How do technological changes in artisanal and small-scale gold mining affect the environment and communities' health?

Nkuba, B.[1,2]*, Muhanzi, A.[1], & Zahinda, M.[1]

[1]Centre of Expertise on Mining Governance (CEGEMI) - Université Catholique de Bukavu -
[2]Institute of Development Policy (IOB) - University of Antwerp
*bossissi.nkuba@ucbukavu.ac.cd

Abstract

In recent decades, artisanal and small-scale gold mining (ASGM) in developing countries has evolved from a labour-intensive, manual process into an increasingly mechanised and technologically advanced activity. Nevertheless, most ASGM operations continue to be informal. There are very few environmental safeguards and there is little appropriate medical care for workers and their communities. In this article, we analyse the health and environmental effects produced by these technological changes through in-depth case studies of two ASGM mines in the east of the Democratic Republic of the Congo. First, we analyse the health and environmental risks created by the introduction of new technologies. Second, we analyse the knowledge, or lack thereof, of local communities and ASGM workers about the risks that these new technologies pose. Third, we analyse the health problems that the community is currently experiencing in relation to these technologies and how the local health system copes with them. And finally, we discuss the possibility of adopting technologies that better protect human health and the environment, as well as the necessity to increase the formalisation of the ASGM sector. Indeed, this study brings to light how unsuccessful formalisation, in an environment where extractive technologies are changing, increases the number of health and environmental problems faced by miners. It builds the case for an increased traceability and accountability of downstream actors for the environments and communities producing the materials their industries need.

Keywords: ASGM, informality, technologies, environment, health

1. INTRODUCTION

All over the world, ASGM has evolved from being a purely manual and labour-intensive activity (Yego et al., 2018) to being a small-scale or even larger-scale activity that is mechanised and uses

advanced techniques and technologies, such as excavators and dredges for extraction and cyanidation for processing (Verbrugge et al., 2021). The negative health and environmental effects of ASGM have been well established in the literature (Mestanza-Ramón et al., 2022). However, few studies have established whether and in what sense technological changes affect miners' health and their environment.

In this article we use qualitative data from two of the largest gold mining sites in South Kivu province, Eastern DRC, to study the health and environmental effects of a variety of recent technological changes. We look at the risks of mercury, nitric acid and cyanide poisoning; asphyxiation; landslides; carbon monoxide poisoning in pits and various injuries by assessing their occurrence throughout different gold production stages (extraction, processing and trade). We also look at how the environment (aquatic ecosystems, vegetation, soil and air) is impacted by dust, tailings and chemicals. We discuss the local and international perception of these risks as well as the factors that enable or hinder knowledge and interventions. We further analyse the occurrence of diseases caused by these risks and the ways in which the local healthcare system and people themselves cope with mining-related diseases in a context where social responsibility towards mineworkers and local communities is absent due to informality. And finally, we discuss possible ways forward and challenges that hinder a better protection of people's health and the environment from the negative impacts of ASGM.

Our contribution is important for three main reasons. First, the only technology whose health and environmental impacts have received a lot of attention is mercury use. Indeed, mercury has taken centre stage in worldwide programmes such as the Minamata Convention (United Nations Environment Programme [UNEP], 2013). Meanwhile, sluice tables, often presented as a 'cleaner alternative to mercury' (Martinez et al., 2021), have had their negative impacts barely analysed, despite the latter varying strongly depending on where and how sluice tables are used (Sousa et al., 2011). Other technologies, such as cyanide, nitric acid, excavators, dredges and ball mills, clearly affect the environment as well as human health. Yet these effects have hardly been documented (with the exception of Knoblauch et al., 2020; Marshall et al., 2020; Razanamahandry et al., 2018 on cyanide). Second, we argue that it is important to study local knowledge and practices related to technology use, since interventions to promote 'cleaner' technologies often fail because they are ill adapted to the local context or mineworkers lack an incentive to adopt them (Nkuba et al., 2019). Third, we discuss the issue of responsibility. The transition from artisanal

mining to small-scale mining produces an increase in productivity and financial gains for capital owners (see Bikubanya & Radley in this issue). More and more, the means of production are in the hands of small-scale mining companies or miners' cooperatives (see Dunia & Geenen in this issue). Yet in the cases under study, this has not resulted in these companies/cooperatives taking increased responsibility for people's health and environmental protection. We argue that this failure to take responsibility has not only caused damages to public health and the environment but also limited mineworkers' access to healthcare, thus promoting a large number of alternative medical options whose effectiveness remains to be proven.

Following the introduction, section 2 presents the framework through which this article is analysed. It looks at the outsourcing of corporate responsibility through supply-chain informalisation and at how technological changes in the ASGM sector have led to greater risks, with no one taking responsibility. Section 3 introduces the research sites of Kamituga and Misisi and discusses our methods. Section 4 analyses the gold production process in these sites, from the extraction of ore to the sale of clean gold, to identify health and environmental risks and the actors causing and/or being exposed to these risks. It also studies different actors' knowledge of these risks and the mechanisms through which they protect themselves from them. In section 5, we examine the medical and non-medical treatment of victims of these risks. Section 6 concludes the article by considering possibilities for cleaner technologies and how formalising the artisanal mining sector, though a useful tool to promote the use of better technologies, is hindered by its high cost and the difficulty of assigning this cost to a right actor.

2. LOCATING TECHNOLOGICAL CHANGE IN AN INFORMAL SPHERE

In this article we focus on risk and protection in two dimensions: environment and human health. We do not only aim to identify risks, but also demonstrate its local understanding, and the protection mechanisms that are, and can be, put in place. At the same time, we understand that questions around risk and protection are not only about the ways in which extraction and processing are organized at the local level, but also about the ways in which this feeds into global supply chains. Ultimately, questions around risk and protection are also about responsibility and the governance of mineral supply chains. In this section, we introduce a framework on mineral supply chain governance, which argues that informality allows downstream actors to evade environmental and health regulations and hence eschew responsibility.

Over the past three decades, social and environmental responsibility in mineral supply chains has been increasingly outsourced to downstream actors buying the resources (Sarfaty, 2015). This was in line with a general shift from public to private regulation (Kaman, 2015) in the neoliberal era, combined with a lack of accountability on the part of some governments in developing countries. But tracing and exposing the connections between the gold buyers and manufacturers on the one hand, and mineworkers on the other hand, is difficult because the globalised and 'massively complicated' gold supply chain consists of many formal and informal actors, as well as actors operating in between both (Bloomfield & Maconachie, 2021).

Due to the relative invisibility of formal actors in the mine, it looks like artisanal miners are just fending for themselves and damaging the environment and their health in the process. However, they are providing an important shield – both in terms of costs and administrative procedures and in terms of reputation if something goes wrong – for companies that badly need gold but do not want to bear the responsibility that obtaining it brings. Indeed, in this sense, the informal nature of artisanal and small-scale mining (ASM) is an important element in the 'smooth functioning' of the global production system, as it enables an increase in profits while risk, regulation and responsibility are escaped/outsourced (Verbrugge & Geenen, 2020).

The informal nature of ASM and the fragmentation of the supply chain reduce access to information in three ways. First, although extractive industries are among sectors absolutely requiring an environmental and social impact assessment (ESIA), environmental impact attenuation and remediation plan (EIAR), and an environmental and social management plan (ESMP) (RDC, 2018), the governments of countries where extraction happens are not able to require them from ASM actors. This is because formal actors of their supply chain are not locally present (nor are they traceable) but also most mineworkers either operate informally (often with no mining permit), cannot afford an assessment, or both (Bryceson et al., 2020; Kinyondo & Huggins, 2021). Second, in addition to ASM's informal nature prevents any prior assessment of social and environmental problems that gold extraction can cause, it also hinders monitoring. Indeed, EIAR and ESMP provide a basis for monitoring how the environmental and social effects are being mitigated and remediated to. Questions such as: reforestation efforts, support to local health care systems, etc. can be monitored vis-à-vis the initial plans included in the EIAR and ESMP. Third, informality reduces public access to information. Indeed, ESIA reports could help inform policy makers and the public on how the environment and local communities' health may

be affected. While Davies (2022) argues that despite pollution is 'out of sight' to the international community, but clearly perceived by the locals; we argue that not all forms of pollution are locally perceived, and that informality prevents mineworkers and local communities from accessing information about these unperceived risks. Thus, the lack of ESIA, EIAR, ESMP and other health and environment protection tools in ASM hinders the monitoring, documentation and local sensitisation about the industry's effects on the environment and local communities.

One of the clearest connections between informality and ASGM environmental impacts can be found in the Minamata Convention. While this convention aims at reducing and, if possible, eliminating mercury pollution from ASGM, most national plans implementing it spend the bulk of their energy and budget on formalising the ASGM sector (Prescott et al., 2022). Prescott et al. (2022) point to the unfairness of artisanal miners or governments of developing countries having to bear the cost of the formalisation of the ASGM sector and suggest that this cost should be borne by downstream actors and developed countries. Thus, although informality is related to poor health and environmental outcomes, the ASGM sector has taken very few significant steps towards its formalisation, since the costs still fall on those who can afford them the least. Moreover, some research has suggested that formalization does not necessarily reduce, let alone eliminate, health and environmental risks (Robles et al., 2022).

The effects of such sustained informality are even more critical in a context of technological change. New technologies applied in artisanal mining increase both productivity and risks. They enable miners to process larger amounts of ore by using some tools and techniques that were traditionally used in the industrial sector only (ball mill, cyanidation, and others). But all of that is done in an informal manner. Thus, none of the tools that help restrict industrial miners (or any other formal actors) from degrading the environment or harming people's health, such as ESIA, can no longer be implemented. As a result, the gold supply chain can benefit from a higher production, and some local actors (who are often local elites who own this technology and run miners' cooperatives, see De Haan & Geenen, 2016) benefit from larger profits but do not bear the environmental and social costs produced by such technological advances.

In this article we use empiric evidence to explain how fragmentation of the supply chain has facilitated the pollution of local environments, dispossessing local communities of crucial resources and inflicting a slow form of violence on miners and communities (Davies, 2022;

Sandlos & Keeling, 2016). This slow violence is experienced through unavoidable risks, actual diseases and complicated access to healthcare, all of which the global industry that uses these minerals does not take responsibility for. The study also analyses how information access varies strongly locally and depends on the type of risk the community is exposed to. It thus argues that even locals are not always aware of the violence they undergo and brings some nuance to the geographic component of the 'out of sight' violence.

3. RESEARCH SITES AND METHODS

This study was carried out in two mining towns in South Kivu province, Kamituga and Misisi, in April, May and August 2021. Kamituga, is located 180 kilometres south-west of Bukavu, the provincial capital of South Kivu, and has 150,000 inhabitants, of whom approximately 10,000 to 16,000 are ASGM workers (Geenen, 2015). It experienced industrial mining since the 1920s by Belgian company Compagnie Minière des Grands Lacs (MGL) and later (1976-1997) by the Société Minière et Industrielle du Kivu (SOMINKI). However, since the 1980s, ASGM has developed in the region at a high speed, becoming the mainstay of the local economy (Geenen, 2015). Since 2011, the Banro Corporation has done exploration in Kamituga (Geenen, 2015). In 2014, the consultancy firm SRK (Steffen, Robertson and Kirsten Ltd.) estimated that from 1920 to 1996, 46.7 tons of gold had been mined and 28.5 tons remained available.

Misisi is situated 365 kilometres south of Bukavu. Unlike Kamituga, its population still experiences conflict, with several armed groups present and active in the area (Bafilemba et al., 2014; Max Impact, 2019). However, this insecurity is neither widespread nor permanent. Indeed, 10 mining sites in Misisi have been validated by the government, civil society and international partners as not involving any armed violence or other similar abuses (Voix du Congo, 2019). In addition, and again unlike Kamituga, Misisi does not have a long history of industrial mining (Kamundala & Ndungu, 2017). The local population discovered gold in the area after the DRC's independence in 1960. Progressively, Misisi became a hub for the gold trade thanks to its geographical position. Not only is it located where three Congolese provinces meet (Tanganyika, Maniema and South Kivu), but it is also well connected to Burundi and Tanzania (via Lake Tanganyika). Thus, Misisi is home ASGM actors coming from all these provinces and countries (Kamundala & Ndungu, 2017).

For this research, 134 interviews were conducted in Kamituga (106 individual interviews and 28 focus group discussions) and 127 interviews in Misisi (99 in individual interviews and 28 in focus groups). The targeted sample represented both mineworkers and other ASGM stakeholders (mineworkers' committees, cooperatives, state structures, civil society organisations and gold trading houses) as well as medical professionals (doctors and nurses), medicine sellers (both in pharmacies and on the streets) and traditional healers. Group and individual interviews lasted one hour on average and were recorded, transcribed and then analysed with NVivo 1.2 software. The interviews aimed at (i) assessing mineworkers' level of understanding and perception of the environmental and health effects of ASGM technologies, (ii) listing the main health problems encountered by artisanal mineworkers in connection with various technologies and (iii) understanding the reasons for the persistence of technologies and practices that are destructive of the environment as well as the possibilities for community involvement in the adoption of better technologies. We supplemented the interviews with field observations (such as on deforestation, water and air pollution, loss of biodiversity and land degradation). The confidentiality of the information shared was always respected.

4. EXTRACTION, PROCESSING AND TRADE

This section presents the identified effects of ASGM on the environment and on mineworkers' and communities' health, starting with the phase of extraction and moving on to consider processing and trade. Three major effects are discussed for the extraction phase: deforestation and loss of biodiversity; landslides, erosion, soil degradation and use of explosives; and water evacuation and compressed oxygen supply in the pits. At the processing and trade phases, four effects are identified: air and water pollution by crushed ore; mercury pollution; cyanide pollution; and nitric acid pollution (see Figures 1 and 2).

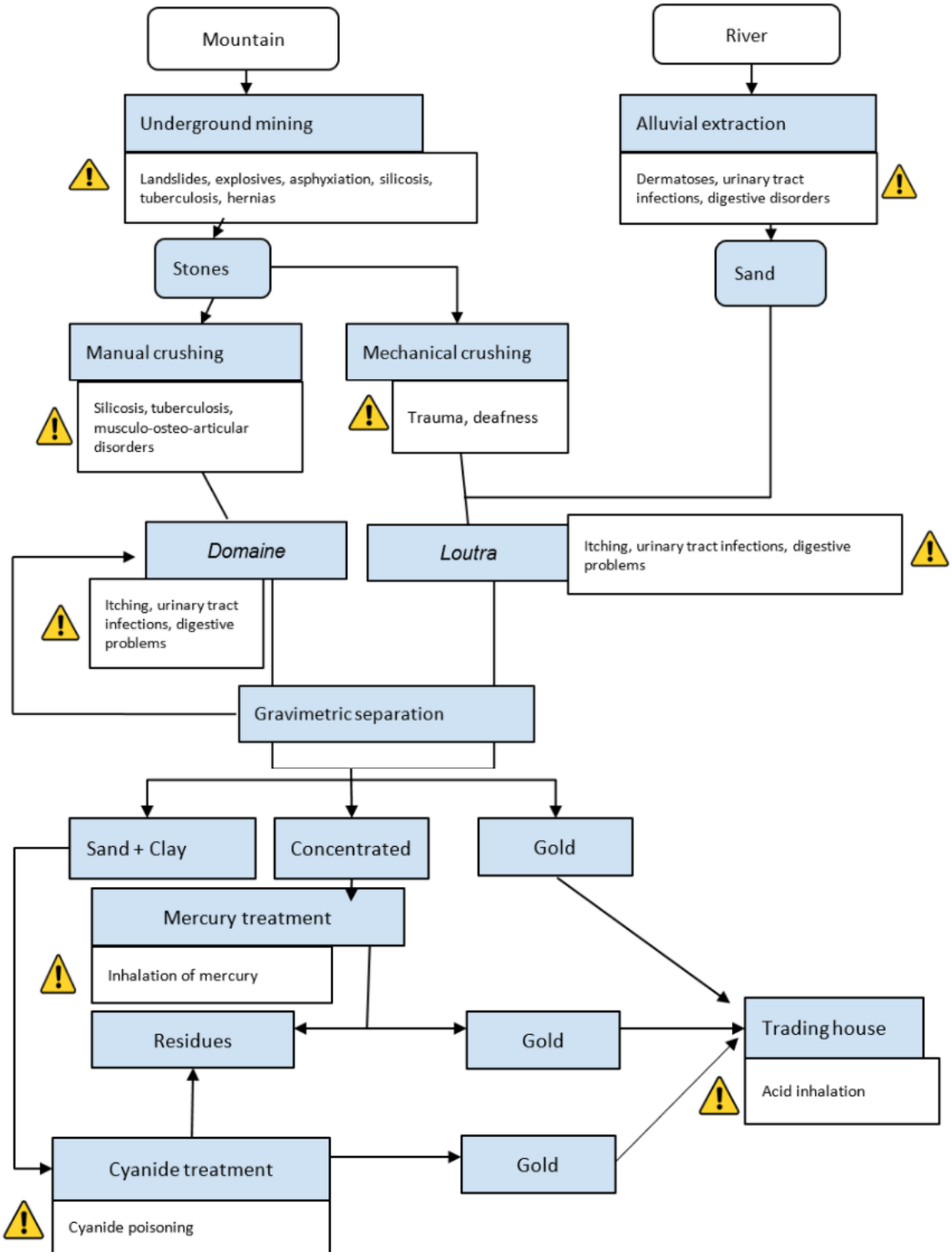

Figure 1. ASGM production process indicating points of risk to the health of mineworkers.

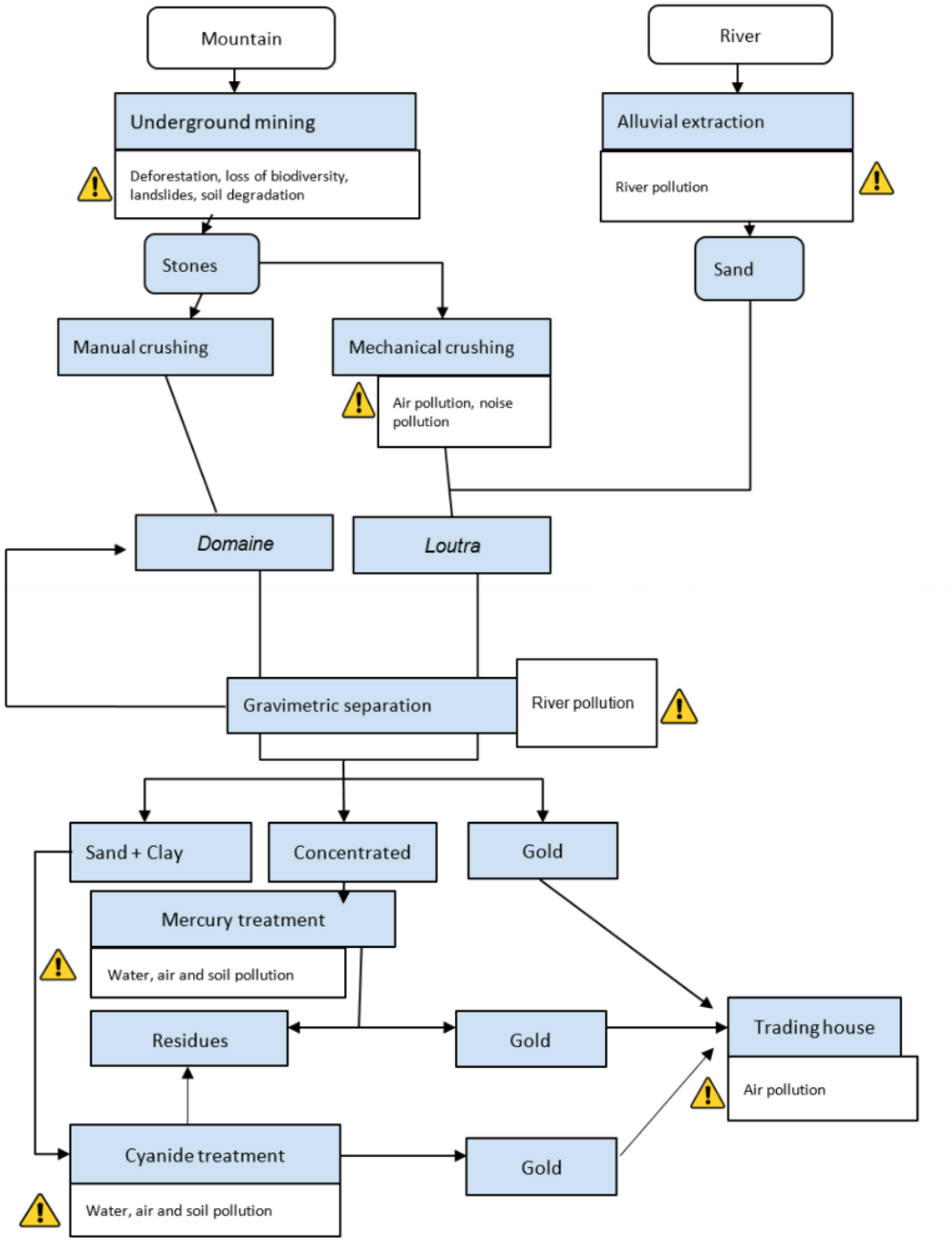

Figure 2. ASGM production process indicating points of risk to the environment.

4.1. Extraction

For the extraction phase, forest and soil degradation were the first issues reported. These issues are well perceived by mineworkers and communities. Despite mineworkers using wood to fortify

their tunnels, deforestation is not a direct consequence of ASGM. It is instead mostly due to the large amounts of firewood necessary to cook for the mining town's residents. Because of this, mineworkers do not feel responsible, since they do not believe that it is the gold rush that has increased wood demand.[1] Since their operations are informal and governmental services are not sufficiently monitoring, ASGM miners do not follow the requirements of the Congolese Mining Code in matters of environmental protection (RDC, 2018). Deforestation, alongside population increases and ASGM, has caused a second problem: biodiversity loss.[2] This affects local food diversity, since the bushmeat and many mushroom species that used to be consumed in Kamituga can no longer be easily found. Deforestation and biodiversity loss are unequally felt. They deeply affect the native community, who is traditionally strongly attached to forestry resources, contrary to most mineworkers, many of whom are not natives.[3] Also, mineworkers and local communities recognise that mining degrades the soil and causes erosion and landslides. These affect miners' safety and local food security. ASGM is known for changes in the landscape and in land use, transforming large expanses of land into a 'lunar landscape' with a succession of holes and tailings, which are not conducive to animal life and where plants have difficulty growing (Adler et al., 2013; Sana et al., 2017) (see Figure 3). Soil degradation and fertility loss (in addition to plant diseases, torrential rains and a lack of fertilisers and pesticides[4]) mean that even those who are not involved in mining have lost interest in pursuing agriculture. From this perspective we can see that, thanks to its informality, the gold supply chain is dispossessing local communities from their forestry and land resources (Sandlos & Keeling, 2016).

Second are explosions, water and smoke. Indeed, thanks to corruption, explosives – though forbidden – are still used to crush rocks that are hard to remove manually. They are associated with landslides,[5] and if not properly handled or of poor quality, they cause accidents that can

[1] Focus group with mineworkers in Kamituga, April 2021.

[2] Interview with a member of the mining community in Kamituga, April 2021.

[3] Interview with a mineworker in Kamituga, April 2021.

[4] Interview with a farmer in Kamituga, April 2021.

[5] Interview with a mineworker in Misisi, June 2021.

sometimes be fatal.[6] They also produce a lot of dust that mineworkers associate with tuberculosis.[7] On the other side, infiltrated rainwater often floods pits, slowing or stopping miners' work. To address this, miners use motorised pumps. Unfortunately, while they fix the water problem, pumps cause more deaths with their exhaust fumes than all other mining fatalities combined.[8] In Kamituga, miners used to power their pump with locally produced hydroelectricity. However, since the limited 1.8 megawatts production at the hydroelectric station barely covered the domestic needs of Kamituga's growing population,[9] they shifted first to diesel pumps. The latter, despite being convenient and readily available, spread carbon monoxide in the pits, which prevents miners' cells from carrying oxygen, resulting in chemical asphyxiation (Goldstein, 2008). To solve this, the State service of assistance to mineworkers (SAEMAPE) banned diesel pumps (allowing only gasoline ones)[10] and miners started using pipes to push compressed air into the pit and evict exhaust fumes from it. Unfortunately, these pipes are pierced by the repetitive passing of miners and ore bags and spread carbon monoxide back into the pit, while air recirculates at the pit's entrance. This causes miners' suffocation, since this issue can neither be predicted nor noticed early enough to enable miners to cover the long distance to the exit of the pit. Thus, by the time they experience difficulties in breathing, they pass out and die if no one helps them get out in the next few minutes.[11]

[6] Interview with a mineworker in Kamituga, August 2021.

[7] Interview with a mineworker in Misisi, June 2021.

[8] Interview with an agent of SAEMAPE, April 2021.

[9] Focus group discussion with the Mungombe Micro Hydroelectric Power Plant Management Committee (CGMHM), August, 2021.

[10] Interview with an agent of SAEMAPE, April 2021.

[11] Interview with mineworkers in Kamituga, April 2021.

Figure 3. (a) Polluted mining site in Kamituga; (b) Mining landscape in Kamituga.

4.2. Processing and trade

In Kamituga, like in many other artisanal gold mines around the world, the ore is physically and/or chemically processed in processing centres (Veiga et al., 2014). However, due to their current expansion and large toll on the environment and the community's health, these processing centres inflict a slow violence on local communities (Davies, 2022). In addition to mercury and cyanide management (Veiga et al., 2014), additional threats are posed by processing centres in Kamituga and Misisi. The average processing centre contains a ball mill (*concasseurs*), a washing pit (called *lutra*) and a washing area with sluice tables (called *domaine*). While increasing mineworkers' productivity (Mulonda et al., 2019), ball mills have also increased pollution by dust,[12] smoke and noise.[13] They also cause several injuries (including serious ones) to *machinistes* (ball mill operators), despite them being cautious and vigilant (avoiding alcohol or any drug that can impair the acuity of their reflexes). Injuries are often caused by ball mills snagging on belts or *machinistes*' or customers' clothing getting tangled in ball mill gears and dragging victims into the grinding system. To be able to immediately stop the ball mill in case of an accident, *machinistes* have to stay exposed to its dust all day long (with no mask in most cases). They only step aside when the dust becomes excessive.[14] This silica-rich dust inhaled by mineworkers and nearby

[12] Interview with a medical professional in Kamituga, April 2021.

[13] Interview with a *machiniste* in Misisi, June 2021.

[14] Interview with a *machiniste* in Kamituga, April 2021.

residents causes silicosis, a disease impairing breathing by building up fluids and scar tissue in lungs, as well as lung cancer and increased susceptibility to tuberculosis (USAID, 2017).

After the ball mill, the crushed ore is 'washed' using banana sheathes sluices in the *domaine*. The *domaine* retains rich tailings, while poor tailings are discharged into the river, increasing its turbidity (hindering the sight and breathing of fish and decreasing oxygen availability for eggs on the riverbed) and altering its chemical composition (further harming fish and other aquatic organisms) (Hérbert & Légaré, 2000). Water from these rivers also becomes unsuitable for domestic use since it can cause diarrhoea, vomiting, nausea and other gastrointestinal problems (De Roos et al., 2017) as well as skin problems and urinary tract infections in people exposed to it through their work.[15] Miners tend to absolve themselves of blame by stating that they pollute much less than the industrial firm SOMINKI used to.[16] Though it is hard compare the environmental and health toll of current ASM activities to previous LSM operations, such statement portray the continuous slow violence and dispossession from clean rivers the community has undergone for generations (Davies, 2022; Sandlos & Keeling, 2016).

Moreover, Kamituga has recently undergone a major change in the geographic distribution of ball mills, and this has increased the number of affected river ecosystems. Until 2021, Banro was conducting exploration work and restricting mineworkers to use ball mills on only one site, locally called Calvaire (French for Calvary or Golgotha) due to the steep slope leading to it. Thus, for many years, only one stream was affected by the large amounts of waste coming from ball mills, *Bitanga* (Nkuba et al., 2017). However, in early 2021, Banro stopped its exploration and enforcement of constraints due to financial difficulties[17]. Thus, mining cooperatives installed ball mills in nearly 10 additional sites, which are closer to mining pits and thus reduce the cost of ore transportation. Unfortunately, this change in geographical distribution of ball mills across the city did not follow any ESIA, nor was any mitigation measure taken against its environmental and social effects such as more capital concentration which may increasing inequalities between the workers and the ball mill owners (Kabunga and Geenen, 2022).

[15] Interview with a mineworker in Kamituga, April 2021.

[16] Interview with a mineworker in Kamituga, April 2021.

[17] Interview with a Banro employee in Bukavu, August 2021.

The rich tailing from the *domaine* is sold to *cyaneurs* (mercury users) to be concentrated and reprocessed with mercury[18] (Nkuba et al., 2017). In Kamituga, using mercury in ASGM is a recent technique.[19] Before the early 2000s, locals were unaware of it, to the extent that when looting SOMINKI's mercury store during the Second Congo War (1998–2003), they poured out all the mercury and took home only the nearly valueless empty barrels for domestic use.[20] Similarly, there is a general unawareness of mercury's health and environmental risks[21] (Nkuba et al., 2019) as well as mercury-free techniques.[22] Despite this limited knowledge, the *cyaneurs* of Kamituga and Misisi pollute less than those in other countries. First, they use a relatively small amount of mercury, since they apply only a few grams measured in pen covers (13.5 grams for each) to their concentrate. Second, many *cyaneurs* work in small pits dug in the ground (*lutra*) which enable them to recover part of the mercury used. Third, they cover the amalgam with leaves that have trichomes, recapturing up to 25% of the mercury.[23] All this results in a ratio of only 1 to 2 grams of mercury used per gram of gold produced (Nkuba et al., 2018).

Aside from mercury, ASGM in DRC has started using cyanide for gold processing (Verbrugge et al., 2021). Though in nature cyanide reacts quickly and forms non-hazardous compounds, it still represents a risk of acute exposure in occupational settings through skin contact and inhalation (Vélez-Torres & Vanegas, 2022). Once in the body, it blocks cellular respiration, causing headaches, anxiety, confusion, vertigo, seizures, convulsions, pulmonary and cardiovascular disorder and renal and hepatic failure; it can lead to death (Desai & Su, 2012). Unlike mercury, cyanide is used at a medium scale (in a fenced and guarded area, with a series of open precipitation tanks and a processing building with a testing lab). In 2021, one cyanidation plant was operational and one under construction in Kamituga, but in Misisi such plants have been numerous since 2014 due to the town's proximity to Tanzania, from where this technology was imported. These plants

[18] Interview with a ball mill manager in Kamituga, April 2021.

[19] Interview with a *cyaneur* in Kamituga, April 2021.

[20] Interview with a *cyaneur* in Kamituga, April 2021.

[21] Focus group discussion with mineworkers in Kamituga, August 2021.

[22] Interview with a *cyaneur* in Misisi, June 2021.

[23] Interview with a *cyaneur* in Kamituga, April 2021.

employ a few permanent workers and dozens of daily labourers. While the latter rarely use personal protection equipment, their limited access to the processing building reduces their chances of inhaling higher concentrations of cyanide. The authorities (most notably those of SAEMAPE and the environment office) still have only limited knowledge about this technology and are thus unable to supervise its use[24] or prevent potential combinations of mercury and cyanide (which create more dangerous substances) in rivers, as strongly recommended by the Minamata Convention (UNEP, 2013). This is in line with Veiga et al. (2014), who argue that the appropriate information is not present with those who need it the most (mineworkers and ASGM supervisors) but instead with those possessing the greatest financial and intellectual capital.

Once they are provided with the adequate level of knowledge, local communities are able to take appropriate steps towards the protection of their health and the environment. This is well showcased in the case of nitric acid, used in trading houses to 'purify' gold before buying it. Due to nitric acid causing skin burns, respiratory ailments, gastrointestinal burns, and eye damage (Shetty et al., 2008) and having an easily perceptible smoke and strong odour (Nkuba et al., 2019), the community forced traders to install chimneys and channel this acid away from their neighbours.[25]

5. HEALTHCARE

The health risks posed by ASGM translate into a large number of diseases. These include several pulmonary, traumatic, digestive, and parasitic pathologies. Unfortunately, mineworkers live in rural areas with very limited health infrastructure, and their income is too low and too unstable to support them in times of sickness. In addition, the informal nature of their work as well as the fragmentation of the supply chain enables downstream gold users to be off the hook for any social responsibility towards them. This leaves mineworkers on their own, with little to no ability to access adequate medical care, which is the second aspect analysed in this section. Also, due to organisational challenges and the socio-economic constraints of mineworkers and the local community, traditional medicine and other means of treatment have re-emerged, taking advantage

[24] Interview with an employee of the cyanide processing plant in Kamituga, April 2021.

[25] Interview with a mineworker in Kamituga, April 2021.

of the weakness of the health system. This section explains the situation of miners' healthcare in Kamituga mining town.

5.1. Mining-related diseases

Cases of trauma (fractures, wounds and contusions); bone, joint and muscle pain due to heavy work; digestive disorders and lung diseases such as tuberculosis, silicosis due to silica dust and proximity are common. Yet patients are not always brought to hospitals,[26] unless the injury or illness is considered serious or life-threatening (such as those caused by ball mills or landslides). They also go to hospitals for respiratory disorders when the fever, cough, chest pain, difficulty breathing and haemorrhages of the respiratory tract these issues cause, become serious and/or chronic. Tuberculosis is very common in the area[27] (Katoto et al., 2018), especially for miners who work in overcrowded pits and those suffering from silicosis due to their exposure to silica dust. Mineworkers are aware of the silicosis and tuberculosis risks but have no way to prevent them.[28]

Malaria, perceived by locals as the most common disease,[29] is pervasive in mines due to stagnant water. Medical doctors also report an increase in typhoid fever cases and *Helicobacter pylori* infections[30] due to faecal, oral or salivary contamination because of poor hygiene and a lack of toilets. Rivers that are contaminated by faeces, urine and mine tailings[31] cause severe itching and infections in mineworkers washing ores.[32] Sexually transmitted diseases (STDs; gonorrhoea, syphilis and HIV in particular) are also common,[33] since many mineworkers live away from their families and, after a good production, often allow themselves a period of 'fun' with excessive alcohol and sex with several partners. Also, their limited sexual education hinders the use of condoms and thus enhances the transmission of STDs. This issue also affects young women, as discussed by Geenen et al. in this issue, who expose themselves to both STDs and teenage

[26] Interview with a mineworker in Kamituga, April 2021.

[27] Interview with a mineworker in Kamituga, April 2021.

[28] Interview with a mineworker in Kamituga, April 2021.

[29] Interview with a mineworker in Kamituga, April 2021.

[30] Interview with a medical doctor in Kamituga, August 2021.

[31] Interview with a mineworker in Kamituga, April 2021.

[32] Interview with a medicine seller in Kamituga, August 2021.

[33] Interview with a mineworker in Kamituga, April 2021.

pregnancies.[34] Finally, cases of mercury and cyanide poisoning are very likely to be overlooked or misinterpreted since the medical staff (both doctors in hospitals and nurses running health posts) lack special training in diseases particular to ASGM communities.[35]

The next section compares the formal way mineworkers access healthcare and the alternative paths they follow when sick (see Figure 4).

5.2. The formal healthcare system and its alternatives

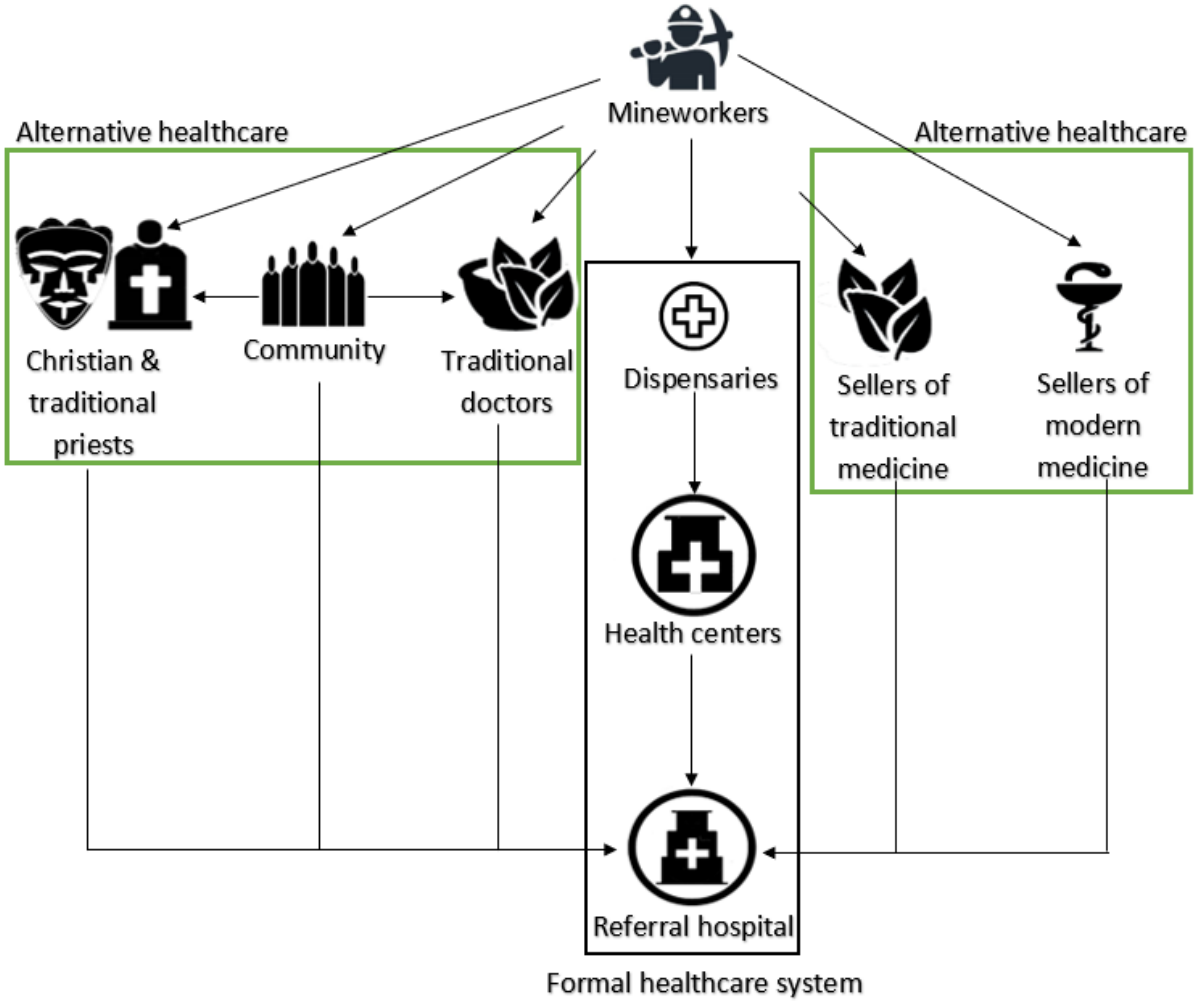

Figure 4. Healthcare access in ASGM.

[34] Interview with a mineworker in Kamituga, September 2021.

[35] Interview with a medical staff member in Kamituga, August 2021; interview with a medical doctor in Kamituga, August 2021.

The Congolese healthcare system runs through a three-step system. Primary healthcare starts at the bottom, with dispensaries offering a minimum service, followed by health centres. Complicated cases are transferred to referral hospitals (World Health Organization, 2006). Kamituga has dispensaries and health centres nearly everywhere in the city, but it has only one referral hospital: the Kamituga General Referral Hospital (HGRK, locally known as SOMINKI hospital after the company that ran it until 1996.

Unfortunately, the lack of medical equipment and personnel in dispensaries and health centres limits what can be done for patients. Dispensaries have no doctors (only nurses), and nearly no medical equipment. They usually only take care of simple malaria cases. Health centres may have a doctor can treat more diseases, as well as blood count test kits and an ultrasound machine for pregnancy monitoring. However, they cannot treat seriously injured patients and asphyxiation cases since they lack X-ray machines[36] and ventilators.[37] Only the HGRK has more advanced diagnostic tools and sufficient staff (seven doctors and 12 nurses), but a lack of reagents for the laboratory and medicine in the pharmacy or the X-ray malfunctioning often delay the care of patients.[38] Also, despite silicosis being very common, its diagnosis remains uncertain and its treatment beyond the capacity of the HGRK.[39]

The fragmentation and informalisation of the supply chain has freed downstream buyers from responsibility for the occupational health of mineworkers. For example, when SOMINKI was running the HGRK, it offered healthcare to its employees, and the local community could access the well-equipped hospital as well. Indeed, as part of their ESIA, mining companies assess the pre-existing local healthcare system and find ways to improve it and provide their workers and their families with free access (SLR, 2013). However, due to informality, downstream gold users do not uphold such standards.

[36] Interview with a medical doctor in Kamituga, August 2021.

[37] Some health centres had one ventilator, but this did not help much since often, multiple miners were affected by asphyxiation at the same time.

[38] Interview with a nurse in Kamituga, August 2021.

[39] Interview with a medical doctor in Kamituga, August 2021.

In addition to the lack of medical equipment in rural hospitals, mineworkers cannot afford medical bills. Indeed, they are not subscribed to any medical insurance or mutuality and have no social programme to support them[40] nor an income high and stable enough to pay upfront.[41] Thus, they turn to medicine sellers, sorcerers, church pastors or traditional healers. While contrary to doctors and nurses, medicine sellers offer free consultations to their customers, they do so with no prior pharmaceutical, medical or paramedical training.[42] Also, their patients often tend to stop their treatments not when it is required but when symptoms disappear.[43] Moreover, some patients/clients prescribe the treatment they used to others experiencing similar symptoms, with no doctor checking whether it is the same disease.[44] Thus, wrong diagnoses and inappropriate medication are frequent and cause many complications. Traditional healers use herbs and roots to treat both common complaints and quite complex illnesses.[45] This profession is often passed from father to son, without any known training and/or supervision by state organisations.[46] The herbs and roots traditional healers prescribe are also sold by street vendors, who prescribe them to patients as well. Sorcerers and pastors treat diseases that are considered to be linked with mystical phenomena and those that hospitals were unable to cure.

Though many locals consider traditional medicine, incantations and prayers to be more effective than hospitals,[47] traditional healers, sorcerers and pastors tend to refer the patients they know they cannot heal to the hospital.[48] In this regard, four types of patients are observed. First, patients who start with a traditional healer and then go to the hospital when they are not cured. Second, patients who first consult a doctor and, when not cured, resort to traditional healers, sorcerers or pastors. Third, patients who resort to the informal health system only. Fourth and last, patients who use

[40] Interview with a member of a cooperative in Kamituga, April 2021.

[41] Interview with a health professional in Kamituga, April 2021; interview with a mineworker in Kamituga, April 2021.

[42] Interview with a medicine seller in Kamituga, September 2021.

[43] Interview with a medicine seller in Kamituga, September 2021.

[44] Interview with a mineworker in Kamituga, April 2021.

[45] Interview with a mineworker in Kamituga, August 2021.

[46] Interview with a traditional healer in Kamituga, August 2021.

[47] Interview with a sorcerer in Kamituga, August 2021.

[48] Interview with a traditional healer in Kamituga, August 2021.

self-administered care following the advice of mineworkers and/or other community members. Based on our interviews, only one in three patients goes directly to a nurse or doctor to seek medical help. More than half of patients first seek alternative healthcare and go to the hospital only after not observing positive effects of their treatment for three to seven days.[49]

In addition to the above healthcare paths, mineworkers have developed their own strategies and techniques to provide first aid for commonly faced health issues. If a miner or miners suffocate in the pits, the victims are first pulled up to the pit entrance. There, cuts are made on the unconscious victims' skin with a blade, and only after these victims are fully lifted out of the pit. However, due to the lack of first aid equipment, the same blade is often used for all victims. This process is thought to help them avoid shock, as they are moved suddenly from an oxygen-deprived environment to an oxygen-rich one. Next, victims are transferred to the nearest health centre. Further treatment depends on whether oxygen therapy is available. If it is not, victims must be transferred to the HGRK where they can be provided with oxygen.[50] Many survivors of suffocation tend to suffer from mental disorders[51] and some irreversible brain damage (Gall, 2016).

6. CONCLUSION: TOWARDS CLEANER TECHNOLOGIES AND FORMALISATION?

Due to the fragmentation of the supply chain and the informal nature of ASGM, many environmental and health damages have occurred. Despite some effects attracting global attention, most went unnoticed, even though they dispossessed local communities of their key resources (Sandlos & Keeling, 2016) or inflicted a form of slow and hardly perceived violence on these communities (Davies, 2022). Our work has helped draw attention to these effects but also to the factors causing and/or enhancing them. Although many researchers consider a responsible and sustainable production of gold to be an ideal that continually eludes scientists, activists and development organisations (Bloomfield & Maconachie, 2021), it still is an ideal that needs

[49] Follow-up interviews with medical staff and community, July 2022.

[50] Interview with a medical doctor in Kamituga, April 2021.

[51] Interview with a mineworker in Kamituga, April 2021.

pursuing because many rural communities, particularly in developing countries, depend on both mining income and the quality of their ecosystems for their survival and well-being.

This article has also shown how technologies that increase miners' income are easily adopted and adapted to and become hard to ban. At the same time, the adoption of technologies that protect the environment while lowering production is way more challenging (Hilson, 2006). Indeed, policy makers should avoid 'just' banning unsafe technologies that increase productivity, since these bans would not be effective. For example, mercury has been banned from ASGM by the DRC's mining code, but this decision has not reduced its use at all (Nkuba et al., 2017). Instead, such decisions tend to informalise the polluting activity, thus reducing ways in which it can still be supervised and have its impacts reduced.

Policy makers should instead prioritise the promotion of alternative technologies that preserve communities' health and the environment while maintaining, and if possible increasing, mineworkers' production. Such technologies have been developed and tested by multiple researchers. Cordy et al. (2015), for example, observed a 50% reduction in mercury vapour concentrations in the urban core of Segovia (Colombia), with a 30% increase in gold production through changes in processing centres. Regarding dust, Gottesfeld et al. (2019) showed that wet-spray misting nozzles and wet stream machines reduce lead and silica dust in ASGM operations, decreasing both direct respiratory and take-home exposures. Balegamire et al. (2022) showed that tailings can be removed from rivers and used as substitutes for sand in the construction of concrete pavers, thus significantly reducing pollution while creating added value from the waste.

Unfortunately, responsible/clean technologies are facing a third challenge: their cost. Indeed, many ASGM workers earn barely enough for subsistence, leaving little room for them to invest in safe technologies or health protection (Tschakert & Singha, 2007). Thus, clean technologies have to not only be better for the environment but also increase miners' production by an amount higher than what it cost to acquire them. Miners will not '...pay a dollar for a piece of equipment or a technique which does not bring in two dollars' (Hinton et al. 2003, p.102). Unfortunately, technologies meeting all these three criteria (preserve health and environment, be affordable, and maintain/increase production) are very rare. Thus, for miners to adopt technologies that may not return their investment, we believe it is necessary to have bodies (governments, downstream buyers, international organisations etc.) that are willing to pay the premium and make cleaner

technologies financially acceptable for miners. These bodies should use a triple approach: lower the cost of cleaner technologies, educate miners and formalise ASGM (Veiga & Fadina, 2020). Educational interventions should focus on educating mineworkers about health and environmental risks and on demonstrating the cleaner technologies (Veiga et al., 2015), while formalisation should focus on putting regulations in place for mineworkers to legalise their activities, be subjected to legal tools such as ESIA and, as a consequence, use technologies that are both efficient and health- and environment-friendly (Veiga & Fadina, 2020).

Of the above three goals, formalisation is the hardest to achieve. Indeed, despite formalisation being recognised as one of the key requirements for more responsible ASGM (UNEP, 2013), it is first an enormous undertaking and second very costly; third, it will require legal tools that are adapted to ASM diversity. With more than 20 million gold miners worldwide not officially recognised, registered, regulated or protected by state laws (Prescott et al., 2022), it is hard to find a model (or a number of fixed models) that works for everybody in such a large and diverse group. This gets more complicated since at the local level the formalisation process is easily captured by a local elite that owns ball mills, cyanidation plants etc. and runs mining cooperatives (De Haan & Geenen, 2016). Mineworkers on the other hand, despite being the target of formalisation processes, are often members of cooperatives in name only, while they have little to no influence on their governance. Thus, while cooperative and technology owners capture increased profits from these technologies and the increased risks mineworkers take while operating them, they do not offer healthcare coverage nor invest in local healthcare systems, preventing the community living in the environment they pollute from easily accessing medication. It is thus key to adopt a bottom-up and site-specific approach in order to discover which intervention will lead to better formalisation processes and positive outcomes for mineworkers, local communities and their environment.

In addition, when it comes to cost, the National Action Plans from the Minamata Convention estimate that formalisation will cost between USD 355 million and USD 800 million worldwide for the next five years (Prescott et al., 2022). We agree with Prescott et al. (2022) that this should not rely on local funds. Indeed, neither miners nor the governments of developing countries can afford such expenses. Instead, gold buyers, developed countries' governments and large gold mining corporations should work together to fund the much-needed formalisation process and require more traceability of all gold used worldwide (Bloomfield & Maconachie, 2021). Finally,

we believe that formalisation should be accompanied by adapted legal tools. Tools such as ESIA should not wait for the ASGM sector to be fully formalised but instead adapt to its progressive nature and the financial constraints of ASGM operations to ensure maximum damage prevention.

To conclude, although adapted technological innovations, formalisation and adapted legal tools are very challenging to put in place, they may represent a rare way to protect the environment and local communities while the latter can still benefit from the increased income technologies provides.

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