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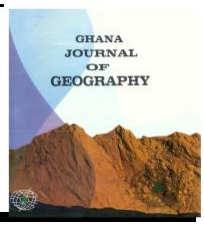

Mercury management in the Artisanal and Small-scale Mining (ASM) Sector: Whither Ghana?

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abstract

Artisanal and small-scale mining (ASM) continues to make significant contributions to economies in sub-Saharan Africa by creating employment avenues and reducing poverty among rural populations. However, a major problem associated with the sector is its role in mercury emissions into the environment. Ghana, a burgeoning ASM country, has participated in several donor supported projects with the aim to reduce and where possible, eliminate mercury emissions but still the country ranks high on the mercury emission list. With an in-depth review of policy documents, complemented by key informant interviews, this paper interrogates why this is so by chronicling the Government of Ghana's involvement in key donor funding projects and pinpoints what is lacking in its approach to minimising mercury emission through ASM operations. The paper reveals that the government's steps to reducing mercury emissions at ASM sites can best be described as 'snail-paced' and cyclical in nature. It proposes a sharp focus on providing affordable mercury-free technologies and paying attention to geological characteristics of sites and other social factors that can boost the use of mercury at ASM sites.

Introduction

There is a consensus among scholars and the international development community on the contributions of artisanal and small-scale mining (ASM) to rural livelihoods - employment generation, poverty alleviation - economic growth, and development at both local and national levels (Osei et al., 2021; Hilson et al., 2019). ASM is possibly the most significant non-farm economic activity that rural populations in sub-Saharan Africa engage in (Hilson et al., 2021). There are over 10 million people in the sub-Saharan Africa region who are directly involved in ASM with another 15 million economically benefiting from the value chain (Hilson et al., 2021). Over 30% of total minerals production in the sub-region comes from the ASM sector and is a significant contributor to the governments' revenues and GDP. Due to the excessive illegalities in Ghana's ASM, it is difficult to provide the exact numbers that are engaged in it; nevertheless, it is generally estimated that over a million people of Ghana's labour force are engaged in ASM and their operations further boost other dependent local economies (Bansah et al., 2018; Osei et al., 2022).

This notwithstanding, ASM plays a crucial role in the release of mercury into the environment. It is the leading source of mercury pollution in the world as it contributes to a third of all emissions (Kessler, 2013; UNEP, 2019). In 2018, about 838 tonnes of mercury was emitted to the air through ASM operations and this corresponds to about 23% higher than the estimates of 2013 (Keane et al., 2023). At the regional level, while emissions are decreasing in Asia, South America and sub-Saharan Africa seem to have emissions increasing. According to the UNEP (2018) data, mercury is the major contributor of emissions into the environment for South America and sub-Saharan Africa. It is projected that for every gramme of gold recovered by ASM processes, there is a corresponding two grammes of mercury released into the environment (Amankwah et al., 2010; Al-Hassan et al., 2019). Mercury, although deadly, and prohibited in many countries for mineral processing, is one of the important metals used by artisanal and small-scale miners in extracting fine gold. The ubiquitous use of mercury for the amalgamation process stems from it being affordable, accessible, easy-to-use, and the ability to be used in many locations. Mercury plays a central role in ASM operations. According to Esdaile and Chalker (2018), between 10-19 million miners in over 70 countries use mercury in their ASM operations. This notwithstanding, evidence from research shows that mercury is toxic, and especially when methylated. The use of mercury at ASM sites causes several deficiencies for humans (miners and non-miners alike) – neuropsychological problems in children, miscarriages among pregnant women, damage of the central nervous system, memory loss, destruction of lung tissue and other acute respiratory challenges (Shandro et al., 2009; Mensah et al., 2016; Vergara-Murillo, 2022). The effects of mercury on the physical environment include the depletion of fish stocks, extinction of species, contamination of river bodies, land degradation to mention but a few (Kim & Choi, 2012; Ofosu et al., 2022).

Ghana places second after Sudan on the list for top gold-producing countries that use significant mercury in Africa; and fourth among the top ten gold-producing countries across the globe (Siam, 2021). Cheng et al., (2022) calculations project Ghana emitting about 61.7 tonnes of mercury. The country has therefore, not been immune from the harmful effects of mercury. Mercury is the chemical mostly used by miners in the amalgamation of ore and the extraction of gold in all mining sites in Ghana. There is documented evidence of mercury's deleterious effects on river courses, agricultural lands, miners' and community health (Clifford 2017; Kuffour et al., 2018; Gyamfi et al., 2021; Attiogbe et al., 2020; Nunoo et al., 2022). In the study by Kuffour et al. (2018), they confirm the contamination of rivers and streams in the Amansie West District of Ghana, with mercury concentrates in such water bodies being higher than the World Health Organisation's tolerable level of 0.001 mg/L. Attiogbe et al. (2020) find similarly high mercury levels in Lake Amponsah due to ASM operations close to the Lake. Additionally, Gyamfi et al., (2021) find topsoils in Gbani, a mining community in the Upper East Region to be severely contaminated by mercury. Moreover, high mercury levels have been found in miners' blood, nails and hair (Afrifa et al., 2018; Kwaansa-Ansah et al., 2019); and fishes have been intoxicated by high mercury levels in Pra and Ankobra (Kortei et al., 2020). In fact, in recent times, the widespread condemnation of ASM operations in Ghana led by the

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media coalition emanate from the alarming environmental effects including land degradation, water pollution, caused by mercury use at ASM sites (Osei et al., 2022). Although the outcry led to yet another ban on all ASM activities in the country, the past ban was lifted without putting in place any concrete measure to reducing mercury pollution in the country.

For many decades, the use of mercury in ASM sites has been of grave concern for donor agencies who have advocated for the abolishing of the use of mercury through various conventions/projects like the Global Mercury Project and the Minamata Convention. This paper thoroughly review the literature and chronical initiatives by the donor agencies towards management of mercury in ASM, with a special focus on Ghana. The central question that this paper addresses is: why have initiatives/projects by the international development community with support from national government towards mercury use and management in ASM seen minimal success? The paper probes the Government of Ghana's (GoG) response to these initiatives, the kinds of alternative technologies introduced so far, the reactions from miners towards the use of these technologies and what propel(s) such responses from the miners. This current research is necessary because Ghana tops most of its contemporaries in mercury emission and this has grave implications on farmlands and agriculture production, water resources, the public health of miners and mining communities in Ghana. It calls for a halt in the seeming 'cycle of technological innovation', a situation portrayed by the government over the years. I propose a sharp focus on the provision of alternative technology that considers geological characteristics of sites and other social factors that boosts the use of mercury at ASM sites.

In order to achieve the objective of the paper, an in-depth review of grey literature on initiatives or projects published by the international organisations and the government of Ghana through its agencies was conducted. Upon simple online searches and data repositories of the international organisations involved, relevant documents related to the topic were systematically examined. Additionally, expert and key informant interviews were conducted with mining engineers, researchers, and miners to unearth the delicate information on issues regarding Ghana's journey toward mercury reduction in ASM. In the ensuing sections, a thorough review providing an elaborate historical account of initiatives that sought to minimalise the use of mercury in ASM at the global level is done. This is followed by a chronicle of Ghana's efforts in response to these donor driven initiatives. This is complemented with in-depth interviews with key informants within the ASM sector to achieve the research objective. Subsequently, the paper proposes the way forward in tackling the mercury problem.

Global efforts to tackle mercury pollution

The international development community led by UNIDO has put in efforts to confront mercury-use at ASM sites across the developing world. The approaches taken so far have focused on reducing and, where possible, eliminating the use of mercury and its release into the environment. Prior to the focus on mercury emissions from ASM, during the 1980s and 1990s, countries and intergovernmental alliances were formed to control the amounts of heavy metals in the environment. These efforts date back to the Aarhus Protocol on Heavy Metals (PHM) in 1998 initiated by the United Nations Economic Commission for Europe (UNECE) which sought to reduce the emission of mercury, lead, and cadmium below the prevalent levels in 1990. Interestingly, as of 2003 when the protocol entered into force, none of the 35 countries that agreed to the PHM neither had a vibrant ASM sector nor was from the African continent. This was probably because although the PHM required parties to lower mercury emissions, the ASM sector was not considered a significant emitter then hence, it was not a target. The PHM emphasised the reduction of mercury in electoral components, clinical components such as thermometers, fluorescent lamps, dental amalgam as well as paints and pesticides. Article 4(1) of the PHM demanded that all parties, subject to their laws and regulations should facilitate their exchange of technologies and techniques designed to reduce emission of heavy metals. It particularly proposed a commercial exchange of available technology and the provision of technical assistance among all parties. Although the PHM did not consider the emission of mercury from ASM sites, it is important to mention it as one of the foremost efforts to reducing the toxic metal in the environment. In the next section, I therefore, narrow in on those projects that considered the sub-Saharan Africa region and had Ghana participating in it.

The Global Mercury Project

By 2001, the United Nations Environmental Programme (UNEP) was ready to take on the mercury challenge even further. At the UNEP intergovernmental conference, a decision was taken to assess the global level of mercury due to its destructive nature although economically relevant. This birthed the Global Mercury Project (GMP), which was implemented between 2002-2007, financed by the Global Environment Facility (GEF) and meant to promote knowledge and capacity building on the connection between ASM, health and the environment (Spiegal and Veiga, 2005). It was also to show ways of surmounting barriers to the adoption of the best practices and pollution prevention measures that limit mercury contamination from ASM. Specifically, the key goals of the GMP included (i) reduce mercury pollution caused by artisanal miners on international waters; (ii) introduce cleaner technologies for gold extraction and educate miners on how to use these technologies; (iii) develop capacity and regulatory mechanisms within local governments that will enable the sector to minimise mercury pollution; (iv) introduce environmental and health monitoring programmes; and finally (v) build capacity in local laboratories to assess the extent and impact of mercury pollution (Spiegal and Veiga, 2005; pg. 363). The launch of this project was received with much enthusiasm by scholars. For instance, Hilson et al. (2018; p.126) described it as the "…most comprehensive undertaking made to tackle mercury pollution at small-scale mines…" then. Spiegal and Veiga (2005) considering that prior, not much investigation had been done to address the mobility of mercury from ASM through international waters, the GMP was the foremost effort to implement a global evaluation and action plan. This project which was piloted in six countries across the developing world included some of the countries with burgeoning ASM sector in the sub-Saharan region such as Sudan, Tanzania and Zimbabwe. Although Ghana joined in the project later, it is disappointing to know that by the end of the GMP, the international community coupled with the national governments had not figured out exactly what cleaner technologies are acceptable for miners at ASM sites.

The Minamata Convention on Mercury (MCM)

Management of the ASM sector is a global challenge (Wireko-Gyebi et al., 2022). It is the Minamata Convention on Mercury (MCM) that elevated the profile of mercury emission from ASM to the global level. Initiated by the UN Environment Programme (UNEP) Governing Council in 2009 after a series of intergovernmental meetings, the MCM was accepted and subsequently introduced in 2013. It was however in August 2017, that the MCM entered into force with a primary aim of reducing the anthropogenic emissions and release of mercury to protect both the environment and human health associated with mercury emissions (Bank, 2020). The MCM is considered by scholars such as Kessler (2013) and Clifford (2017) as the most far-reaching efforts in the fight against mercury use and towards protecting future generations of the eminent repercussions of the use of mercury. Eriksen and Perrez (2014) refer to it as a comprehensive response to the global problem of mercury usage in ASM. These praise singing are premised on the belief that the convention took the right approach by directing countries to come up with their own plans to reduce or eliminate mercury in ASM (Kessler, 2013). A key criticism of the MCM, however, is the comfort it gives to countries by not enforcing a phase-out date for mercury use in ASM. Since signatory countries to the MCM agree to have 'more than significant' mercury emissions through ASM, it is probably envisaged that they would hasten initiatives to tackle the problem.

The Global Environment Facility (GEF) has been a key companion and pro-active partner of the international community's determination to achieve the goal of the MCM. It is one of the two components of the funding mechanism of the MCM to facilitate dealing with the mercury problem at the global level (UNEP, 2021). The GEF undertakes its mandate through financial investments and capacity building of teams at the national level as well as external implementing agencies with a two-core support system which helps developing countries and economies in transition to develop the Minamata Convention Initial Assessments (MIA) and the National Action Plans (NAPs) to meet their obligations concerning ASM operations. By the end of 2020, the GEF had funded the development of about 48 NAPs in line with the requirements of the MCM. The GEF for instance, has committed over a USD1 billion towards the reduction of mercury use and exposures in Ghana's ASM (see table 1 below). Despite this huge investment, efforts by the Government of Ghana to meet the MCM goal has seen minimal success.

A crucial goal of the UNIDO and the other implementing organisations' assistance in addressing the mercury problem is a search for more environmentally safe and high-yield gold extraction alternatives that will drastically reduce or eliminate the use and discharge of mercury into the atmosphere. For all these initiatives/projects, it is obvious that the focus has been on evaluating the health and environmental effects associated with the use of mercury, demonstrating cleaner technologies, and a persistent push for a formalisation of the ASM sector.

Table 1: Donor support for Mercury management in Ghana 2015-2023

Implementing Agency	Purpose	Funding agency	Amount donated
UNITAR	Collaborate with EPA to provide national framework for the implementation of the Minamata convention	Swiss Government	N/A
UNITAR	Support the EPA with the development of the Minamata Initial Assessment	Global Environment Fund	N/A
UNDP	Minamata Convention Initial Assessment to determine national requirements and needs for ratification	Global Environment Facility (2016)	USD200,000
UNIDO	Preparation of National Action Plan	Global Environment Facility (2016-22)	USD500,000
World Bank	Reduce exposure to mercury and uPOPs pollution in pilot sites and strengthen the institutional capacity to manage and regulate ASM and e-waste.	Global Environment Facility (2020)	USD8,715,595

Ghana's response to mercury pollution

UNIDO has been at the forefront of the numerous technical assistances to the ASM sector which target the introduction of cleaner technologies for the reduction of mercury pollution (Wireko-Gyebi et al., 2022). Addressing the mercury problem in ASM can be a very sensitive one for governments and development partners alike. Across the developed world - countries such as Korea, Japan, the USA and Canada - and the European Union have implemented various policies to inhibit the emission and pollution of mercury on human and environmental health; mainly through phasing out foods that contain mercury. For mineral-endowed developing countries such as Ghana, Uganda and Tanzania who are dependent on the ASM sector for economic growth and development, much is expected in their reactions to mercury pollution. Governments must provide strategies and guidelines that ultimately promote the elimination of mercury in ASM sites. As Zolnikov and Ortiz (2018) advocate, governments' support in the management of mercury in ASM is crucial.

It is estimated that 80% of all mercury demand in Ghana comes from the ASM sector. The Government of Ghana (GoG) therefore, admits to gold extraction with mercury amalgamation of concentrates by miners as one of the three main routes for mercury pollution; gold extraction contributes significantly to the release of mercury into the air, land and water. In fact, out of the total estimated mercury input, about 56% emanates from gold extraction (Ministry of Environment Science Technology and Innovation, 2018). Although the country witnessed a substantial decrease in the imports of mercury between 2000-2013, by the end of 2013, official data from the government estimated that about 1169kg of mercury was imported from three countries including Belgium, China and Lebanon. However, this contradicts World Bank data which suggests an estimated consumption of mercury between 49-91 tonnes annually staggeringly revealing the possible existence of illegal mercury business (Ministry of Environment Science Technology and Innovation, 2018). Clearly, the importation of mercury into the country that ends up in ASM sites are copiously done by local people and foreigners who are part of the value chain (Hilson et al., 2018). Ghana's response in curtailing mercury-use is showcased by the ratification of the MCM and subsequent production of the Initial Assessment Report, National Action Plan, and technological innovation.

Ghana's ratification of the MCM in managing mercury pollution

Ghana was the 40th party to sign on to the MCM. After ratifying in 2017, the government's Minamata Initial Assessment aimed at establishing a sound foundation to undertake future work towards the implementation of the Convention. This, besides the NAP, is the government's effort towards the eradication of mercury in response to the MCM. The government launched the Initial Assessment Report on mercury in 2021 to initiate the discourse on mercury management in the country. Due to the fluidity in data on ASM, the UNEP provides a guidebook and toolkit that ratified countries use in calculating ASM productions and the level of emissions from the sector. Based on the toolkit, Ghana reports that the major mercury release source include gold extraction with mercury by artisanal and small-scale miners, the use and disposal of mercury-added products, waste incineration and open-waste burning. Per the report, gold extraction with mercury from concentrates form about 50% of total mercury release sources. Several priority actions are recommended by the report, but the one which focuses on emissions from ASM is reducing and where feasible, eliminating the use of mercury and mercury compounds in ASM operations (UNDP, 2024). Ghana articulates well on paper how it intends to achieve this in its National Action Plan but the challenge to surmount this hurdle persists.

Countries that ratify the MCM are required to have National Action Plans (NAPs) that outline their approaches to reducing mercury emissions from ASM (Hilson et al., 2018). The Convention further specifies that each NAP elaborate strategies to eliminate the following most common bad practices among ASM miners: (i) whole ore amalgamation, (ii) open burning of amalgam (i.e., without a mercury capture device), (iii) burning of amalgam in residential areas, and (iv) use of cyanide on mercury containing tailings or sediment without first removing mercury. Whilst some countries do not have either of these practices, Ghana falls culprit to all four (Keane et al., 2023).

Thus, Ghana projected its support to reducing mercury in ASM by putting forward its National Action Plan (NAP) in compliance to Article (7.3) of the MCM in 2017 with support from the GEF. The NAP, among other things, exposes the best and worst practices in Ghana's ASM and offers to specifically achieve: (1) mercury-free alternatives promoted and adopted, (2) protection of vulnerable populations and populations with high exposure to mercury, (3) mercury emissions and releases to the environment minimised or eliminated, and (4) mercury storage standards established and facilities available (Ministry of Environment Science Technology and Innovation, 2018). The question is; after outlining these plans, how does the government intend to practically tackle them?

Unlike some NAPs produced in the sub-region, the GoG unfortunately does not move a step further from outlining the steps to achieving the objective of the MCM. An expert interviewee who participated in this research confidently claimed that these steps outlined in the NAPs have been done 'devoid of research'. The expert further argued that even though the government intends to promote mercury-free alternatives and get miners to adopt that, "there are no known technologies in the system in the first place, least talk of their adoption"[1]. Further investigation into why there is no trace of the implementation of the NAP strategies, an officer of the Environmental Protection Agency (EPA)[2] attributed it to "the lack of funds". Implementation of the NAP is therefore, stalled because the government lacks the financial capability to do so. And since donor investments (as seen in Table 1.) have been minimal on the development of technologies and their availability to miners, it can be postulated that taking these measures can take a long time.

Ghana's search for alternative technology

Keane and her colleagues identified forty-eight technologies produced under various mercury-free ASM projects implemented across the developing world and amongst these innovations is the direct smelting process (Keane et al., 2023). Direct smelting, according to Keane et al., (2023) is a traditional method of producing gold from concentrates by applying heat to separate gold from impurities that are present in the concentrate. Meanwhile, in the very unlikely event, would one find a few miners engaging different technologies including 'gold catcher', retorts and other unpopular technologies for ore processing at ASM sites across Ghana. So far, the most cited technology in the literature, produced to be used by miners in Ghana is the furnace for direct smelting which was piloted (and never enforced) under the Ghana Mercury Pollution Abatement Project. The European Union launched this project with the aim of reviewing the mining and processing methods used by small-scale miners in Ghana, and further develop an alternative method for extracting gold from concentrates without the use of mercury (Amankwah et al., 2010). By the end of the first phase of the Project, Styles et al., (2009) conclude that miners would accept any method that was inexpensive, fast, easy to use, transparent and suitable for small batches of concentrates. Based on the promptings of Styles et al., (2009), during the second phase of the project, experts introduced and tested the direct smelting process at a few ASM sites. Based on their field trials, Amankwah et al., (2010) demonstrate direct smelting as an appropriate innovation for small-scale miners in Ghana. This, however, is yet to be adopted by miners in their operations.

Research by Amankwah et al., (2010) produced the first version of technology for direct smelting. Locally labelled the '*sika bukyia'* to mean

[1] Interview with Mining Engineer, April 2024

[2] Interview with EPA Officer, April 2024

gold furnace, the 45mins process is described as effective for gold recovery. According to Wireko-Gyebi et al., (2022; p. 102576), "direct smelting method seems to be the best method which will better serve the needs of Ghana's ASM operators" since about 99% of gold particles can be recovered by this method compared to 88% recoveries through amalgamation. More so, direct smelting takes a shorter time to execute. Meanwhile direct smelting is yet to be utilised by artisanal and small-scale miners in Ghana due to cost of furnace and fuel, and the processing capacity as furnace can take only small batches of ore processing (see Amankwah et al., 2010). The mining engineer who participated in this research, however, had a different perspective on the *'sika bukyia'*. He literally doubted the ability of the *sika bukyia* to recover more gold although he accepted that the direct smelting process has the potential to give more recovery when used for large-scale mining. According to him,

"Since mercury is the technology to beat, any other technology you bring in must be better: easy to use, cost effective and give more mineral recovery. The miners have rejected it [sika bukyia] because they feel it's a waste of time. If it gave miners that recovery level the researchers claim, do you think the miners will not accept it?".

Additionally, he contended that "the publicity about the direct smelting process being a better option has gone ahead of the actual uptake of the furnace" because consistently mercury amalgamation though hazardous has given miners that acceptable range of gold recovery.

Because the GoG is unable to fund technology development, most of the technologies deployed and tested in the country are introduced by donors, individuals or companies interested in doing business with the sector. There are therefore several technologies currently being marketed by private businessmen to miners. The mining expert interviewed reveal that the EPA is executing a programme which mandates it to sample all available mercury-free technologies currently on the Ghanaian market and across the world to test which ones fit the local context. It is expected that this programme will make a list of the technologies that potentially can be obtained by the government. The Minerals Commission (MC) together with a private business has recently also introduced the 'gold catcher' to miners especially those participating in the community mining scheme. This 'gold catcher' is projected to give nearly 100% recovery but that has also been criticised by the key informant who described that as 'a concentrator' because it gives miners just the concentrates after doing the crashing and sluicing but unfortunately, this technology has no smelter. And this, according to the mining engineer means "misdiagnosing the problem". He lamented;

"…even the Minerals Commission does not understand what we mean by alternatives to mercury. How can you bring a machine that only produces concentrates and not smelting? If you look at our challenge, the miners have not complained of producing concentrates, the issue is how do we get our gold out of our concentrates without using mercury?

Government's top-down regulatory approaches marginalise a proportion of the miners who operate outside the legal framework. In a conversation with a miner[3], he bemoaned the Mineral Commission's invented trading system to sell cleaner technologies to artisanal and small-scale miners. According to this miner, the MC 'keeps the machines in their office' and expects miners to commute from all over the country to Accra to buy at exorbitant prices of more than USD200,000.

Rethinking mercury management in a rapidly growing ASM sector

Despite many laborious efforts to have cleaner technologies in the ASM sector, till date, a major constraint for most artisanal and small-scale miners relates to the availability and accessibility of appropriate, economic and environmentally friendly technology (Wireko-Gyebi et al., 2022). The availability of technology from developers and adoption by miners remains a challenge. Time and time again, scholars have asserted the essence for the international community who are usually the implementing agencies spearheading the provision of technical solutions to artisanal and small-scale miners to extensively engage the latter before developing the technologies (Hilson 2001; Hilson et al., 2018). Marshall and Veiga (2017) for instance accuse the technology developers and educators of being engaged in a 'guess work' and practicing 'trial and error' initiatives due to the absence of miners' engagements. But the approach adopted during the execution of the GMP should be revisited. According to Speigel and Veiga (2005), during the first phase of the GMP, emphasis was placed on participatory processes in developing country-specific and community-specific capacity-building models that, wherein community members identified what equipment is needed most and what techniques should be demonstrated. This approach of technology demonstration campaigns should be enhanced in Ghana to facilitate area-specific models mainly because of the different geologies of mining communities. Besides, the underlisted factors must be considered in Ghana's quest to reducing mercury emissions through ASM operations.

Technological advancement

Direct smelting, as a process, could indeed be a better alternative to amalgamation, as it generates the final product in a one-step process compared to the three-steps process of amalgamation. This process is even followed by the large-scale mines at their gold assay labs. However, when it comes to ASM, while the process is short and recovery is high, so far, the smelting furnaces developed by Amankwah and his colleagues (2010) lack a few features that would promote adoption by miners. Interactions with a mining engineer reveal that the design of the furnace has undergone three versions already but still does not satisfy the needs of miners. He further explained;

"that furnace you see in the research paper is the first version. There have been two more versions to get it right, but still the miners do not want it. But the good thing is the people on that project know what to do, so I'm sure they will try and get something soon".

An interview with a researcher at the University[4] confirmed

"the current machines must be redesigned taking into consideration good temperature controllers by engaging our local manufacturers to come up with something. There is something also with the ignition systems which must be attended to; and perhaps the most important being the cost of operation".

Miners are also greatly concerned about the minimum weight of concentrate that can be smelted at a time and the operation cost of smelting. Since Amankwah et al., (2010, p.7), agree that "direct smelting is not well-suited for samples with low gold content" it is pertinent to make available different technologies for different mining sites and not the usual one-size fits all approach. When mercury amalgamation remains the default processing method in the absence of alternative technologies, ASM will continue to emit more mercury into the environment.

Operational cost of technologies

Small-scale miners are often considered rich as their entrepreneurial ventures are dimmed profitable due to the ever-surging gold prices on the world market and the extravagant lives miners' exhibit. As such one may overlook how the technologies available are highly priced. Although the prices of these technologies vary, it could range from about USD45,000 - being value placed on Mercury-Free Alluvia Technology set up by the Compact Monitor in Ghana (Keane et al., 2023) to about the USD200,000 indicated by an interviewee. During interactions with miners, a common complaint about the technology is the cost: "how can we buy a machine for USD200,000; even if it is on hire purchase, you can imagine how long it can take to offset that bill". Besides the cost of the technology, extra costs of utilities and other inputs should be considered.

Developing high priced technologies puts an unnecessary financial burden on the miners, hence their aversion to the alternative and reversion to the 'old ways' of using mercury. Maina et al., (2021) in their report on East Africa conclude that the financial component of alternative functionable technology available for miners can be a restraining factor that prevents miners from accepting good practices. To curb this challenge, some scholars have proposed the establishment of partnership along the value chain. With this collaboration miners focus on mining while the private business invests in alternative technologies and operate as processing companies. This arrangement may not work well in different contexts so must be tested first.

Geological considerations

A key point worthy of consideration is the geological base of minerals in Ghana. Gold extracted from hard rocks and those from alluvial have different geological characteristics, minerology etc thus will need different technologies for processing. The developers of technologies should therefore, consider the variance in geological features of mining communities without compromising on characterising and analysing ASM sites differently. This goes to underscore the idea that there should be several alternative technologies at any point in time so the appropriate one for a particular geology is adopted by the miners. For example, the 'gold furnace' technologies developed currently cannot outperform amalgamation in alluvial mining sites.

Social dynamics

As suggested by Hylander et al. (2007) there must be some structural and social contexts hindering the termination of the amalgamation process at ASM sites. There are some social and economic barriers that stand in the way of miners accepting new technologies to change their operation. For instance, in most ASM communities where mercury is used, there are the 'mercury dealers' who ensure the metal is readily available. Keane et al. (2023) report that in Uganda, middlemen play a crucial role in mercury supply in the ASM sector. The middlemen and miners have an arrangement whereby the former usually finance the gold extraction and processing by providing mercury to

[3] Interview with small-scale miner, April 2024

[4] Interview with University Researcher, April 2024

the latter and the latter must sell their gold to the former. The middlemen therefore, become the main source of mercury supply; thus middlemen/gold buyers can work against the adoption of alternative technologies.

Hilson et al., (2024) show the illicit flow of mercury from neighbouring countries into Ghana and further transmission from Ghanaian ASM sites into Burkina Faso etc. Due to this chain of business, clearly, eliminating mercury emissions will be met with resistance from the group of dealers who are making livelihoods from the sale of mercury. This is a sensitive aspect of the social dynamics involved in mercury-use in ASM and should be considered. According to Smith (2019), one weakness that undermines many mercury reduction projects is a failure to attend to the socio-technical nature of mercury issues in ASM, focusing solely on technical aspects or educational approaches, rather than incorporating the full complexity of ASM reality. Clearly, the approaches used so far least consider the numerous non-miners whose livelihoods also depend on the marketing of mercury on ASM sites.

Conclusion

ASM is undoubtedly a driver of rural development considering the enormous benefits to persons directly and indirectly involved in the sector. Unfortunately, mercury use in ASM operations makes it a very dangerous activity creating much harm to the miners, non-miners and the environment. Although the impacts or dangers of mercury are usually masked to miners, communities have displayed utmost abhorrence to the visibly devastation from mercury use. For Ghana, it is worrying that the country is among the top five countries with significant mercury release through ASM operations. Unfortunately, successive governments have taken brutal means to combat this by imposing complete ban on ASM activities. It is however, obvious that this method would not work since the numerous bans have yielded no results; the ban only exacerbates illicit market for mercury.

There have been efforts at the international level to make ASM a mercury-free activity by supporting the introduction of alternative technologies. Unfortunately, the adoption of these technologies among miners is minimal. Eliminating mercury use in ASM is proven very complex, as approaches must address technological, socio-economic and other factors to tackle the (dis)continuity of mercury use among miners. So far GoG's method to manage mercury exposes a rather lackadaisical approach to the ASM formalisation process in Ghana such that the unavailability of alternative technology and where available, highly priced defeats the whole purpose of eliminating mercury from ASM. This *modus operandi* creates more illegal miners and when most of the miners' activities are outside the legal framework, we can anticipate how far mercury-free initiatives will go.

Even though Ghana's NAP proposes massive changes in artisanal miners' operations to manage mercury at ASM sites, till date, the government has not presented requisite technological solutions. Until the right steps are taken, the cycle of developing 'unwanted' technologies will not end and the goal of reducing the emission of, and subsequently eliminating mercury use in the ASM sector will not be achieved. The consequences on the environment and human health are undoubtedly dire. This paper therefore, concludes that the introduction of technologies is very necessary, but the geological, socio-economic, technical factors listed above be considered. More alternatives should be made available to miners at every point in time to enable them to choose what technology suits their production. The absence of appropriate mercury-free technology will only increase mercury emissions into the environment. Although the MCM does not put a timeline on the eradication of mercury in ASM, countries such as Ghana with 'most significant emissions' and yet slow paced with the development of acceptable mercury-free technologies will be sitting on a possible 'chemical time bomb.'

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The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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