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The hazardous nature of small scale underground mining in Ghana

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ABSTRACT

Small scale mining continues to contribute significantly to the growth of Ghana's economy. However, the sector poses serious dangers to human health and the environment. Ground failures resulting from poorly supported stopes have led to injuries and fatalities in recent times. Dust and fumes from drilling and blasting of ore present health threats due to poor ventilation. Four prominent small scale underground mines were studied to identify the safety issues associated with small scale underground mining in Ghana. It is recognized that small scale underground mining in Ghana is inundated with unsafe acts and conditions including stope collapse, improper choice of working tools, absence of personal protective equipment and land degradation. Inadequate monitoring of the operations and lack of regulatory enforcement by the Minerals Commission of Ghana are major contributing factors to the environmental, safety and national security issues of the operations.

1. Introduction

Small scale mining (SSM) may refer to the mining of ore deposits by individuals or groups of persons with little technical know-how and characterized by minimal or no mechanization. Some countries define SSM operations based on output and human resources needed (Coakley, 1999). However, the definition of SSM in Ghana has been based on the amount of capital and human resources needed. The Minerals and Mining Act 2006 (Act 703) of Ghana defines small scale gold mining operation as the mining of gold by any effective and efficient method that does not involve substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of 10 or more persons. Small scale mining is recognized as a major contributor to national income and a pillar for poverty reduction in developing countries (Hentschel, Hruschka, & Priester, 2003). Small scale mining of minerals such as gold and diamond has provided employment for thousands of Ghanaians, especially indigenes of SSM communities, and has made significant contributions to the foreign exchange earnings of the country. In 2014, the sector produced 1.49 million ounces of gold representing 34.3% of Ghana's total gold output (Ntibrey, 2016). The sector has also helped in stemming rural-urban migration, and provided raw

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materials for both foreign and local mineral industries. As a result SSM is recognized by government as a cornerstone of a multimillion dollar industrial sector, the products and sales from which are controlled. The government of Ghana under the auspices of a German Non-Governmental Organization (NGO), Gesellschaft Technishe Zusannebarbeit (GTZ), and the World Bank has undertaken a number of initiatives to formalize and regularize resident SSM operations (Hilson, 2001).

In Ghana, SSM has been carried out for hundreds of years. It is currently and widely operated in the country by both licensed operators and unlicensed miners popularly known as *galamsey* operators. According to the Ministry of Lands, Forestry and Mines of Ghana, the number of small scale miners increased rapidly by 941.73% from 1984 to 2004 following the promulgation of the Small Scale Gold Mining Law, PNDC Law 218 of 1989. The legalization was to revive the SSM sub-sector, facilitate supervision and minimize associated environmental hazards.

Although the efforts by government and the NGOs have noticeably improved the efficiency of operations, certain serious concerns continue to be largely ignored by the miners, the Minerals Commission and government, and have increasingly become unmanageable. Ground failures resulting from weak unsupported or poorly supported stopes have led to fatalities and various degrees of injury in recent times. Dust and fumes generated from chiseling, drilling, blasting, grinding and crushing of ore are potential health threats. Most of the stopes worked in by the miners are accessed by adits without adequate ventilation systems in place, leading to the accumulation of dust and fumes in the underground workings. Health hazards related to dust and fumes are well documented in the literature (Dockery et al., 1989; Bascom et al., 1996; Gielen, Van Der Zee, Van Wijnen, Van Steen, & Brunekreef, 1997; Pope, Hill, & Villegas, 1999; Yu, Sheppard, Lumley, Koenig, & Shapiro, 2000; Dockery, 2001; Gan, Man, Senthilselvan, & Sin, 2004; Gauderman et al., 2004; Jansen et al., 2005; Colucci, Veronesi, Roveda, Marangio, & Sansebastiano, 2005; Bansah & Amegbey, 2012). SSM activities can generate high levels of noise which can result in hearing impairment, as the use of hearing protection is largely ignored by the miners. Other problems related to noise include stress related illnesses, high blood pressure, speech impairment and lost productivity as described by many researchers (Pulles, Biesiot, & Stewart, 1990; Maschke, Harder, Hecht, & Balzer, 1998, Maschke, Harder, Ising, Hecht, & Thierfelder, 2002, Maschke, Ising, & Arndt, 1995; Ising & Kruppa, 2004).

Small scale mining operations endanger the environment by inducing land degradation and contaminating surface and groundwater resources. Wide open excavated areas are left unreclaimed while heavy metals, total suspended solids, dissolved solids, and other water contaminants are introduced into water bodies by mining and mineral extraction activities of the small scale miners. Mercury amalgamation technique, which is heavily relied on for gold extraction can pose serious health threats and is deleterious to a wide range of ecological entities (Harada, 1995).

Even though, SSM in Ghana is by law limited to only Ghanaians, the last decade has seen a large increase in involvement by foreign nationals, mostly Chinese miners and migrants from neighboring Togo, Burkina Faso and Ivory Coast and others from western and non-western cultures. The small scale mining activities of these foreign nationals have involved the destruction of cocoa farms, wide areas of land and protected forests, and reported as security threat to the people of Ghana (Al-Hassan & Amoako, 2014). In 2013, an inter-ministerial taskforce (drawn from the military, immigration and police) was set up by the president of Ghana to crackdown on these illegal miners. During that year, the Ghanaian authorities arrested and deported over 4500 illegal Chinese miners (The Guardian, 2013). The Chinese foreign minister visited Ghana in 2014, and pledged Beijing's support to help tackle the illegal small scale mining issue (Agence France-Presse, 2014). Although government's interventions have reduced the scale of illegal mining activities by foreign nationals, there are still some foreign nationals operating in remote mining areas (e.g. Manso Nkran) of the country.

The influx of migrant miners has led to a higher level of mechanization of the operations (use of excavators, trucks, dredging machines, crushers, etc.) and has increased the scale of mining. Consequently, this has increased the levels of land degradation, rechanneling of river/stream courses, and contamination of surface water bodies in terms of increased turbidity, total suspended solids (TSS), and total dissolved solids (TDS) to unacceptable levels. Bansah and Bekui (2015) report unacceptably high turbidity levels of water samples from the Bonsa River in the Western Region of Ghana, and attributed the levels to pronounced mining activities in and around the river. The colour of most streams in the vicinity of the operational areas can also be described as aesthetically objectionable.

It is publicly known that small scale miners in Ghana operate in unsafe conditions, and pose serious threats to other land users and the environment. However, very little research has been conducted to ascertain and address the safety and environmental issues related to small scale underground mining in Ghana. This paper therefore identifies the safety issues in small scale underground mines in Ghana and suggests methods to improve the safety of operations. Field visits were made to four different small scale underground mines; Dakete Mining Limited, Mohammed & Co. Small Scale Mining, Johnson Mining Company Limited, and Stejoan Mining Group, around Tarkwa in the Western Region of Ghana to assess the conditions of operations. Mine owners and mine operators were interviewed on site while the underground workings were accessed for relevant first hand information. Visits were also made to the office of the Minerals Commission, a regulatory body, to interact with personnel on their views on small scale underground mining in Ghana and the need for health and safety training for the mine operators to mitigate the dangers associated with SSM operations in Ghana.

2. Legal and regulatory framework of small scale mining

According to the World Bank, small scale mining is widespread in developing countries in Africa, Asia, Oceania, and Central and South America (World Bank, 2013). Small scale mining (both surface and underground) is practiced in Ghana and is also reported to occur in South Africa, China, Zambia, Congo, Rwanda Philippines, and India (Bugnosen, 2001; CIFOR, 2012; Chakravorty, 2001; Gunson & Yue, 2001; Hentschel et al., 2003; Kambani, 2003). In an effort to manage and promote an efficient SSM sector, the South African, Chinese, Indonesian and Ghanaian Mining Laws, for example, make some provisions for small scale mining. The legal requirements while sharing some similarities, vary from one country to the other. This section briefly reviews the relevant legal and regulatory framework regarding SSM in South Africa, China, Indonesia and Ghana.

2.1. South Africa

Small scale mining in South Africa is regulated by the Mineral and Petroleum Resources and Development Act (MPRDA) 2002. The Department of Mineral Resources (DMR) established the Directorate of Small-Scale Mining to develop and address the challenges faced by the small-scale mining sector in South Africa (DMR, 2011). Mutemeri, Sellick, and Mtegha (2010) report low level of compliance as one of the challenges facing the SSM sector. They further indicated that small scale miners do not comply with the requirements to submit monthly production reports, making it difficult for government to accurately quantify the mineral production and other statistics of the sector.

The SSM sector in South Africa is categorized into: (i) artisanal or subsistence mining operations (new entrants); (ii) sub-optimal formal mining operations; and (iii) entrepreneurs with upfront capital (DMR, 2011).

The Mine Health and Safety Act (MHSA), 1996 and amendments regulate health and safety in small scale mining. The Mine Health and Safety Council was set up to advise the Minister on issues of legislation, research and promotion of occupational health and safety in the mining industry. It also oversees research in the mining sector pertaining to issues of health and safety (Mutemeri et al., 2010). The MHSA (Act 74, 2008) provides for safety, health and environment (SHE) training, and requires employers to keep training records for individual employees. Environmental management is regulated by National Environmental Management Act (NEMA) 1998 by guiding the environmental provisions provided under the Mineral and Petroleum Resources and Development Act (MPRDA) 2002.

2.2. China

The mineral industry in China is governed by the 1986 Mineral Resources Law and the 1996 Mineral Resources Law. According to Shen, Dai, and Gunson (2009) substantial body of law relating directly or indirectly to the artisanal and small scale mining sector exists in China. These laws, regulations and measures are grouped into four categories (Andrews-Speed, Yang, Shen, & Cao, 2003) as follows: (i) laws and regulations of right to mineral resources; (ii) regulations of coal mining operations; (iii) laws, regulations and measures of environmental protection and land management; and (iv) regulations of township and village mines (TVMs).

Shen et al. (2009) indicate that the first category was promoted by the restructured former Ministry of Geology and Minerals Resources (now Ministry of Lands and Natural Resources). The Ministry implements the rules and issues exploration and mining licenses. The second category covers mine development, operations, production, management, marketing and safety. The third category, which relates to environmental protection and management, is administered by the Ministry of Environmental Protection. Laws and regulations regarding the protection of soil and water ecosystems are covered under this category. The final category of regulations is specific to small scale mines. The regulations in this category address a wide range of issues from engineering and safety standards, to inspection procedures, role of different levels of government, responsibilities of mine managers, employee contracts, and the legal status of township and village mines.

2.3. Indonesia

The Indonesian Mineral and Coal Law (2009) allows Indonesian citizens, as individuals or cooperatives to apply for a license to conduct small scale mining in designated areas. According to Macdonald, Lund, Blanchette, and Mccullough (2014), a mechanism of licensing, permitting, management and control of small scale mining is not clearly stipulated in the law. However, the management and control of SSM is fully decentralized to regional governments. The decentralization of authority is recognized as a significant contributor to unintended growth in illegal small scale mining in Indonesia (Gita, Primanti, Zaki, & Ismawati, 2012). As a signatory to the 2013 UNEP International Treaty on Mercury, the use of mercury in mining is illegal in Indonesia.

It is reported in the literature that Indonesia lacks the institutional and technical capacity to provide adequate assistance to assess impacts or enforce compliance, especially at the local and regional levels (Sousa, Veiga, Meech, Jokinen, & Sousa, 2011). According to Macdonald et al. (2014), the sheer numbers of artisanal and small scale miners and locations, combined with poorly understood temporal and spatial variability of impacts on aquatic ecosystems complicate efforts of local and regional environmental managers to regulate activities.

2.4. Ghana

In 1989, the Small Scale Gold Mining Law (PNDCL 218), Mercury Law (PNDCL 217) and the Precious Minerals Marketing Corporation (PMMC) Law (PNDC Law 219) were promulgated after the government recognized the contribution of SSM to Ghana's development. The Minerals Commission of Ghana, which is responsible for assisting the Minister of Mines with small scale licensing procedures and monitoring of operations, established seven small scale mining district centers (in Tarkwa, Dunkwa-on-Offin, Bibiani, Asankrangwa, Assin Fosu, Akim Oda, and Bolgatanga) to provide technical extension services to the miners and improve supervision. In particular, the district centers were required to perform the following functions: (i) compile a register of all small scale gold miners and prospective small scale gold miners specifying such particulars as may be determined by the secretary; (ii) supervise and monitor the operation and activities of the small scale gold miners and prospective small scale gold miners; (ii) advise and provide such training facilities and assistance as may be necessary for effective and efficient small scale gold mining operations; and (d) submit to the Minerals Commission in such form and at such intervals as may be directed by the commission, reports or other documents and information on small scale gold mining activities within the district (Small Scale Gold Mining Law, PNDCL 218 of 1989). Currently, there are nine district centers that include the Wa and Konongo district centers to provide such services to the small scale mining community.

Under the law, no person shall engage in or undertake any small scale gold mining operation unless granted a license. The law allows provision of mining license to only Ghanaian citizens who are 18 years or over and registered by the district center in the designated area. The procedure by which individuals have to obtain small scale mining licenses are described by the miners as tedious and expensive, hence most small scale miners operate illegally. Institutionally, the Minerals Commission is responsible for policymaking and regulatory activities in the mining industry. A 2002 report by the Commission indicates that 420 SSM concessions were licensed in Ghana. Of these, nine were diamond licenses and 411 were gold. One thousand four hundred and thirty six (1436) licenses have been issued to small scale miners in Ghana as of April 2015 (Ntibrey, 2015).

The Ghanaian laws legalize the use of mercury in SSM; "a small scale gold miner may purchase from any authorized mercury dealer such quantities of mercury as may be reasonably necessary for the purposes of his mining operations" (Small Scale Gold Mining Law, PNDCL 218 of 1989). The Minerals and Mining Act, 2006 permits the use of explosives by small scale miners with the written permission of the Minister on the recommendation of the commission (Parliament of the Republic of Ghana, 2006).

Unlike China and South Africa, the PNDCL 218 has no specific regulations or measures for ensuring safety and the protection of health and the environment in the small scale mining sector. Under section 11 of PNDCL 218, "a person licensed to mine gold under this Law may win, mine and produce gold by any effective and efficient method and shall in his operations observe good mining practices, health and safety rules and pay due regard to the protection of the environment". This provision is vague, as neither "effective and efficient method" nor "good mining practices" are defined, giving room for miners to operate in the manner they like, and posing a challenge to monitoring officers in effectively discharging their duties. The Minerals and Mining (Health, Safety and Technical) Regulation, LI 2182 offers regulations regarding health and safety in the mineral industry of Ghana. This regulation however, lacks specific and detail requirements for health and safety issues in small scale mining operations. Of significant mention is the absence of specific regulations regarding small scale underground mining in Ghana.

There are over 18 legislation and reforms (ICMM, 2015), of which 10 have been repealed. These legislations and reforms are however more geared towards the large scale mining. The few available regulations are not enforced to the letter. According to Macdonald et al. (2014), law enforcement in artisanal and small scale mining in Ghana is poor and often unevenly applied.

3. Small scale mining methods

The nature of the mineral deposit generally dictates the mining method to be employed for exploitation. Historically, SSM methods for exploiting mineral deposits have involved the *anomabo*, chisel and hammer, underground "ghetto", and the dig and wash methods. More recent methods that involve the use of simple inexpensive Chinese-made equipment or more expensive and sophisticated machinery are being practiced. These recent methods brought about as a result of influx of Chinese nationals into Ghana are locally referred to as "changfa", "more blade", dredge, and alluvial washing plant methods in resident communities. The following sections briefly discuss the SSM methods adopted in Ghana.

3.1. *Anomabo method*

This method is a dredging method used in the mining of gold bearing gravel from river beds. In this method, a miner dives and scoops the gold bearing gravel from the river bed. The gravel is put in a bucket, hoisted up onto a raft and then washed onshore. This method is employed after the rainy season when loose materials are eroded and deposited on the river beds (Yamoah, 2002, pp. 18–19). Typically, a crew of two persons is involved in this mining method.

3.2. *Chisel and hammer method*

According to Tepkor (2005, pp. 5–9), this method is employed for mining hard rock (lode) formations occurring mainly as outcrops. The vegetation and the top soil are removed either manually or mechanically to expose the rock. Chisels and hammers are used to fragment the gold bearing rock. The broken rock is transported to be crushed and ground by mechanical crushers or manually with metal mortars and pestles into fines. Sluicing is usually used to recover the gold particles from the ground materials (Acheampong, 2009, pp. 3–22).

3.3. *Underground "ghetto" method*

This method involves mining of hard rock from underground workings. The workings are mostly in old and abandoned mines and are accessed mainly by shafts or adits. The fragmented gold bearing rock is carried to the surface in bags by the miners for processing. The underground method employed by small scale miners is labour intensive and also involves high risks due to possibility of stope collapse in poorly supported stopes.

3.4. *Dig and wash method*

This method is used for mining alluvial gold deposits that occur on the banks of rivers, in old valleys, on terraces, or in the tailings dumps of old mine workings. Tools such as spades, shovels and pickaxes are used to dig the materials. The dug material is then transported and usually stockpiled along the banks of nearby streams or water bodies where they are subsequently washed.

3.5. *Changfa method*

The changfa method originated from the name of a Chinese-made (changfa) diesel powered rock crusher that is used for crushing excavated auriferous deposits. The unit is mostly fabricated and welded or assembled locally in Ghana by Chinese entrepreneurs. The method typically involves excavating ore deposits manually with simple tools such as pickaxes, shovels or spades. Head-loads of the materials are then carried (by women in most instances) or in wheelbarrows (by men) to the changfa location for processing. The materials are re-handled by shoveling into the crusher for comminuting. A water pump connected to the crusher continuously pumps water, mostly from a sump onto a sluice board (usually lined with a blanket) connected to the crusher chute for washing. After a while the changfa motor is shut down and the blanket is removed and washed in a drum containing water to obtain the trapped gold for further processing. Typical duration of operation is 8 h/day with the labourers earning between US$25 and US$40 a day. Fig. 1a shows a changfa used in Tarkwa for crushing rocks at a SSM site.

3.6. *"More blade" method*

This method is a modified form of the dig and wash method. It involves the use of excavators for mining in the pit. It is usually done close to a stream or river where the water can be directed into the pit. The site owner hires a gang of typically 50 people. A 10-person crew is assigned a sluice board in the pit. The excavated products are re-handled with shovels onto the sluice boards where the materials are washed, as some members of the crew manually fetch water and pour it onto the sluice board. Other members of the group may also use pans to wash the materials, complementing the sluice board washing. It is labour intensive and the employees typically work for 6 h a day with an average income of US$25 per person for every 3 days. Fig. 1b shows the "more blade" method of mining.

3.7. *Dredge method*

This mining method is similar to conventional methods using suction dredges. However, the suction dredge in this method is locally made from discarded metals and powered by two changfa motors. The gold-bearing sediments are excavated directly by suction from the stream/river bed and transported hydraulically onto sluice boards mounted along the bank of the stream/river for washing (see Fig. 1c). This method is less labour intensive than the changfa and "more blade" methods. It typically involves a crew of 5 persons who together, usually

Fig. 1 – Artisanal Small Scale Mining Methods: (a) Changfa in Operation, (b) "More Blade" Method, and (c) Typical Dredge Method: Changfa motors (arrowed red), suction hose (arrowed blue) and working platform (arrowed dark orange).

earn a little over US$500 over a period of three weeks, if yields are high.

3.8. *Alluvial washing plant*

This method is quite mechanized and is less labour intensive. It involves the use of two excavators and a mini washing plant. The two excavators work in tandem: the first, excavating the auriferous deposit and stockpiling it adjacent to the second excavator; and the second, re-handling the excavated materials onto the washing plant for washing. This method has high output and typically involves a 9-person crew.

4. Socio-economic impact of small scale mining

There is a wide range of published literature by researchers and international organizations such as the World Bank, International Institute for Environment and Development (IIED), and the International Labour Organization (ILO) on the socio-economic significance of small scale mining (World Bank, 2013; Kitula, 2006; Hilson, 2001; Bryceson & Jønsson, 2010; Chakravorty, 2001; Mwaipopo, Mutagwaba, Nyange, & Fisher, 2004). The World Bank describes the artisanal and small scale mining sector as an important livelihood and income source for the poverty affected local population. According to the Bank, the artisanal and small scale mining sector ensures the existence for millions of families in rural areas of developing countries. It estimates that about 100 million people (workers and their families), depend on artisanal and small scale mining compared to about 7 million people worldwide in industrial mining (World Bank, 2013). The sector has made immense contributions to the production of minerals in the world.

The small scale mining sector contributes largely to the economy of host countries. In China, for example, the artisanal and small scale mining sector employed over 5 million people and produced over half of the mineral production in 2006 (Shen et al., 2009). The small mining sector in Ghana is reported to contribute significantly to the growth of the country (Amankwah, Frempong, & Niber, 2015; Aryee, Ntibery, & Atorkui, 2003; Hilson, 2006; Yakovleva, 2007). It offers direct or indirect employment to mostly unskilled or less-skilled individuals from the rural communities where they are practiced, as watchmen, mechanics, electricians and equipment operators, porters, food sellers etc. Although, there is no precise data on SSM population in Ghana, the Minerals Commission estimates that more than 1,000,000 persons directly engage in SSM in Ghana.

Ghana earns foreign exchange from the export of minerals. According to the Minerals Commission of Ghana, the small scale gold mining sector contributed 7% of the $694,970,543 gold revenue to the government in 2002. According to Ntibrey (2016), artisanal and small scale mining contributed 34.3% (1.49 million ounces) of total gold production in 2014, and 33.9% (1.44 million ounces) in 2013. All the diamonds produced in Ghana since 2008 came from artisanal and small scale mining (Ntibrey, 2016). The industry also provides some of the raw materials for mineral-based domestic industries. These include kaolin for the manufacture of local paint and cosmetic powder, salt for pharmaceutical products, mica for the ceramic industry and gold for the manufacture of jewels (Acheampong, 2009). According to Oblokuteye (2010, pp. 15–17), the commencement of SSM activities in rural areas has helped in the minimization of the problems of rural-urban migration. Indeed, according to the World Bank, small scale mining helps to stem rural-urban migration (World Bank, 1995).

However, the sudden influx of miners to new areas, in an attempt to escape poverty and get rich, introduces different cultures sometimes to the disadvantage of the indigenes. The dominance of male miners creates fertile grounds for prostitution and sexual promiscuity. There is also the danger of increased levels of truancy, school dropout and rising illiteracy levels as school-age children get engaged in SSM activities (Al-Hassan & Amoako, 2014).

5. Environmental and safety issues in SSM

SSM over the years has resulted in a wide range of negative impacts on the environment (Kitula, 2006; Aryee et al., 2003; Bonzongo, Donkor, & Nartey, 2003). Tarras-Wahlberg, Flachier, Lane, and Sangfors (2001) studied the environmental impacts and metal exposure of aquatic ecosystems in rivers contaminated by small scale gold mining in the Puyango River basin of Southern Ecuador. Their study found that the discharge of cyanide, mercury and metal rich tailings into rivers of the Puyango catchment area from small scale mining were causing considerable environmental impacts. Cyanide and metal levels in the rivers were found to exceed environmental quality criteria.

In Ghana, the environmental impacts of small scale mining (mostly surface operations) have included water contamination, destruction of flora and fauna, land degradation, and mercury contamination of soils and water (Aryee et al., 2003; Babut et al., 2003; Hilson, 2002; Bonzongo et al., 2003). There are also reported cases of disregard for basic safety protocols resulting in death, damage to property and to the environment (Al-Hassan & Amoako, 2014). The following sections discuss the various environmental and safety concerns associated with SSM in Ghana.

5.1. *Effect on land*

Coomson (2004, pp. 5–9) describes land degradation as the major impact of SSM on the environment in Ghana. Flora and fauna are destroyed in the process of mining. The dimensions of surface SSM openings vary from shallow (<30 m) to deep depths (>30 m). The mining of deep deposits typically produce wider openings than shallow deposits. The openings are often left unreclaimed after the ore extraction. Small scale underground openings are commonly not backfilled after mining. These openings have the tendency of collapsing and trapping or killing farmers, hunters, and animals. Water may also fill abandoned stopes or pits, serving as potential breeding zones for mosquitoes. Examples of deep trenches and pits left after mining by small scale miners in Ghana are shown in Fig. 2a.

Fig. 2 – Environmental Impacts of SSM: (a) Abandoned deep pits and trenches, (b) Excavated river bank.

5.2. *Effect on water*

SSM of alluvial gold is believed to be the major cause of river water pollution in Ghana (Al-Hassan & Amoako, 2014; Aryee et al., 2003). Due to the dredging activities and the washing of alluvial gold in the water, siltation is common in major rivers and streams where the miners operate. The operations have also changed some water courses of streams and rivers (Oblokuteye, 2010), depriving downstream users of their only source of water. Fish and other aquatic organism die-off can occur, altering the food web significantly. Individuals depending on the rivers for fishing are forced to abandon their source of livelihood resulting in less food availability in the communities. The Bonsa River, for example, which was relied on by farmers and some community members for their source of drinking water and fish has been affected by illegal small scale mining. Fig. 2 (b) shows a section of the Bonsa River where the mining activities occur. Piles of excavated materials have been heaped along the river bank with trees felled into the river. The impact of small scale mining on aquatic ecosystem in other parts of Ghana is reported by Babut et al. (2003) and Donkor, Bonzongo, Nartey, and Adotey (2006a).

5.3. *Air quality, noise and poor ventilation*

Air pollution resulting from mining related activities comes from the generation of dust and emission of mine gases especially during drilling, blasting, grinding and crushing of ore. Al-Hassan and Amoako (2014) discuss ambient air quality deterioration by fine particulates released from the sieving of crushed rock obtained by small scale mining. In surface operations, dust and emissions are diluted by the wind. However, due to the confined nature of small scale underground mining (SSUM) operations, dust generated in the stopes accumulates, and serves as a potential health threat to the miners. Most of the stopes are accessed by adits (same opening for entry and exit) without any ventilation system in place. This issue is typically as a result of ignorance on the part of the operators. Some of the small scale mining operators interacted with were unaware about the existence of fans that can supply the underground workings with adequate air.

The small scale underground miners typically resume working in the stopes after blasting, when they no longer see suspended dust particles, or smell the blast fumes. However, this approach can be misleading since fine inhalable particles can remain suspended and not seen with the eye. Mohammed & Co. small scale underground mine attempts to solve the air quality problem in their stopes by installing a ventilation fan to decontaminate the underground workings.

Small scale mining activities can generate loud noise that can result in hearing impairment of the miners and nuisance to the residents of SSM communities. The changfa crushers produce loud noise that can affect the hearing of the operators who often operate the machines without any form of hearing protection. People who live in close proximity to the operations see the small scale mining activities as major source of nuisance. For example, residents at Nkanponase, a community located opposite to the University of Mines and Technology in Tarkwa complain about nuisance from blasting activities by small scale miners who operate in close proximity to the community. According to the 67 year old queen ("ohemaa") of the community–Nana Afua Nakra, the sudden blasting activities conducted by the miners frighten the community members who believe that such practices could endanger their health:

> "They don't tell us about the blasting; we only hear of sudden loud noise and ground vibrations from their blasting work. We get frightened; sometimes it happens even when we are sleeping, and personally, it makes my heart beats faster. The last time for example, I had all my louver blades come off the building".

To support some of her claims, the queen mother granted access for visual inspections of the interior walls of her bedroom where cracks attributed to the blasting were discovered in the building. A 70-year old carpenter and other community members shared similar complaints. According to the community members, all efforts to address the issues have proven futile. Fig. 3 shows structural deformations in building structures at Nkanponase that are attributed to blasting activities by the small scale miners.

5.4. *Ground failures*

Ground failures resulting from unsupported or poorly supported stopes and poor pit design have led to fatalities and various degrees of injury in recent times. In early 2016, six small scale miners were killed at Kyekyere in the Ashanti Region of Ghana when a pit wall collapsed. A collapse that

Fig. 3 – Cracks in the walls (bedrooms) of Building Structures at Nkanponase. ***Residents attribute the cracks to blasting activities by small scale miners.***

occurred in 2015 killed 17 people at a small scale mine in the Central Region of Ghana. And at least 45 people were killed in 2010 when an illegal gold mine collapsed after heavy rains, while at least 18 people (including 14 women) were killed in November, 2009.

Opoku-Antwi (2010) indicates that small scale miners invariably do not report accidents that occur at the mining sites because of fear of drawing public attention. Indeed the public only gets to know of accidents that result in fatalities at the small scale mining sites. Non-fatal accidents are kept hidden from the general public. Hand and feet injuries that ever occurred in the small scale mines (the authors visited) were never reported to authorities or made public.

In the authors' opinion, the ground failures can be attributed to lack of planning, ignorance of the nature and types of rock (in terms of strength and stability), and inappropriate choice of mining methods, occasioned by lack of technical expertise of the operators. This problem can be overcome by involving professional engineers (including mining and geological engineers). However, most of the professional engineers interacted with do not find small scale mining dignifying, besides the low incomes and therefore do not want to associate themselves with such operations.

5.5. *Impacts of mercury amalgamation technique*

Although the use of mercury for processing of ore has serious adverse effects on human life and the ecosystem, not much attention has been given to mercury contamination in Ghana (Donkor, Nartey, Bonzongo, & Adotey, 2006b). Unfortunately, there is no reliable data to assess the extent of mercury contamination in the communities in which mercury is used. Literature available on mercury contamination by small scale mining in Ghana include Bonzongo et al. (2003), Babut et al. (2003), Serfor-Armah, Nyarko, Adotey, Adomako, and Akaho (2005), Kwaansa-Ansah, Basu, and Nriagu (2010) and Donkor et al. (2006a, 2006b). Babut et al. (2003), for example, in a United Nations Industrial Development Organization (UNIDO) study to determine the environmental impacts of mercury prior to the introduction of mercury retorts, conducted analysis on river water, soil and fish samples obtained from Dumasi, (a small scale mining village with about 2000 people) in the Western Region of Ghana. The results showed significant contamination of soil sediments. Most of the fish fillets were also found to have accumulated mercury levels that exceed the United States Food and Drug Agency (US-FDA) action level. The fish from the rivers were reported to be unfit for consumption.

Mercury amalgamation technique is heavily relied on for processing gold-bearing ores because mercury is inexpensive and readily available to the miner. All the small scale mines visited utilize mercury for extracting the gold. The technique simply involves mixing of washed ore with mercury. The gold bearing concentrate combines with the mercury to form an amalgam. The mercury amalgam is heated to get rid of the mercury to obtain the gold. A careful observation of the amalgamation process by the authors at some of the small scale mines revealed the high possibility of mercury losses. Apart from the evaporation of the mercury vapour into the atmosphere (because the retorting is done openly), the mercury sometimes pours onto the ground. The mercury is typically kept in small dispensing bottles. At one of the mines, a miner inadvertently stepped on one of these bottles, forcing its contents out onto the ground. Even though the mercury was recovered, there were still some losses. These findings were consistent with that of Babut et al. (2003) that mercury losses in SSM mainly occur during amalgamation.

Also, the miners do the amalgamation without any form of personal protective equipment (PPE) such as gloves, overalls and nose protection. This makes them susceptible to mercury poisoning, or agents of mercury transfer to other systems (such as food and drinking water), as small scale miners commonly share food or drinking water with their colleagues and friends. It is not uncommon to find a small scale miner holding an amalgam with the bare hands.

6. Materials and methods

To ascertain the safety and environmental issues in small scale underground mining in Ghana, field visits were made to four licensed small scale underground mines at Tarkwa in the Western Region of Ghana. Visits were also made to the office of the Minerals Commission to interact with the district officer and his assistant (secretary) for relevant information such as number of licensed operators and logistics, and in general, their views on the small scale underground mining operations. The underground workings of the small scale mines were accessed for first hand information about the operations, while mine owners and operators were interacted with on the safety and environmental issues of their operations. Rock samples from the stopes of each mine was taken for rock strength analysis to determine the uniaxial compressive strength of the rocks in which the miners operate. The following sections describe the study site, methodology of study, and the mining and safety practices at the small scale underground mines in Tarkwa, Ghana.

6.1. *Study site and methodology*

Tarkwa which is host to eight licensed small scale underground mines is a historical mining community with series of old abandoned underground mine openings. It currently hosts three large scale mining companies including Goldfields Ghana Limited, AngloGold Ashanti Iduapriem Limited, and Ghana Manganese Company Limited (all operating surface mining). Goldfields Ghana Limited and AngloGold Iduapriem Limited produce gold, while Ghana Manganese Company produces manganese. Tarkwa is the capital city of the Tarkwa-Nsuaem Municipal Assembly and is located on latitude 5.3000° N and longitude 1.9833° W. The city is 300 km west of Accra (the capital of Ghana) by road. The 2013 census data put the population of Tarkwa at 34,941, with the main occupation of the people being mining.

The city has a small scale mining district support center to provide technical and extension services to the small scale mining sector as required by law. According to the district officer at the Minerals Commission, over 300 licenses have been issued to small scale miners to conduct small scale mining in the Tarkwa district. However, there are only 15 licensed small scale mines currently in active operations; five are surface operations and 10 are underground operations, of which four are in Tarkwa, and the others in the Nsuaem area of the Western Region of Ghana.

These four licensed small scale underground mining operations that produce gold in Tarkwa include Dakete Company Limited, Johnson Mining Company Limited, Stejoan Mining Group, and Mohammed & Co. Small Scale Mining. Together, these mines employ 507 permanent and casual workers: Dakete, 162; Johnson, 200; Stejoan, 100; and Mohammed & Co., 45. The industry is male dominated with the average age of the workers being 35 years. The income of the employees ranges from US$ 62 to US$ 400 per month for 8-h shift, depending on the nature of work. For example, a woman carrier who is paid a daily wage of 10 Ghana cedis (US$ 2.57) earns a monthly income of US$ 77 if she works every day for 30 days, while a miner, who chisels the rock, loads and carries the materials himself to the surface for processing may earn US$ 300 per month for 8-h shift.

Due to poor record keeping, statistical data at the mines are sketchy. However, it is estimated that more than 60% of the workers are indigenes of Tarkwa and have typical family sizes of five. The others include Ghanaians from other parts of the country and foreign nationals. The highest educational qualification of a worker is a three-year junior high school certificate. The typical working duration is 8 h; 8:00 am to 5:00 pm, with an hour break from 12:00 pm to 1:00 pm. The workers come to the surface to eat their lunch during the break time. Except Johnson Mining Company Limited which operates three shifts per day (24 h), all the other mines run one shift per day.

6.2. *Mining process*

The processes of mining at the small scale underground mine are captured under exploration, mine development, rock fragmentation, material handling, processing and marketing. Exploration involves the work done to gain knowledge about the grade, volume, orientation and all important information about the mineral to be mined. It helps to determine the economic viability of the proposed mining project. Development basically refers to making access to the mineral of interest in preparation for mining (extraction from the ground). In materials handling, fragmented or excavated materials are transported to a suitable location for processing. While processing involves the use of either physical or chemical methods (or both) to extract the mineral of interest from associated waste (gangue) materials, marketing basically involves the sale of the extracted mineral. The processes are described as follows:

(i) Exploration: Small scale miners generally do not conduct exploration. Where exploration is conducted, it is typically done on trial and error basis. The miners rely on their instincts, and experience gathered over the years by operating in a particular geological setting to identify mineral bearing rocks. They sample the materials (or rock) arbitrary with simple hand held tools such as chisel, hammers, picks and shovels into sacks for a confirmatory test. The test involves pounding the samples with metallic mortar and pestle into fines. The fines are then transferred into rubber pans (made from discarded car tyres) and water is added. The mixture is panned several times to ensure that the gold settles at the bottom. The suspension is decanted, leaving the gold concentrate (if any) at the bottom of the rubber pans. To the miner, obtaining some gold at the end of the washing is enough confirmation of the presence of gold in that area.

(ii) Development: Access to the orebody is through adits abandoned by old mechanised mining operations, or ones that have been constructed by the small scale miners themselves. The access to Stejoan is an abandoned adit with a ladder-way equipped with a wooden ladder for passage and iron beams for support. Johnson is accessed via an abandoned adit and a manually constructed adit. The abandoned adit is equipped with metal rails for support. Dakete and Mohammed are currently accessed by two abandoned adits. However, Dakete in previous years was accessed by manually constructed adit. Some of the mine accesses are shown in Fig. 4a and b. The development of adits by the miners is labour intensive since simple tools are used. The process involves loosening the in-situ formation with metallic hammer and chisel, and mucking the fragments into sacks using hand shovels, and manually transporting the load to the surface. These accesses are sometimes risky and dangerous as the miners have to descend into the stopes by holding onto ropes. At Dakete for example, a guide rope is used to descend into the stope by holding onto the rope as the miner descends into the stope. In narrow adits, the miner crawls into and out of the stope.

(iii) Rock Fragmentation and Material Handling: The principal cycle of operation in small scale underground mine operation involves: fragmentation of in situ rock; loading of ore into sacks; and hauling to the surface. These are similar methods to those applied during the development stage. That is, the orebody is fragmented with chisel and hammer, and loaded into sacks with shovel and carried to the surface for processing. When it becomes difficult to use rudimentary tools to break the rock, blasting with the use of explosives is adopted to break the rocks. This is done by drilling one to 2 m deep blast holes into the working face and charging with either dynamite or ammonium nitrate fuel oil (ANFO). The explosives are detonated to effect the fragmentation.

After the blasting, the rocks are loaded into sacks and carried on the heads, shoulders or the backs to the surface (see Fig. 4c). A sack of load is typically 30–50 kg depending on the strength of the miner and how quick he wants to meet his target for the day. Sometimes, the sacks are tied to a rope and pulled to the surface by dedicated crew locally called *loco boys* (after locomotive). Some of the underground mines combine both manpower and semi-mechanised operations for material handling (see Fig. 4d). At Johnson for example, the broken rock is manually loaded into wheelbarrows and pushed to discharge its content through a chute into a wagon that is anchored to a winder on the surface. The material is hoisted to the surface when the load in the wagon reaches the expected level for processing.

6.3. *Auxiliary operations/activities*

The auxiliary operations include support systems, use of personal protective equipment, ventilation, lighting, and dewatering. These activities/operations are very necessary since the accidents that occur in small scale underground mining are as a result of not observing such activities. The following sections describe the auxiliary activities at the four small scale underground mines. Some of the safety failures that have led to fatalities and various degrees of injuries, and continue to pose safety threats are also described.

Fig. 4 – (a) Adit, (b) Descending into a stope using rope, (c) Miner carries broken rocks on the back, and (d) Wagon for carrying materials by pushing.

(a) Support systems and ground failures: Stress redistribution can cause ground failures when an excavation is made into the ground. According to Mireku-Gyimah (2015, pp. 10–52), weak to medium strength orebody and country rock are susceptible to caving. It therefore becomes important to support underground openings to ensure that the openings are safe and accessible during the mining period.

The small scale underground miners typically operate more than one active stope that may either be supported or unsupported. In the supported stopes, waste rock, wooden pillars, bamboos and timbers are used to support the underground openings. At Dakete and Stejoan, sacks are filled with sand and or waste rocks, and then packed to reach the roof of openings to provide support. Timber logs are also used for supporting underground openings at Dakete. However, most of these timber logs show signs of deterioration (see Fig. 5a). Mohammed & Co. combines bamboo, wooden pillars and timber for supporting the stopes. Unlike Dakete, the timber supports at Mohammed & Co. do not show significant deterioration. Freshly installed bamboo at Mohammed & Co. at the time of this study, aims to prevent loose rocks from falling from the roof of the drives and walkways (see Fig. 5b). Johnson and Stejoan utilize wooden pillars, bamboos and waste rocks for supporting the drives.

In the unsupported stopes, the voids are left open without any form of support. At one of the stopes in Dakete, for example, a 30 m wide stope was left open without support, while loose materials were found to have been left unsupported (see Fig. 5c). Pillars left as supports in old abandoned mine workings were gradually robbed by the small scale underground miners. This practice has the potential of causing the stopes to collapse, and injuring or killing the miners in the process. In 2010 for example, a stope collapse killed one miner at the Mohammed and Co. site. The miner according to the workers was working in an unsupported stope when the stope collapsed and killed him instantly. Fig. 5d shows wooden and timber support in a wide open working area.

To understand the conditions of the rocks (in terms of strength) worked on by the small scale underground miners, two rock samples from the roof, footwall and orebody were obtained from unsupported active stopes of each mine for strength analysis. Compressive strength tests were conducted on the samples at the geotechnical laboratory of the University of Mines and Technology in Tarkwa, Ghana. The testing procedure involves cutting (sawing) the samples into cubes of size 50 mm, and loading axially using a uniaxial compressive strength test machine until the samples fail. The load at which the samples fail is recorded and used to compute the uniaxial compressive strength of the rock by dividing that load by the surface area of the sample. The results of the rock strength test are given in Table 1. It is observed that the country/host rocks are weak to moderately strong. These rocks require artificial supports to make the workings stable and safe.

(b) Personal protective equipment (PPE): The Occupational Safety and Health Administration requires employers to provide their employees with PPE and also ensure its use when engineering, work practice and administrative controls are not feasible or do not provide sufficient protection (OSHA, 2003). According to the Personal Protective Equipment at Work Regulations, 1992 (as amended), PPE should be regarded as the last resort to protect against risks to health hazards. The regulations

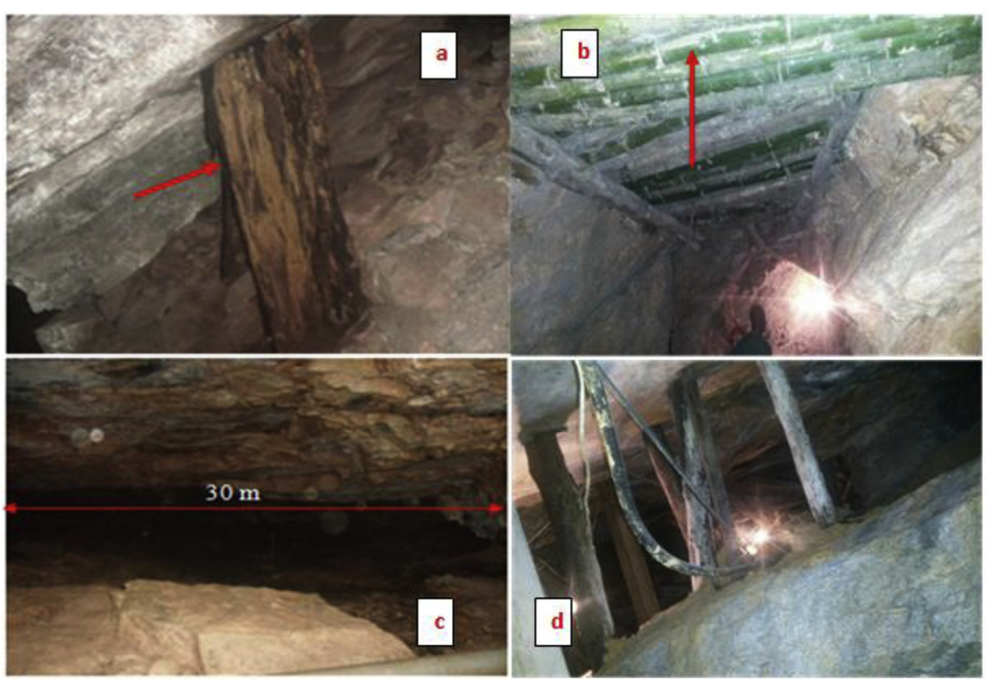

Fig. 5 – (a) Deteriorated timber support, (b), Bamboo support, (c) Wide Stope without any form of support, and (d) Wooden and timber support in a wide opened working area.

Table 1 – Mean uniaxial compressive strength of rocks at the small scale underground mines.

Mine	Source of sample	Compressive strength, σ (MPa)	Interpretation of compressive strength, σ (MPa)
Dakete Mining Limited	Footwall	133.93	Very strong
	Orebody	213.69	Very strong
	Hanging wall	97.41	Strong
Stejoan Mining Group	Footwall	52	Strong
	Orebody	32	Medium strong
	Hanging wall	43.2	Medium strong
Johnson Mining Company Limited	Footwall	18.8	Weak
	Orebody	69	Strong
	Hanging wall	42.4	Medium strong
Mohammed & Co. Small Scale Mining	Footwall	24	Weak
	Orebody	52.8	Strong
	Hanging wall	52	Strong

Criteria: Extremely strong >250; Very strong 100–250; Strong 50–100; Medium strong 25–50; Weak 5–25; Very weak 1–5; Extremely weak 0.25–1. Values are in MPa.

prioritize the consideration of engineering controls and safe systems of work. In Ghana, the Minerals and Mining (Health, Safety and Technical) Regulation, LI 2182 requires the use of PPE by underground miners to minimise risk and the severity of injuries to them. As described earlier, the small scale underground miners do not have adequate engineering and administrative controls and safe systems in place, due to the fact that the operations are mostly done by unskilled labour. One important engineering control that is adopted by all the operators is the use of support systems in some of the drives and walkways to prevent ground collapse.

However, due to the manual and hazardous nature of the activities at the mine, it is not uncommon for the miners to experience bodily injuries from rock falls, sharp (rock) edges, working tools, etc. Suitable PPE for use in the underground mining operations that can minimize the severity of injuries may include safety boots, protective helmets, nose mask, safety glasses, reflective overalls, ear plugs, lamps and oxygen supply set. Although, the Personal Protective Equipment at Work Regulations, 1992 (as amended) and the Occupational Health and Administration require employers to provide their employees with suitable PPE, the employers of small scale underground mines often ignore the regulatory requirement. The small scale miners generally operate without personal protective equipment. Some of the underground miners (over 60 people) encountered at the mines operate without the use of PPE. According to the miners, any miner who ever used safety boots had obtained it as a gift from a friend who works in the large scale mining company. Three persons who have personally acquired their safety boots but do not use them indicate that they feel uncomfortable in them. Rubber sandals (see Fig. 6a) are worn by most of the miners who believe that such sandals provide them with firmer grip on the ground and prevent them from falling. Some of the small scale miners do not recognize the importance of PPE. They refer to their sandals as the "best and most comfortable PPE". The predominant use of dry cell battery-powered torches which sometimes fail as a result of battery die-off can pose serious safety risks to the miners as they have to walk or work in the dark places.

At Johnson Mining, however, the mine owner provides the miners with PPE such as helmet, safety boots, safety glasses, dust mask and rechargeable lamps. Even though these may not be adequate, the situation is improved compared to what pertains at the other mines. The mine owner ensures that every miner who goes underground uses the PPE provided. In general, safety concerns regarding the use of PPE and safe systems of work by the underground miners are totally ignored. The story as told at Dakete Mining about a miner who was severely injured in the left foot is reported as follows:

The miner was originally contracted as a loader in 2012 to load broken rocks using hand shovel into pans for women carriers to convey the load to the crusher station. As a loader, his wage was Ten Ghana Cedis (US$ 2.60) for 3-h working duration, when the women carriers have met their target for the day. On 5th November 2012, when the mine was about commencing drilling and blasting operations, they discovered that the loader had knowledge in drilling (because he was an underground miner at the erstwhile Amalgamated Banket Area Underground mine, now Goldfields Ghana Limited, Tarkwa). He was absorbed into the mainstream employment of the company as drill help with a daily wage of Fourteen Ghana Cedis (US$ 3.64) and then increased to Sixteen Ghana Cedis (US$ 4.16) in December, 2012. In March 2013, he anchored a drilling bit to the drill stem and begun drilling into the rock of the working face. Suddenly, the drill bit got disengaged from the drill stem and without much control the powered drill stem landed on his left foot and pierced through the foot, injuring him severely.

Even though safety failures such as lack of training and failure to secure are of significance in this case, the degree of injury could have been reduced if the miner had worn safety boots. Three years after the incident, the underground miners operate without the requisite training and personal protective equipment. Fig. 6b shows an underground miner digging rocks with a pickaxe.

(c) Dust, fumes and poor ventilation: Dust and fumes (e.g. carbon monoxide and oxides of nitrogen) are generated during chiseling, drilling, blasting and processing. Due to poor ventilation, dust generated in the stopes

Fig. 6 – Some safety conditions in small scale mining in Ghana: (a) Miner going underground in rubber sandals, (b) Much equipped miner breaks rocks using pickaxe, (c) Dust from sieving milled ore, and (d) Changfa operators without PPE.

accumulate and can endanger the health of the miners. Except Mohammed & Co., all the other mines do not have ventilation systems to augment the natural ventilation and clear blast fumes and dust from the working areas. Mohammed & Co. uses a ducted ventilation fan which pushes the air towards the working face. This however, can cause trapping of mine gases and blast fumes in fractures or crevices in the working areas. The fumes and gases can be released into the workings in the event that the fan ceases to operate or is shut down, a situation that can be injurious to the health of the miners as they will unknowingly inhale harmful gases. None of the small scale underground mines conducts environmental monitoring. For example, there is no dust or air quality monitoring conducted to determine the concentrations of dust or toxic gases that are released through the activities.

Processing of materials obtained from the underground workings is typically done on the surface. The ore material is crushed, ground and then sieved to obtain the fines. These processes generate dust at each level. Persons involved in such activities (who usually do so without any form of nose protection) are exposed to inhalable dust particles. Fig. 6c shows a dust laden environment where women sieve the milled ore (Al-Hassan & Amoako, 2014), while Fig. 6d shows a changfa operator without PPE.

(d) Drainage systems: It is important to prevent the working areas from flooding to ensure safe operations. The underground workings are typically dewatered using pumps. However, poorly selected water pumps and characteristically leaking pipes that are common in the operations make the stopes highly susceptible to flooding. The SSUM operators purchase water pumps from the market without following any pump selection procedures. The result is using cheap and low capacity pumps that cannot handle the rate of water inflow into the stopes. This together with the leaking pipes does not ensure proper drainage, hence flooding of the stopes. In 2015, the two pumps at Stejoan were overwhelmed, leading to flooding of the entire mine. Consequently, the mine ceased operations for almost 12 months until the water was pumped out of the mine with the help of pumps from Mohammed & Co. The water from underground mines is also discharged directly into the environment without conducting any test to ascertain the quality of the water.

(e) Lighting: Poor electrical connections and exposed electric wires are common and sometimes located close to leaking pipes. Dry cell operated torches used by miners are mostly substandard and their batteries often run down quickly. Experienced miners are able to walk through the darkness to safety in the event of losing their lights. However, this practice can endanger the safety of the miners due to the possibility of being electrocuted or falling into an opening. These poor electrical connections and naked electrical wires are common at Dakete. To overcome the issues with dry cell torches, Johnson and Mohammed & Co. provide their underground workers with rechargeable lamps to provide them with light throughout the shift. The underground lighting system at Mohammed & Co. is better organized, as the company has an underground transformer and with all electrical works supervised by a trained electrician. Fig. 7 shows poor electrical wiring in a stope.

6.4. *Processing and marketing*

In processing, the broken rocks are crushed, milled and refined to obtain up to 23 carat gold. The rocks are fed into the changfa for crushing into granular sizes and further reduced into fines by milling machines. The fines are transferred into plastic bowls (containers) and mixed with water and thoroughly stirred with the bare hands until "homogenous" mixture is obtained. This is done carefully to ensure that the gold settles at the bottom of the container. The mixture is decanted to get rid of the gangue (waste), leaving the gold concentrate. Mercury is introduced into the concentrate to form mercury-gold amalgam. The amalgam is transferred onto a cotton handkerchief and squeezed until it becomes compact; this also removes excess mercury. It is then heated on charcoal fire to remove the mercury by evaporation. Nitric acid is introduced to further remove impurities. All these activities are typically done without the use of PPE. Fig. 8 shows some processing activities conducted by the miners without safety precautions.

The sponged gold is subsequently fluxed with borax and smelted in a locally made refractory clay crucible. The molten gold is then poured into a mould containing palm oil for cooling and preventing the gold from getting stuck in the mould. The density and mass of the refined product are measured to ensure that it meets their set standard of 22.5–23 carat, even though the miners typically report 23 carat. The products are sold to buyers at prevailing market price. Where a miner is sponsored by a financier, the gold is sold to the sponsor at an agreed discounted price. Table 2 summarizes some of the major issues pertaining to small scale underground mining in Tarkwa, Ghana.

7. Discussions

Small scale mining in Ghana has evidently provided employment to thousands of people, and continues to provide raw materials for both foreign and locally based mineral industries. The sector also plays a significant role in stemming rural-urban migration, as well as providing foreign exchange earnings to the government. These significant benefits, however, have been negated by the frequent environmental and safety issues. These issues are the result of lack of valuable technical input into the operations. The sector has remained unattractive to professional engineers with the technical know-how to effectively and efficiently manage the operations. The absence of these professionals have resulted in the use of unskilled workers, poor selection of mining methods, inappropriate choice of working tools, rampant disregard for standard safety protocols, nonexistent standard operating procedures, and improper handling of materials. For example, the injuries sustained by the driller at Dakete in 2013 could have been avoided if there were drilling engineers and safety professionals to ensure that the driller had received adequate training and observed safety protocols. Also, the flooding of Stejoan could have been mitigated if professional engineers were involved in the selection of the pumps and advised on installation and maintenance.

The issues confronting the SSM sector can also be attributed to lack of effective monitoring by the Minerals Commission of Ghana, probably due to inadequate staffing and logistics. These findings are consistent with Hilson (2002), who indicates that inadequate staff and a pool of highly obsolete research resources make it incapable for the Minerals Commission to facilitate sufficient environmental improvement in the sector. Indeed, at the Tarkwa small scale district office are only two inspectors; the district officer and his assistant who have to conduct at least one inspection per month at each of the 15 operating mines. Additionally, the district office has only one vehicle for their activities and a single hand held

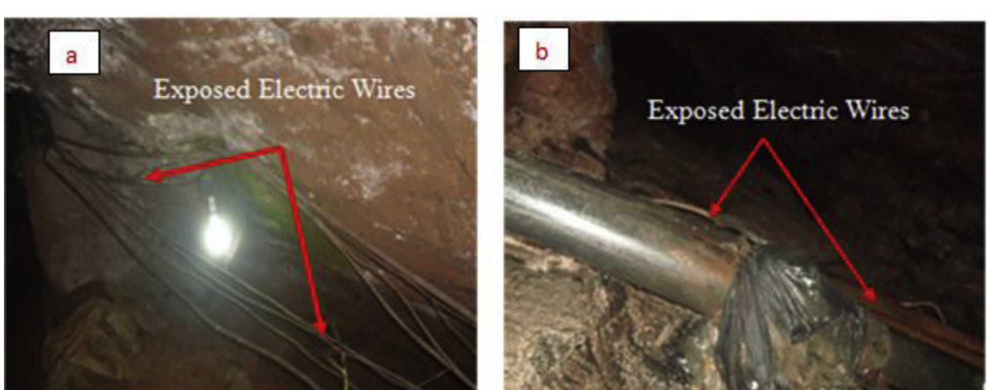

Fig. 7 – Poor electrically connected stope: (a) Naked electrical wires, (b) Naked electrical wires close to corroded leaking pipe covered with a polythene.

Fig. 8 – (a) Miner stirs slurry with bare hands, (b) Miner holds mercury-gold amalgam in the palm.

Table 2 – Summary of activities and safety concerns at the small scale underground mines.

Item		Dakete Mining Limited	Johnson Mining Company Limited	Mohammed & Co. SSM	Stejoan Mining Group
Mode of Entry		Adit (2*)	Adit (2*)	Adit (2*)	Adit (1*)
Mining Method		Open stoping	Open stoping	Opening stoping	Open stoping
Ventilation Fan		No	No	Yes (1*)	No
Dewatering Pump		No	Yes (1*)	Yes (1*)	Yes (2*)
Illumination of Drives & Working Face		No	No	Yes	No
Safety Officer		Yes**	No	No	No
Rescue Team		No	No	No	No
Emergency Evacuation Plan		No	No	No	No
Hazard Signage		No	No	No	No
Air Quality Sensors & Alarm Systems		No	No	No	No
Fresh Air Chamber		No	No	No	No
Ladder Way		No	No	No	No
Ventilation Shaft		No	No	No	No
PPE	Reflective Vest	Yes	No	No	No
	Overall	No	No	No	No
	Steel Toe Boot	No	No	Yes	No
	Helmet	No	Yes	Yes	No
	Ear Plug	No	No	No	No
	Lamp	No	Yes	Yes	No
	Self Rescuer	No	No	No	No
	Hand Gloves	No	Yes	No	No
	Safety Goggles	No	No	No	No
	Nose Mask	No	No	No	No
Operating depth below Ground		183 m	200 m	100 m	250 m
Support Systems	Active Stopes	Unsupported	Unsupported	Unsupported	Unsupported
	Drives & Walkways	Unsupported, Timber	Unsupported	Bamboo and Timber	Unsupported
Materials Handling		Manual	Manual & semi-mechanised	Manual & semi-mechanised	Manual

* Quantity/Number of items,** Officer is a Junior High School graduate who has received some training in mercury handling, personal safety, and first aid, but has no standard certification in health and safety management.

geographic positioning system (GPS) for field exercises. Moreover, at a stakeholder sensitization workshop presentation on the 23rd November, 2015 at Tarkwa, inadequate staffing and logistics was listed by the small scale district officer as one of the key challenges facing the small scale mining department of the Minerals Commission. The situation has partly contributed to lack of enforcement of policies and regulatory requirements, and has led to noncompliance by the SSM operators. This is also corroborated by Macdonald et al. (2014), that law enforcement in artisanal and small scale mining in Ghana is poor and unevenly applied.

An effective follow-up monitoring and evaluation, together with requisite training of the operators will enhance the small scale mining operations and minimize the hazards and negative impacts of the sector. This requires strengthening the capacity of the officers and the provision of logistics. There is also the need for an urgent effective policy direction and implementation to curtail the involvement of foreign nationals in SSM activities. The crackdown and deportation of over 4500 illegal Chinese miners from Ghana in 2013 was a good initiative by the government to arrest the situation. However, there are still some foreign nationals (fronted by

Ghanaian citizens) that involve in the exploitation of the precious minerals.

Mitigating the involvement by foreign nationals and the negative impacts of the mining activities requires effective participation of the national and local governments, to make the necessary by-laws; security agencies to arrest and prosecute offenders; the Minerals Commission, to ensure implementation of regulatory requirements and conduct effective monitoring of operations; the Environmental Protection Agency, to educate the miners on environmentally friendly activities; the Ghana Immigration Service, to ensure that foreign nationals admitted to Ghana are in the country for the purpose to which their visas are granted; chiefs and elders of the rural communities, to avoid leasing their lands directly to the miners; and the people of Ghana, to report unregistered/unlicensed operations or offenders to authorities.

8. Conclusions

This study highlights the socio-economic, environmental, safety and security issues associated with the exploitation of precious minerals and metals in Ghana. A case study of four small scale underground mines is also presented to highlight the hazardous nature of the SSM activities.

Analysis of the results indicates that SSM of gold continues to make significant economic and social contributions to the socio-economic growth of Ghana. It provides jobs for the rural poor, raw materials for the local mineral industry, and contributes to the national income.

However, poor monitoring of the operations and lack of policy and regulatory enforcement by the Minerals Commission of Ghana have led to series of environmental, safety and national security issues and threats. The small scale underground mining sector in Ghana is inundated with unsafe acts and practices which lead to ground failures, improper choice of tools, land degradation, absence of personal protective equipment, drilling and blasting in confined spaces.

To mitigate the negative issues associated with small scale mining in Ghana, it is required of the Minerals Commission to improve its monitoring activities, enforce regulatory requirements and organize workshops for the miners on innovative and safe methods of operation. Other key stakeholders such as the Environmental Protection Agency, the security agencies, chiefs and landowners, and the local and national governments must play their roles to mitigate the negative impacts of the sector and enhance the socio-economic contributions of the small scale mining sector in Ghana.

Acknowledgement

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