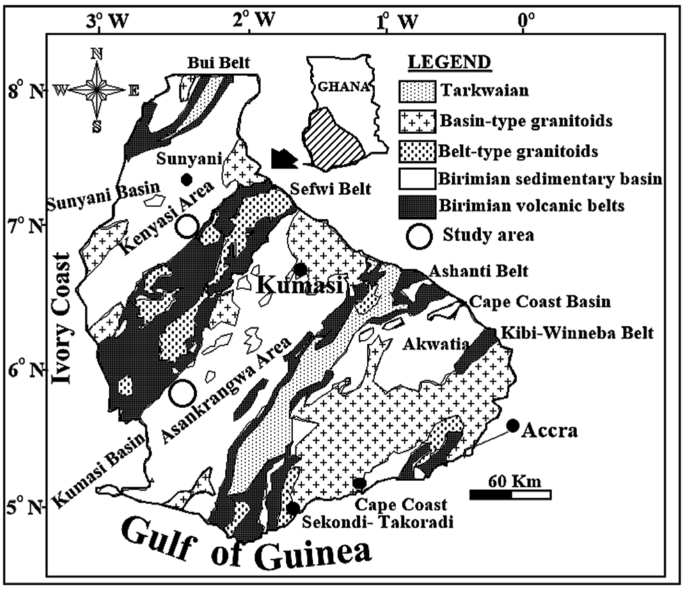

Fig. 1 Geological map of southern western Ghana showing the study area (e.g. Leube et al., 1990)

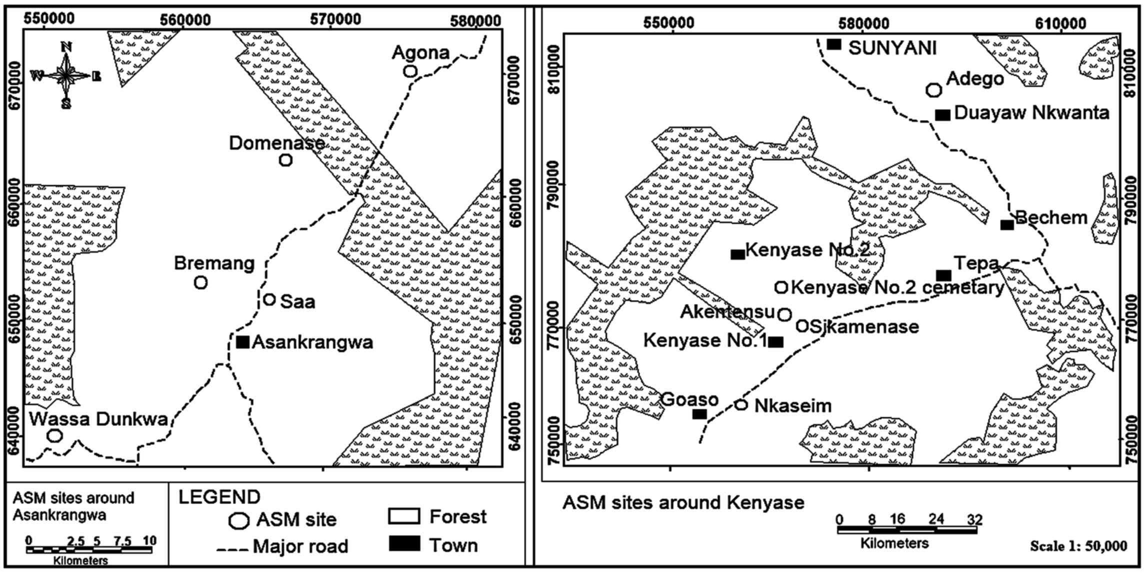

Fig.2: Sketch maps of ASM sites at Asankrangwa (left) and Kenyasi (right) areas

Site Selection and sampling design

Five ASM sites each located in the Asankragwa and Kenyasi areas were selected. Five of the selected sites are registered with the Minerals Commission, while the other five are not registered. Maps showing sampling locations are presented in Fig. 2.

A total of 250 respondents, 25 each from the 10 sites were selected for questionnaire administration. The respondents belong to 4 active classes of workers, namely; Project site overseers, Shallow-depth workers, Deep-level workers, and Ore treatment and workshop workers. A fifth category, consisting of passive workers exist as food vendors and other service providers. Total population at the sites is estimated to be about 41400.

The number of workers in each of the 4 active classes of workers is about 600. Saunders et al. (1997) estimated a minimum sample size of 254 for a population size of 750; the sample size of 250 respondents at 5% level of significance was therefore adequate for a valid data generation. Some metrics of social and operational parameters evaluated for impact assessment are (1) Accident awareness; (2) Monitoring of mining activities by regulators; (3) incident reporting trends and; (4) Common causes of accidents.

Noise and dust monitoring

The sites were monitored for dust and noise pollution generated from the crushing plant sites. Noise levels were measured using a noise dosimeter and referenced to the American Conference of Governmental Industrial Hygiene Occupational Exposure Limit (ACGIH 2013). The sound level meter was pre-calibrated according to manufacture's directions and set up at the crushing plant for taking eight hourly records. Also, clouds of silica dust from crushing operations at ASM sites were determined using a personal sampling pump connected to Tygon tubing and attached to a worker's collar. The other end of the Tygon tubing was connected to the PVC pre-weighed cassette and a 10-mm nylon cyclone. Samples were sent to the Bureau Veritas Laboratory in the United States for analyses.

Accident Rates Evaluation

Data on accidents was provided by the ASM operators for a one year period. The number of injuries and fatalities recorded and reported were estimated quantitatively to establish measurable incident rates (IR) at the workplace as published by OSHA (2009). For example, the standard percentage base rate for estimation of incident rate is dependent on a rate of 200,000 labour hours, which amounts to 100 employees working for 40 hours in the week and 50 weeks in the year (OSHA, 2009). Man hours worked was calculated from the total numbers of (i) workers (W) at site; (ii) months (M) worked in a year (M/yr); (iii) days worked per month (D/month) and; (iv) hours (H) worked per day (H/day) thus:

$$\text{Man hours} = [W * M/yr * D/month * H/day] \text{ ------ } (1)$$

The OSHA Recordable Incident Rate or Incident Rate (IR) is calculated by multiplying the number of recordable cases by 200,000, and then divided by the number of labour hours. The Fatal Incident Frequency Rate (FIFR) is based on the relevant worker population estimated at the sites using the formulas (OSHA, 2009):

$$IR = \frac{\text{Number of OSHA Recordable Cases}}{\text{Number of Employee labour hours worked}} \times 200,000 \text{--- } (2)$$

$$FIFR = \frac{\text{No.of Fatalities}}{\text{Total Man-hours}} \times 200,000 \text{ ----- } (3)$$

Risk Assessment and Risk Management

The process of risk management protects the project against adverse consequences of pure risk due to activities or hazards by reducing the severity and variability of losses. Pure risk is situations that present the opportunity for loss. Hazards associated with the ASM sites covered seven major activities such as: (i) Digging to expose the ore; (ii) Handling of explosives; (iii) Tunnelling; (iv) Shaft sinking; (v) Underground mining; (vi)Working in an unconsolidated environment and; (vii) Ore preparation and beneficiation.

The hazards were evaluated for significance by probing with the following factors: (1) can the hazard pose a risk to life and property; (2) can the risk be a source of concern to interested parties; (3) can the impacts of the risk be a source of financial loss and; (4) can the impact lead to potential legal issues. A positive response to any one of the above

TABLE 1
Risk Matrix

RISK MATRIX		CONSEQUENCE				
		Rating				
LIKELIHOOD		1 Negligible	2 Weak	3 Moderate	4 High	5 Excessive
5 Very high	Rating	5	10	15	20	25
4 High		4	8	12	16	20
3 Moderate		3	6	9	12	15
2 Minor		2	4	6	8	10
1 Unlikely		1	2	3	4	5
RISK SIGNIFICANCE		Low 1 to 5	Medium 6 to 10	High 11 to 17	Extreme 18 to 25	

implies the hazard is significant and therefore can be evaluated using an issue-based risk assessment method (Anon, 2007). Rating values were assigned to the likelihood (L) and consequence (C) of risk due to a hazard, using a 5 to 1 rating system. The rating value of 5 represents the worst case scenario and 1 represents the best case scenario for the likelihood of the risk and the consequence of harm due to the hazard (Foli *et al*., 2012).

The risk of the hazard was then determined from the 5 by 5 rated risk matrix chart. The risk rank (RR) values were estimated by tracing the assigned rating value from both axes to the intersection point (Table 1). An Initial Risk Assessment (IRA) was based on existing safety conditions that defined the common causes of accidents at the ASM sites. The process was repeated as Residual Risk Assessment (RRA) after suggested recommendations were incorporated.

The prioritisation of hazards was based on the RRA values.

Results and discussions

Dust and Noise Monitoring

Dust and personal noise exposure level monitoring results from the ten ASM sites were presented in histogram charts and compared with the American Conference of Governmental Industrial Hygienists (ACGIH) for the dust generation and noise emission (ACGIH, 2013) as presented in Fig. 3.

In Fig. 3a, results from all the sites, except site 4 were above the ACGIH of the occupational exposure limit (OEL) of 0.034 mg/m^3 for a 12-hour shift for dust emission. In Fig. 3b, all the sites recorded noise levels above the OEL of 85, which is the Threshold Weighted Average (WTA). The above results imply that workers at the ASM sites, irrespective of project status are prone to air impact health risks, particularly excessive dust generation (e.g. Chen *et al*., 2012).

These impacts are due to blasting and crushing of competent ores for the beneficiation of the gold. Such risks can be reduced through the regular maintenance of the crusher system to perform at low noise levels. Also, during crushing of consolidated ores, the material can be treated with dust suppressants to reduce

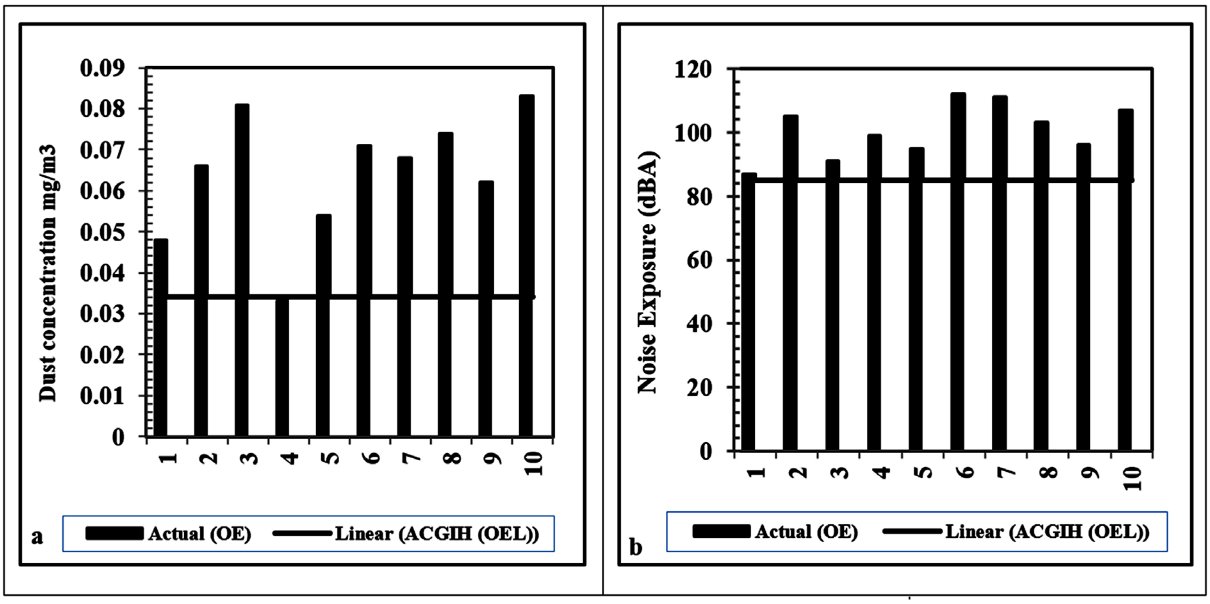

Fig. 3 Silica dust sampling (a) and noise monitoring results (b)

dust levels. Finally, the use of the appropriate PPE must be intensified to control both the dust and noise impacts.

Evaluation of social and operational parameters

The evaluation of Awareness of hazards, use of personal protective equipment (PPE), field monitoring by regulatory bodies, accident reporting trends and common causes of accidents are presented in histograms in Fig. 4.

Fig. 4a shows that 179 (71.6%) respondents are not aware of any mining risks, while 225 (90%) do not use PPEs due to reasons such as (1) high cost of purchases; (2) inferior equipment and; (3) personal discomfort during usage. In Fig. 4b, 166 (66%) respondents confirmed that registered sites are monitored annually, while 191 (76%) indicated that

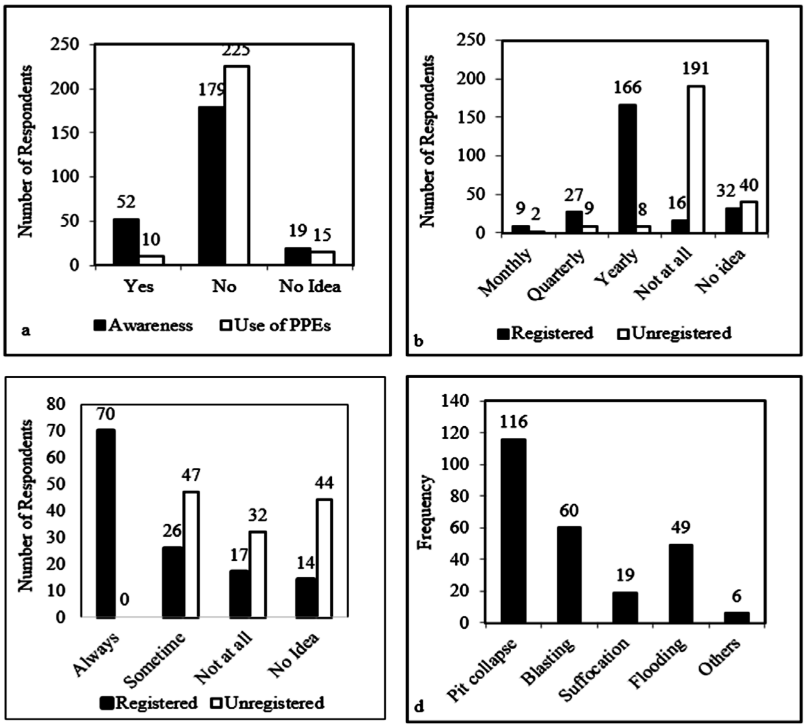

Fig 4: (a) Awareness of hazards and risks and uses of PPEs; (b) Field monitoring by regulatory bodies; (c) accident reporting trends; (d) causes of accidents

unregistered sites are not monitored. This trend may be due to the visibility of registered sites as against the unregistered sites, where work is generally done out of the reach of regulators. Another reason may be due to the aggression of workers of the unregistered sites which scares regulators away.

Fig. 4c shows that accidents are always or sometimes reported at registered sites, as against the unregistered sites; the disparity may be due to the fear of victimisation by workers at the unregistered sites. In Fig. 4d, the causes of accidents are in the order of Pit Collapse; Blasting; Flooding; Suffocation; and others. The above causes of accidents influenced recommendations made for the evaluation of the Residual Risk Assessment.

Accident Rates Evaluation

Incident Rate (IR) and Fatal Incident Frequency Rates (FIFR) were evaluated using data recorded from the relevant sites using equations 1-3 and are presented in Table 3.

From Table 3, both rates are lower at the official sites than the unofficial sites. Site 9, which is unofficial is the only site that recorded a fatality rate of zero but at the same time recorded a substantial number of injuries. This, therefore, suggests that there is a high probability of fatality to occur at the site 9 if precautionary measures are not put in place. For every major injury, there are about ten 10 minor injuries that require some attention, 30 accidents that could result in property damage and 600 incidents (Bird et al., 1969).

Risk Assessments

The initial risk assessment (IRA) and residual risk assessment (RRA) of the seven main hazard classes are compared and presented in Fig. 5.

In Fig 5, the RRA values are significantly lower than the IRA values for all the seven hazard classes due to the inclusion of the recommendations for risk reduction.

The percentage gain from reviewing IRA of the hazard classes by conducting an RRA ranges from 42% to 51% (average 47%). The order of prioritisation of the hazards is in the decreasing order of; H2 (Handling of explosives), H1 (Digging to expose the ore), H4 (Shaft sinking), H5 (Ore preparation and beneficiation), H7 (Underground mining), H6 (Working in poorly consolidated environment) and H3 (Tunnelling). The RRA process and the subsequent prioritization changes the understanding of the risk posed by potential workplace hazards and builds safety and health hazard awareness. The RRA also would help create a more resilient work environment and set the direction for good management of the potential workplace hazards and the associated

TABLE 3
Sampling site classification

No	Site Name	Vulnerable Population	Man-hrs/yr	Reportable injuries	Fatalities	FIFR	IR
			Asankragwa area				
1	Saa (U)	3800	9500000	35	3	0.06	0.74
2	Agona (R)	5400	13500000	-	2	0.03	-
3	Wassa Dunkwa (R)	7300	18250000	40	3	0.03	0.46
4	Domenase (R)	3300	8250000	-	1	0.02	-
5	Bremang (U)	1200	3000000	-	4	0.27	-
			Kenyasi area				
6	Sikamenaso (U)	5200	13000000	65	7	0.11	1.00
7	Nkasiem (R)	7000	17500000	-	5	0.06	-
8	Akentensu (R)	6100	15250000	45	1	0.01	0.59
9	Adengo (U)	1700	4250000	48	0	0.00	2.26
10	Kenyasi No 2 (U)	400	1000000	-	1	0.20	-

Registered = R; Unregistered = U

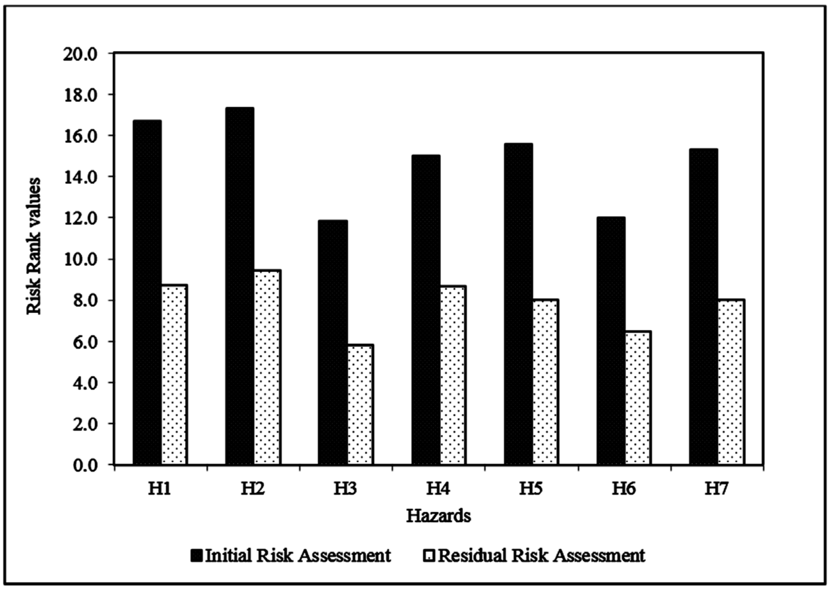

Fig 5 Chart comparing initial risk assessment (IRS) and residual risk assessment (RRA)

impacts. The detailed risk assessment for all the hazards is presented in the Appendix.

Conclusion and Recommendations

The results of the evaluation show that dust and noise pollutions are prevalent in the ASM sector. Ignorance about the risk of exposure to workplace hazards, low patronage of basic PPEs and low level of monitoring of activities are the main causes of accidents at ASM sites. In particular, activities at the unregistered sites are a great challenge for effective monitoring of safety and health issues. The study also shows the relevance of risk assessment of potential hazards at the ASM sites. Enforcement of all the safety requirements and massive education are therefore very necessary.

It is also recommended that: (1) risk assessments and ranking should be enforced requirements in the ASM sector to promote the culture of process reviews in the country; (2) acquisition of permit by all manner of ASM operatives must be ensured to improve monitoring and finally; (3) accident reporting and investigations procedures should be established and properly managed. These would assist in determining the trend of accidents at the ASM sites. Results can be used as operational standards for managing health and safety issues, more importantly, pertaining to ASM operations in Ghana.

Acknowledgement

We would like to acknowledge the contributions of all owners and workers of the Artisanal and Small-Scale Mining sites that allowed data capture on their respective concessions.

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Appendix (i to vii): Issue-based Risk Assessment of Major Hazards

Hazard Type	(i) Digging to expose the ore							
Tasks	**Impacts**	**Initial Risk Assessment L**	**C**	**RR**	**Recommendation**	**Residual Risk Assessment L**	**C**	**RR**
Use of hand-held tools and equipment such as compressors	Personal injuires	5	4	20	1) Mechanisation of load movement to and from ground; 2) Appply weight of loads and added personal support; 3) Regular shift system; 4) Adequate PPE usage required.	3	3	9
	Hearing impairment from air compressors (> 105dBA)	4	4	16	1) Stick to required standards; 2) Regular planned maintenace for eqquipment; 3) Adequate PPE usage required.	3	3	9
Heavy load handling	Load falls and equipment damage during excavation	4	5	20	1. Maintain the minimum safe distance from the edge of open ends.	3	4	12
	Workers falling from height during access into excavations	4	5	20	1) Provision ladder of adequate length; 2) Training in issues relating to working at height; 3) Point of contact during access and egress.	3	3	9
	Influx of water into excavations	3	3	9	1) Regular checks for water seepage or leackages from ground and installed facilities; 2) Institute dewatering mechanisms.	2	2	4
Ergonometrics	Ground instability and collapse of side walls and roof	4	5	20	1) Use benches or berms or batters; 2) Install and ensure efficiet ground support systems.	3	4	12
	Bodily vibration syndrome and recurrent strain injury over time	4	3	12	1) Purchase appropriate equipment, monitor and regulate exposure times; 2) Effective maintenance for A V systems, chain and bar; 3) Appropriate PPE usage.	3	2	6

Hazard Type	(ii) Handling of Explosives							
Tasks	**Impacts**	**Initial Risk Assessment L**	**C**	**RR**	**Recommendation**	**Residual Risk Assessment L**	**C**	**RR**
Imappriopriate storage of detonators and explosives	Untimely initiation or blasts	4	5	20	1) Provision of seperate magazines or apartments in the magazine with concise identification criteria; 2) Keep combustible materials within 8 m away from magazines; 3) Tidy magazine environment; 4) Detonators and explosives must be separately stored; 5) Exhaust old stocks befofore using new one; 6) Optimise use of magazines; 7) Ensure stable stacking systems.	3	4	12
Reckless handling of explosives during loading and blast hole loading activities	Untimely initiation or blasts, fly rock and misfires	4	5	20	1) Prevent any form of accidental contact with detonators; 2) Do not temper with detonators and accesories, or carry them in your pockets; 3) Ensure good communication links; 4) Ensure good attachment system and correct stemming method.	3	4	12
No security and use of untrained personnel	Personal injury	4	4	18	1) Ensure well secured magazine, and store only authorized explosives..	3	3	9
Infective tie up	Misfire and injury	3	4	12	1) Employ simple tie up system mechanism and use only competent personnel.	2	3	6
	Personal injury, dust, fireball - to injury to persons, equipment damage etc.	4	5	20	Ensure that all pre-blasting precautions are in place e.g. 1) adequate communication system; 2) Temporal blockage of access ways to blasting site; 3) Use of competent blasmen and 4) Adequate post firing inspection system.	3	3	9
	Untimely initiation or blasts	3	5	15	Follow standard procedures as stated above	2	4	8
	Poor or lack of coordination and communication	3	5	15	Follow standard procedures as stated above	2	4	8
	Damage to intrastructure due to vibration.	4	4	16	Follow standard procedures as stated above	3	3	9
	Personal injuries	4	5	20	Follow standard procedures as stated above	3	4	12

Hazard Type	(iii) Tunnelling/Adit Construction							
Tasks	**Impacts**	**Initial Risk Assessment L**	**C**	**RR**	**Recommendation**	**Residual Risk Assessment L**	**C**	**RR**
Digging of ground	Mass movement	4	5	20	1) Accurate and regular Geological and geotechnical evaluation of side walls; 2) Ground support sytems requied	3	3	9
	Competency of side walls	3	3	9	1) Accurate and regular Geological and geotechnical evaluation of side walls; 2) Ground support sytems requied	3	2	6
Furnishing tunnel with vital services	Confined spaces	4	3	12	1) Installation of modern ventillation systems to control airborne contaminants to improve air quality; 2) Provision of appriopriate PPEs as a stop-gap or provisional measure.	3	2	6
	Inadequate or poor ventillation	2	4	8	1) Installation of modern ventillation systems to control airborne contaminants to improve air quality; 2) Provision of appriopriate PPEs as a stop-gap or provisional measure.	1	3	3
Material transport	Seepage leackages, leading to flooding	3	4	12	1) Dewatering systems required; 2) Regular geotechnical and hydrological surveys and monitoring.	2	3	6
	Falling objects and humans from working height	3	5	15	1) Provide safe access and egress; 2) Good ground stabilisation systems such as cable bolting and mersh support required.	2	4	8
	Groundwater contamination from oil spills and other consumables	3	4	12	1) Keep all earth movement equipment in good condition; 2) contaminant neutralisers and oil-water separator required.	2	3	6
	Heat and humidity	3	3	9	1) Installation of ventilation equipment and improve lighting	2	2	4
	Temporary lighting supplies and adhoc ventilation systems	3	4	12	1) Regular planned maintenace for eqquipment	2	3	6
	Poor air quality (noise, dust etc.)	3	4	12	1) Stick to required standards; 2) Regular planned maintenace for eqquipment; 3) Adequate PPE usage required.	2	3	6
	Large scale materials and equipment handling	3	3	9	1) Mechanisation of material movement and transport; 2) Manual material handling techniques required for emergency situations.	2	2	4
	Groundwater contamination from oil spills and other consumables	3	4	12	1) Improve dewatering systems to prevent suddn flooding conditions; 2) Gas detection systems required to eliminate the incidence of gas poisoning.	2	3	6

Hazard Type	(iv) Shaft Sinking							
Tasks	Impacts	Initial Risk Assessment			Recommendation	Residual Risk Assessment		
		L	C	RR		L	C	RR
Limited Shaft dimensions or limited work space	Confined space injuries	4	4	16	1) Mechanised ventilation system required; 2) Dust extraction; 3) Supply of breathing equipment .	3	3	9
	Unstable grounduring lifting and removal of materials	3	3	9	1) Shaft head stabilisation and removal ofwaste material; 2) Lining or support of the shaft column.	2	2	4
	Inappriopriate and deffective hoisting components	4	5	20	1) Regular maintainance of hoisting equipment and systems	3	4	12
	Inadequate communication systems during underground operations.	3	3	9	1) Establishment of effective communication network; 2) Training and competency of workers	2	3	6
	Poor mining techniques leading to structural defects to the ground	4	5	20	1) Adopt the effective mining principles; 2) Monitoring of the pit infrastructure; Ensure adequate support systems.	3	4	12
	Materials falling and seapage of water along the shaft walls	4	4	16	1) Maintaining minimum safe distance from the edge of the shaft to waste; 2) Provision of effective wall support.	3	3	9

Hazard Types	(v) Underground Mining							
Tasks	Impacts	Initial Risk Assessment			Recommendation	Residual Risk Assessment		
		L	C	RR		L	C	RR
Excavation of ore	Poor conditions	2	5	10	1) Competent geological and geotechnical personnel required for regular monitoring	2	4	8
	Inadequate lack of installed ground support leading to failures and serious and fatal injuries.	4	5	20	1) Competent geological and geotechnical personnel required for regular monitoring	3	4	12
Transportation of materials and equipment down and up the shaft	Collapse or slump of wall	4	5	20	1) Effective ground support required; 2) Regular monitoring and maintenance of stabity features at the mining front	2	5	10
	Materials falling off due to undercutting	4	4	16	1) Maintain a minimum safe distance from the edge of the excavation; 2) Establish good communication and housekeeping; 3) Use of adequate PPEs.	2	3	6
	Instability of the excavation and adjoining structure	3	5	15	1) Competent geological and geotechnical personnel required for regular monitoring	2	4	8
	System Failures	4	4	16	1)The installation of mechanical systems are required for material transport; 2) Alternative material and personnel transport as backup for the mechanical set up.	2	3	6
	Access to subsidence zones	3	4	12	1) Competent geological and geotechnical personnel required for regular monitoring	2	3	6

Hazard Types	(vi) Working in unconsolidated environment							
Tasks	Consequence or Effect	Initial Risk Assessment			Recommendation	Residual Risk Assessment		
		L	C	RR		L	C	RR
Unregulated excavations and or material removal from working environment	Dam, diversion or storage facility collapse	3	5	15	1) Monitoring of dam levels and the provision and effective control of spill ways ; 2) Geotechnical assessment of the strengh of retaining walls.	2	4	8
	Flooding of mine area	3	5	15	1) Ensure no underground water piping systems 2) Install effective dewatering mechanisms.	2	4	8
	Pumping system failure	3	3	9	1) Planned maintenance schedule	2	2	4
	Excessive rainfall event	3	3	9	1) Natural hazard management procedureand work reschedulling	2	3	6

Hazard Types	(vii) Ore preparation and beneficiation							
Tasks	Impacts	Initial Risk Assessment			Ore Treatment and Processing Recommendation	Residual Risk Assessment		
		L	C	RR		L	C	RR
Inappropriate access to operating machinery	Personal injuries	4	4	16	1) Peronal safety conditions and drills required	2	3	6
	Breakdown or failed mechanical systems	3	4	12	1) Planned maintenace schedule for all mechanical systems; 2) Confirmation of energy isolation during maintenance" as part of the controls to prevent the risk of unwanted unwanted release of energy	2	3	6
Crushing of ore	Unwanted pressure releases and equipment falure	3	4	12	1) All couplings well tucked; 2) Installation of whip checks ; 3) increased level of monitoring; 4) Competency and awareness Training; 5) Regular planned maintenance scheduee etc.	2	3	6
Milling of ore	Mechanical and physical hazards	4	4	16	1) Planned maintenance schedule; 2) Confirmation of energy isolation during maintenance" as part of the controls to prevent the risk of unwanted unwanted release of energy 3) Isolation of crushing plant from populated areas; 4) appropriate use of PPEs .	3	3	9
	Contact with processing chemical through all contamination pathways.	5	4	20	1) Avoid skin contact – use PPEs (gloves, overall and respiratory protection)	4	3	12