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Invisible and ignored? Local perspectives on mercury in Congolese gold mining

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Abstract

Many scholars have documented mercury use in artisanal and small-scale gold mining as well as its harmful effects on the environment and human health. In spite of this, amalgamation with mercury is still widely used as a technique to separate gold from the ore concentrate, and (inter)national initiatives to reduce the use of mercury seem to have little effect at the local level. This article digs deeper into this puzzling fact, by presenting a case study on mercury use in the Democratic Republic of Congo (DRC). Using empirical data collected in the Kamituga gold mine, we show that the local population and miners are not sufficiently aware of mercury's potential risks because adverse effects are not immediately visible. The more dependent people are on mining activities, the less eager they are to give up short-term economic benefits (by reduction of mercury use) to gain long-term societal benefits (i.e. protection of their health and the environment). In addition, mercury use is governed by formal as well as informal norms and actors across different scales. Due to financial, material, technical and human constraints, there is a lack of awareness raising and ineffective law enforcement. These factors lead to mercury being used near and in residences as well as within catchments of important rivers. The overall consequence is that mercury remains a major yet invisible threat to human health and the environment in the DRC.

1. Making mercury visible

1.1. Gold mining & the environment: the case of the DRC

It is difficult to know how much gold is being produced in the Democratic Republic of Congo (DRC). According to the latest available figures from the Extractive Industries Transparency Initiative (EITI), 31.8 tonnes of gold was extracted by large-scale firms in 2015 (EITI, 2017). In addition, artisanal and small-scale miners produce an estimated 11.6 tonnes per year (IPIS, 2016), most of which is generated informally by *ca.* 200,000 miners who are active in hundreds of mining sites in the Eastern part of the country (idem). Gold extracted outside of large-scale activities is smuggled out by a network of Congolese and foreign traders, sometimes involving armed actors and rebel groups. The informal and sometimes militarized nature of artisanal gold production and trade has received international attention, resulting in numerous publications, as well as a range of policy initiatives, on so-called conflict minerals (for an overview and critique see De Brier and Southward, 2015; Diemel and Hilhorst, 2018; Vogel and Raeymaekers, 2016). Tensions between large-scale and artisanal miners, as well as socio-economic problems associated with artisanal mining, have also been documented (Perks *et al.*, 2018; Geenen, 2015; Bashwira, 2017).

The environmental issues related to gold production in the DRC have received far less attention, despite the overlap of mining activities with forestry resources. This is quite remarkable, given that the DRC has the world's second largest tropical forest which is crucial for the planet as a carbon sink and biodiversity sanctuary (Krantz *et al.*, 2018; Xu *et al.*, 2015). Gold mining is definitely having an impact on deforestation, but also on water siltation, soil degradation, dust pollution, wild life poaching and water pollution with acids, copper, lead, arsenic, cyanide and/or mercury (Hund *et al.*, 2017; USAID, 2010). However, the extent of these impacts remains poorly understood. Somehow – maybe because of the magnitude of the socio-economic and security issues the country is facing – the environmental impact has remained relatively invisible in research on mining in the DRC. Secondly, very little is known about how these environmental threats are perceived by local communities. Whilst these communities are benefiting from the income generated by mining, they are nevertheless likely to suffer the consequences of deforestation, water and dust pollution and soil degradation. However, although some of these effects are highly visible, others are not.

This article thus aims to *render visible* the threat of mercury use by (a) gathering knowledge on mercury use and governance in Congolese gold production, and (b) assessing the knowledge on environmental impact among the population living in and around the mines, as well as within the public and technical services governing the sector. We argue that mercury pollution - since its effects are not visible in the short term - is not perceived as a direct threat, neither by local communities nor by the public services involved in the mining sector. Our work contributes to the general debate on mining and development by bringing in an environmental perspective. It builds on Bashizi *et al.*'s (2016) proposition of a political ecology approach that examines the multiple links between resources (such as minerals, soil and water) and broadens the narrow focus on economic growth to take into account more important questions related to social justice, resource redistribution, fair management and environment conservation. Our findings also contribute to the more specific literature on the effects of mercury use in gold mining (reviewed in section 1.2) by studying local-level practices and perceptions, and by highlighting the importance of both formal and informal mercury governance, from the international down to the local level.

Data have been collected in Kamituga town in South-Kivu province. Kamituga hosts some of the most important artisanal gold mines in the country, as well as a large-scale gold mining concession owned by Banro Corporation, a multinational that is at this moment in the exploration phase[1]. Although our study focuses on mercury, this is not the only chemical that is used for extracting and processing gold. Acids and cyanide are important as well (Garcia *et al.*, 2015; Veiga *et al.,*

[1] In other sites in Eastern DRC, Banro is already producing gold and using cyanidation (see Geenen, 2015; Geenen, 2018; Geenen and Verweijen, 2017).

2014b), though less so in our study area. Acids are commonly used to dissolve silver, copper and other base metals associated with gold, to clean the gold when it is sold in local shops (Garcia *et al.*, 2015). In Kamituga, acid use has been reduced after local people complained about the smell. Gold shops are now instructed to only use acids indoors and under a chimney. Cyanide is not (yet) being used by artisanal and small-scale miners in the area, nor by Banro, which has not yet entered into commercial production.

1.2. Gold mining & mercury: a global challenge

Artisanal miners use mercury (Hg) to separate gold from the rest of the ore or ore concentrates from gravity processes. This technique is used in more than 70 countries where artisanal scale gold mining (ASGM) is practiced by some 16 million miners who are producing 12 to 15% of the gold mined worldwide (UNEP, 2018; Esdaile and Chalker, 2018; Seccatore *et al.*, 2014). Artisanal miners prefer using mercury because it is inexpensive, readily available, produces fast results and is easy to use (Gonçalves *et al.*, 2017).

Nevertheless, the harmful effects of Hg have been clearly established (Cordy *et al.,* 2011; Gibb and O'Leary, 2014). Humans can be exposed to mercury through inhalation of its vapor (inorganic mercury) and from consumption of fish contaminated with methylmercury (one of its organic forms). Methylmercury can bio-accumulate and bio-magnify through the food chain to reach very high concentrations (Gerson *et al.*, 2016). Methylmercury affects the neurological system, causing tremor, ataxia, emotional changes, memory problems, vision disorder weakness, insomnia, muscle atrophy, twitching, headaches and children's limited performance on cognitive function tests (language, attention, memory, visuospatial skills and motor functions). It affects blood, lungs, kidneys, immunity, the endocrine system, reproduction and embryonic development (Rice *et al.*, 2014; Gibb and O'Leary, 2014; Turaga *et al.*, 2014). Fish are also affected by methylmercury via adverse effects on their gills, liver, kidney, blood, reproduction, nervous system, cognitive function and behaviour (Authman *et al.*, 2015). Inorganic mercury also causes neurologic and renal impairment in humans (Li *et al.*, 2015).

The problems associated with use of Hg in gold mining are not impossible to solve. The most commonly recommended strategies are a combination of efficient handling techniques (use of retorts or fume hoods for mercury recovery) and more advanced density-based separation techniques (sluices, centrifuges, spiral concentrators, vortex). This approach has been successfully implemented in Colombia where mercury losses to the environment have been reduced by 63%, leading to a 50% decrease in airborne mercury concentration despite a 30% increase in gold production (Cordy *et al.*, 2015; Garcia *et al.*, 2015).

The United Nations has developed a guideline (the UN International Guidelines on Mercury Management in Small-Scale Mining) to help mining communities reducing their mercury pollution (Spiegel and Veiga, 2010). The guideline focuses on: (a) ore concentration (prevention of amalgamation of the whole ore by using copper plates, adding mercury to mills, sluice boxes or other concentration equipment), (b) environmental and health protection (restriction of the location of mercury use to protect village/residential and water bodies, protection of children and pregnant women), (c) regulatory oversight and capacity building, (d) accountability and liability, (e) emission control (use of retorts, exposure control and ventilation facilities, appropriate fume hoods) and (f) waste control (recycling and reusing mercury, tailing management, storage and disposal).

While the use, effects and remediation techniques have been well studied (Cordy *et al.*, 2011; Gibbs and O'Leary, 2014; Hilson, 2006; Veiga *et al.*, 2014a), very few studies have focused on the perception of communities who cause and undergo these environmental and health threats. Among these, Sana *et al*., 2016 and Zakrison *et al.*, 2015 analysed the awareness of miners on the negative effects of ASGM on health and the environment in Burkina-Faso and El Salvador. Both studies found that miners are aware of existence of negative impact of ASGM. Charles *et al*. (2015) analysed the level of knowledge of different groups in the mining communities on health effects of mercury and arsenic in Tanzania and found limited awareness on these threats. The present study analyses not only the level of knowledge of local communities on mercury and other gold mining related risks, but also their assessment of the trade-off between these risks and the income gold mining produces. It furthermore analyses the governance of mercury and how it affects these perceptions.

2. Methods

The study was conducted in Kamituga, a town where 13,000 to 16,000 artisanal miners are active (Buraye *et al.,* 2017), within a total population of *ca.* 190,000. It is located on a mid-altitude plateau (between 970 and 1366 m.a.s.l.), 180km South-West of Bukavu (Fig. 2). The Kamituga mining area is drained by the Zalya River and its effluents form part of the Congo basin. Industrial mining started here in the 1920s by the MGL (*Minière des Grands Lacs*) and later SOMINKI (*Société Minière et Industrielle du Kivu*, from 1976 to 1996). Artisanal mining has boomed since the 1980s and has become the main pillar of the local economy. Since 2011 however, a new multinational corporation (Banro) has started exploration in the area (Geenen, 2015). Although they have obtained a research permit from the Congolese government, de facto they tolerate artisanal miners working within their concession.

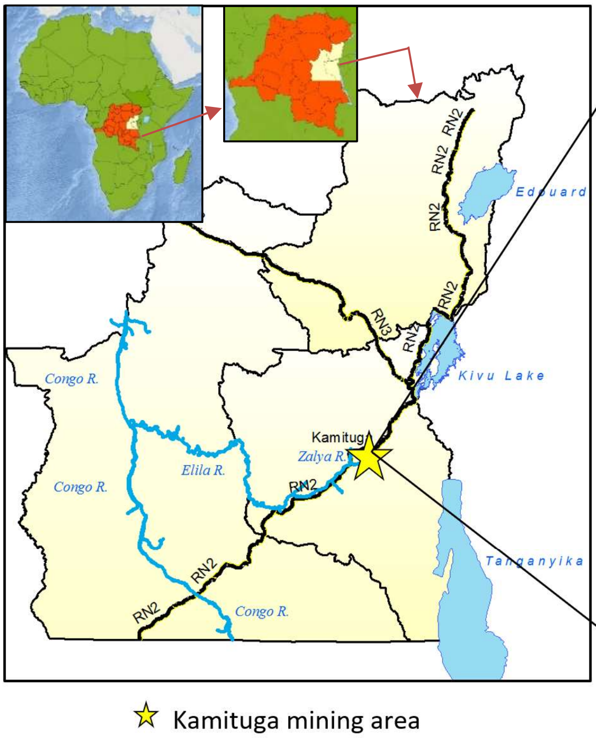

Fig. 2: Map of the Kivu region showing Kamituga mining site and surrounding rivers

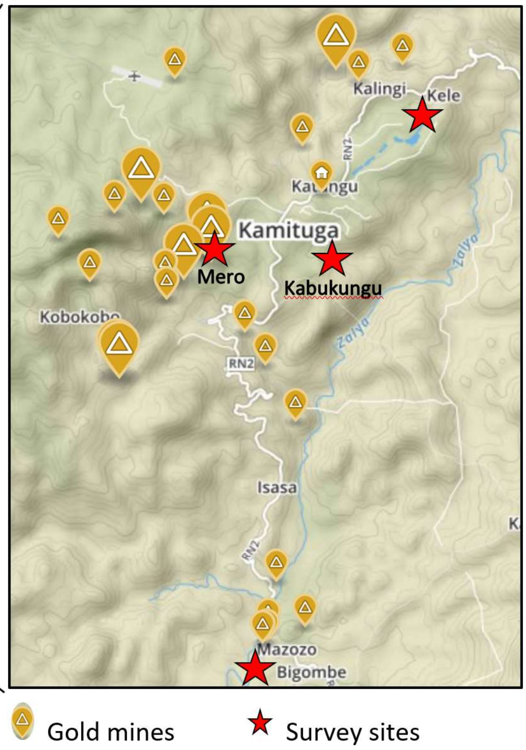

Fig. 3: Map of Kamituga showing gold mines and the four-selected survey areas

The current study is the first to document mercury use in this particular mining area. Therefore, the first step in the research was exploratory and qualitative. Twelve focus group discussions of 5 to 8 people and 10 individual interviews were organized with miners and other key stakeholders. Miners were randomly selected, based on a list made available by the miners' committee (COKa) and previous socio-economic studies in the same area (Stoop *et al.*, 2016). For the other stakeholders, focus group discussions or interviews were organized depending on the availability of local organizations' representatives. Discussions lasted on average two hours and included a participatory mapping exercise of gold mines and areas of mercury use. Then questions were asked on extraction and treatment processes as well as on the use of mercury (see the interview guide in Appendix 2). These discussions were completed by field observations, informal talks and study of documents.

The second step involved a household survey with a 216-sample size. These households were selected in four neighbourhoods of Kamituga: Mero, Kabukungu, Kele and Bigombe (Fig. 3). These areas were selected because of their differences in location vis-à-vis mining activities and affected rivers. Mero is very close to a lot of underground mining pits and contains many gold treatment units. Kele is far from the mining pits but closer to farming activities; while Kabukungu is located in between Kele and Mero. Bigombe is located further south on the banks of the Zalya River, which is a source of water for bathing and other household activities. Systematic sampling was applied (since there was no pre-existing household list), with a skip of four households. A questionnaire was then used (see Appendix 2), to document the household's socio-demographic and economic characteristics, access to information, appreciation of how mining impacts on the local economy and the environment; knowledge on the effect of gold mining-related hazards; and mitigation efforts. The population in our sample was young (average age of 36 years), with limited formal education and working mostly in agriculture (51%), mining (29%) and small trades (18%). The closer people are to the town centre and to mining areas, the more they are involved in mining activities. On average respondents had been living in Kamituga for approximately 20 years (Appendix 1).

This study has some limitations. First of all, we did not quantify the mercury emissions from gold mining in Kamituga, and we have not compiled data on human health effects. These aspects, however, will be part of a broader study the first author is undertaking, to assess the impact of inorganic pollutants from gold mining on the environment and human health. In the present work we deliberately focus on advancing our understanding of how and why mercury is used and how it is governed, as we believe this is an essential starting point for development of any policies or interventions. Secondly, although the sample within the selected neighbourhoods was randomized, the size is not very big. However, the combination of a survey with a variety of qualitative data collection methods (interviews, participatory mapping, focus groups, observation) together with the authors' deep understanding of the context improves the study's validity.

3. Mercury in Kamituga

If we want to understand and solve the problem of mercury pollution, we need to look beyond the technical aspects. We need to comprehend how gold production and trade are organized, how mercury use is governed (formally and informally, from the international down to the local level), and how local communities themselves understand the problem. As Hilson (2006:1) already argued, 'the mercury pollution problem will not be resolved until governments and donor agencies commit to carrying out research aimed at improving understanding of the dynamics of small scale gold mining communities'.

3.1. Mercury in the production process

In this section we describe in which stages of the production process mercury is used, how and where it is used and how much is being used. All information is based on our own observations in the field, on informal talks and formal interviews in Kamituga.

Gold ore is extracted in four different ways by artisanal miners: (a) underground mining in mountains, using non-mechanized tools such as chisels and shovels, (b) alluvial mining in river beds, using panning techniques, (c) recovery of gold from colluvial and eluvial ores, using hydraulic monitors (locally called *débordage*), and (d) recovery of gold from waste soil (locally called *kokora*) (Nkuba *et al*., 2017; Geenen, 2015). No matter which of the abovementioned extraction techniques are used, the gold is concentrated using wooden sluice boxes with banana sheathes (locally called *biporo*) then the concentrate is subsequently amalgamated.

The amalgamation is done by mixing a pulp containing 80% of water and 20% of concentrates[2] (or tailings from a *loutra*[3]) with 60-90 grams of mercury in a 20L bucket for 10 to 15 minutes. Afterwards, water and tailings are slowly transferred into a second bucket for further amalgamation, while mercury and gold amalgam remain on the bottom of the bucket because of their higher density. The excess mercury is removed by filtration using a piece of cloth. The excess mercury is recovered and re-used for future amalgamations. The gold amalgam thus obtained is stored until a subsequent mercury evaporation step. Usually the concentrates/tailings are amalgamated 4 to 5 times, to make sure no extractable gold is left. The collected gold amalgam is heated to evaporate mercury, leaving gold on the utensil (usually a spoon). Veiga *et al.* (2014b) show that the amalgams contain as much mercury as gold (40-50% Hg and 50-60% Au) and most of this mercury is released in the air at the evaporation stage (up to 98%). The tailings are disposed of anywhere near the house where the treatment has been conducted (for potential future reprocessing, however these tailings can release the mercury they contain through evaporation).

In Kamituga, mercury was sold at 130 to 200 USD/kg (for wholesale quantities) in 2016, while the international price was 29-35USD/kg (Lassen *et al.*, 2016). However, miners buy mercury at a higher price from retailers: 13.5-15g (a pen cap) for 5 USD or 60-65g (a coffee spoon) for 20 USD, which adds up to 300-370$US/kg. Despite the fact that miners complain about the expense, the cost of mercury does not seem to be a factor limiting its utilization. Even at this high cost, mercury use is still highly profitable. According to the interviewed miners, the real constraining factor to amalgamation is the availability of concentrates or tailings to process (which is linked to variations in ore extraction). Mercury is imported from Tanzania and locally sold by gold traders, who use it to secure their gold supply (they give mercury to the miners on credit, in return for a future supply of gold) (see Geenen, 2015).

The total amount of mercury released to the environment in Kamituga is hard to determine, since there are large variations not only among users (depending among others on their ownership of a *loutra* or not, proximity of their *loutra* to mines), but also variations over time, because the activities depend on the availability of concentrates or tailings. As Geenen (2015) has previously explained, artisanal gold production is highly unpredictable and depends on a range of controllable (such as access to manpower and finance) and uncontrollable factors (climate conditions, depth and location of the vein, quality of the ore), making the amount of mercury usage similarly unpredictable.

With respect to where mercury is being used, our research reveals that mercury is used in the town, in or near people's houses (mostly in their backyards), not in the mining sites themselves (miners take their concentrates home for amalgamation). A mapping analysis based on both a participatory mapping exercise and a digital elevation model (Fig.5) also shows that the areas where mercury is

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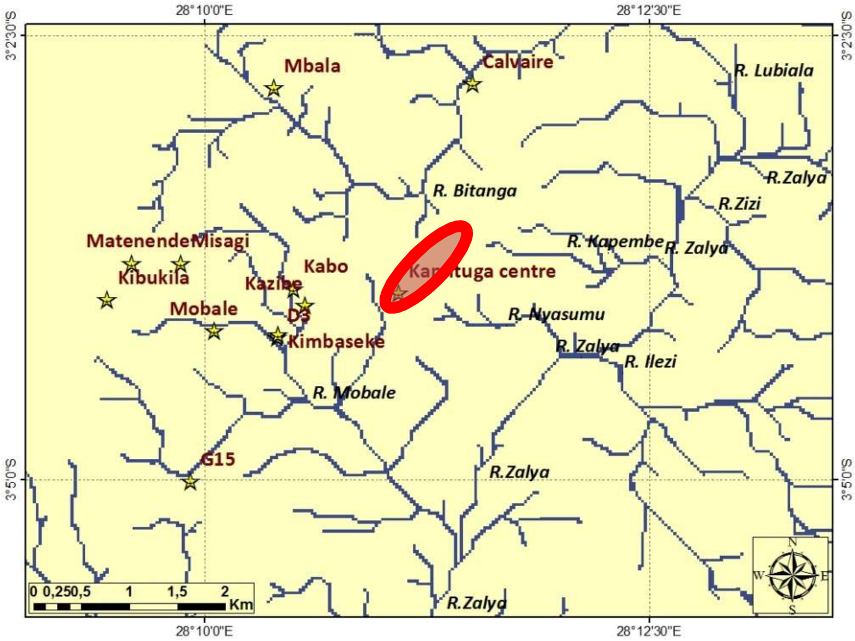
[2] In Kamituga, whole ore amalgamation is not used (this could cost them 10 to 12 times more mercury (Veiga *et al*, 2014)).

[3] A *loutra* is a place where miners separate gold from their ore. They first mix the milled ore with water in a *karahi*, and then they decant the water with the ore's light particles in the pit, leaving the heavy gold and concentrate in the *karahi*. After separation, miners keep gold and concentrates, while the decanted tailings remain in the pit (as payment for the pit and equipment owner). For large quantities of ore, this technique is replaced by sluices, which are not used in *loutras*, but near streams.

used are within the catchment of 3 tributaries of the Zalya river, namely Bitanga, Nyasumu and Kapemba.



Legend:

Gold extraction sites

Rivers

Mercury use area

Fig.5: Map of mercury use and potentially affected rivers in Kamituga

3.2.Mercury governance

In this section we describe how mercury use is governed from the international down to the local level, paying attention to different actors involved as well as to formal and informal norms.

The Minamata convention is an initiative led by the United Nations that aims at reducing/eliminating all forms of mercury use worldwide (UNEP, 2013). Although the DRC has not ratified the convention, it has been involved in the initiative since 2013 and has benefited from UN support. An assessment of current mercury use (MIA: Minamata Initial Assessment) has already been conducted in the DRC's major gold extraction provinces (Nkuba *et al.*, forthcoming) in order to inform a National Action Plan (NAP).

Aside from the international effort, the DRC's mining sector is internally regulated by the mining code (RDC, 2018) and the mining regulations (RDC, 2003), which both include provisions on environmental protection. The mining code (RDC, 2018) states that environmental protection is a sufficient reason for the Prime minister to forbid any mining activity in a given area (Article 6). Furthermore, the code requires mining companies to submit an Environmental and Social Impact Assessment, an Environment Impact Attenuation and Rehabilitation Plan and an Environmental and Social Manangement Plan to the Congolese Environmental Agency (ACE) (RDC, 2018). The Minister of Mines can only grant a mining permit if the ACE has granted the environmental certificate (Article 79). Later, the ACE must run an environmental audit (Article 185). The code stipulates that not only companies, but also artisanal miners must respect all environmental norms (Article 112). Regarding mercury, the mining regulations (RDC, 2003) forbid treatment of minerals using mercury, cyanide or other harmful chemicals, unless done in a plant that has been licensed by the Ministry of Mines. The article further warns that artisanal miners using mercury or other harmful products may have their license withdrawn (Article 238). Article 575 specifies that only gravity-based separation and other techniques not using chemicals with harmful effects on the environment are allowed. However, as is often the case in the DRC, law enforcement is very poor.

The Ministry of Mines has a technical department in charge of assisting artisanal miners towards more productive and responsible mining, called SAEMAPE (*Service d'Assistance et d'Encadrement des Mines Artisanales et de Petite Echelle)*. This department is theoretically best suited to help miners reduce and eliminate their mercury use, but it faces multiple challenges. First, instead of providing services to the miners, SAEMAPE's main task so far has been collecting taxes (see Geenen, 2015). Legally, it collects an annual payment of 50 USD per mining pit, plus 10 extra USD per month, for pits in the production phase[4]. Aside from that, however, SAEMAPE's agents are also involved in illegal taxation. One of the most common practices, as in many other public services, is the negotiation for a delayed payment. In this case, the miner gives a percentage of the tax he is supposed to pay to the tax collector for the latter's personal use. In return, the collector allows a delay of payment (of an unknown duration). In many cases, the tax collector does not even declare the mining pit in his report so that he can continue receiving payments from the miners without knowledge of his superiors. This situation hampers transparency in the sector and allows illegal activities such as use of explosives and mercury to continue undisturbed. The second major challenge SAEMAPE faces is a lack of skilled human resources. The Kamituga office, for instance, has seven agents, among which only two went to secondary school. Third, most agents lack motivation to do their job correctly, since they are not yet being paid by the government and do not know when they will be. Until they are paid, their only source of income is the illegal taxes they receive from miners and traders. These three constraints cause poor performance regarding many tasks, including mercury mitigation, to an extent that neither the Kamituga office nor any other office within Mwenga territory (a major gold mining area in Congo) has ever reported mercury use.

However, SAEMAPE provides a good opportunity to train miners, due to their very high presence in mining sites. But this is only possible if its agents are educated in cleaner techniques and if they were not corrupted.

The Mining Administration office is the governmental institution responsible for granting licenses to artisanal miners (at provincial level) and withdrawing them in case of illegal practices. Locally, it even has an office in charge of environmental protection, but according to our interviews, this

[4] 40% of these taxes goes to SAEMAPE, 35% to the governor's office, 10% to the provincial Ministry of Mines, 10% to the provincial Mining Division and 5% to the local security comittee (based on the "*Arrêté Provincial 13/037/GP/SK*").

office does not consider mercury use mitigation as a priority. It focuses instead on deforestation caused by miners clearing a field for digging tunnels or using wood for construction of tunnels. This office faces the same challenges as SAEMAPE. Its staff acknowledges the use of mercury but admits that no action is being undertaken to mitigate it. Aside from the Ministry of Mines, the Ministry of Environment should be concerned about mercury use as well. However, their Kamituga office does not focus on mercury or any type of pollution caused by mining. Instead, they do some awareness campaigns on deforestation, as well as hygiene and sanitation.

We have interviewed six other categories of stakeholders (NGOs, civil society structures, miners' organizations, mining companies, gold traders and media). Though many NGOs have included environmental protection in their mission statement, very few have undertaken any action in this regard, the main reason being a lack of funding and donors' interest. Civil society organizations, despite not facing a human resources challenge (they have enough university-educated people in their ranks), acknowledge not having any information on mercury's health effects. Local media do not recall having broadcasted any awareness programme about the environmental impact of mining, since nobody has paid them to do so. Miners' associations focus on issues such as conflict mediation, illegal taxation and safety; mercury is not among their prime concerns. However, they claim to be open to discuss more environmentally-friendly techniques. For mining companies and gold traders, a reduction of mercury use would not necessarily be in their best interest. Gold traders, as specified above, provide mercury to miners to guarantee a steady gold supply. Corporations such as Banro, which are faced with the presence of artisanal miners inside their concessions, generally invoke artisanal miners' so-called poor practices to delegitimize their activities. In the case of Kamituga, Banro tolerates the artisanal miners within its perimeter, but they do not intend to make a formal cohabitation agreement (shedding off this responsibility to the government), nor do they allow artisanal miners to upgrade (confiscating crushing mills for example, see Mulonda *et al*., forthcoming).

The generalized lack of awareness-raising or action on environmental protection translates in our findings. The household survey revealed that very few people (less than 25%) have either participated in, or heard from their friends or relatives (without participating themselves) about, any action regarding environmental protection (Fig. 6). The next section will dig further into these local perceptions.

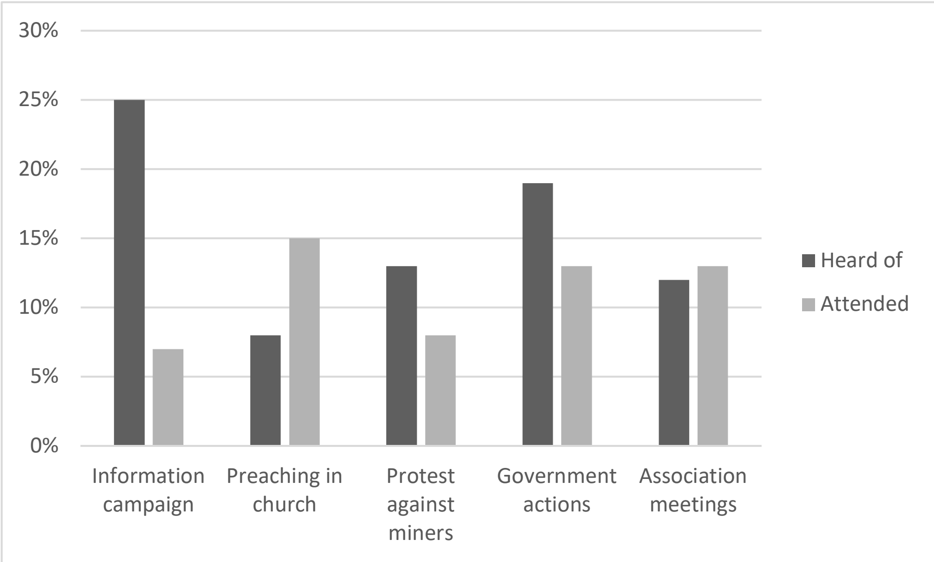


Fig. 6: Percentage of people who participated in, or just heard of, actions undertaken for environmental protection

3.3. Perspectives on mercury

In this section we discuss respondents' knowledge on and perceptions of the impact of gold mining on environment and health. The analysis is based on data from the household survey as well as interviews and focus group discussions.

3.3.1. Knowledge on mercury effects

Both miners and non-miners showed a lack of knowledge on mercury-related risks. However, even though miners lack awareness on health and environmental risks associated with mercury use, they do not consider mining to be riskless. They are well aware of other forms of pollution, mainly rivers' siltation. Exceptionally, miners who previously worked for SOMINKI, the industrial company operating in Kamituga between 1976 and 1997, do suspect mercury to be harmful, although they are not informed about the specific effects. Their suspicion is based on the restricted access Sominki enforced in areas where mercury was being used. Among the local population, very few people consider mercury (Fig. 10) or cyanide (Fig. 12) to be a problem for humans, animals and water. They consider deforestation (Fig. 7), soil erosion (Fig. 8), water siltation (Fig. 9) and use of acids (Fig.11) to be the major detrimental effects.

We conclude that neither miners, nor the population surrounding the mines, has appropriate information on the specific risks posed by mercury because there have been no awareness campaigns. Miners do not willingly ignore mercury-related risks, they are just not informed about them. This calls for more focused policy interventions, including awareness programmes. For cyanide, the awareness is even less, although Banro uses it on a large scale in its operational sites in the region (namely Twangiza and Namoya).

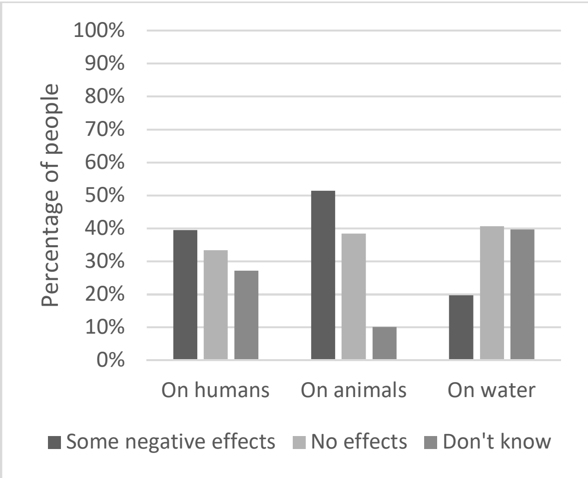


Fig. 7: Knowledge of local people on effects of deforestation

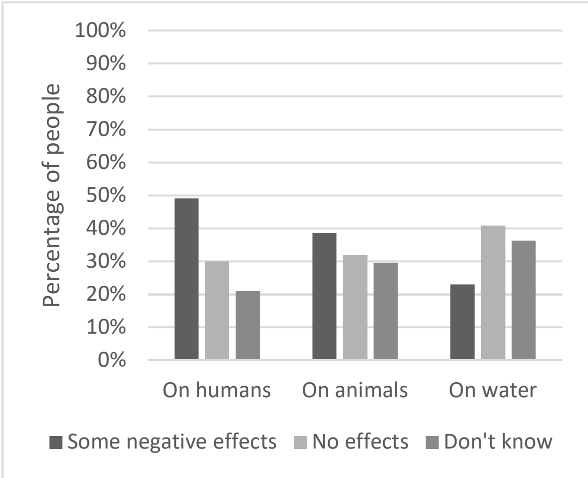


Fig. 8: Knowledge of local people on effects of erosion

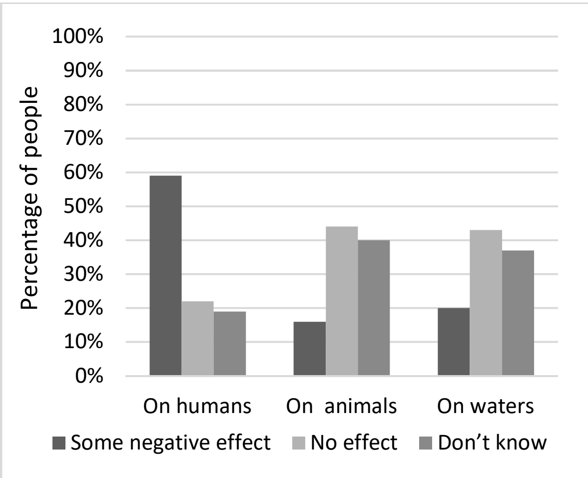


Fig. 9: Knowledge of local people on effects of water siltation

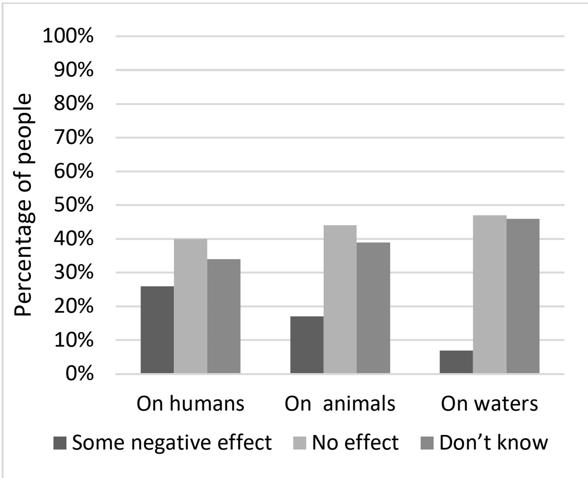


Fig. 10: Knowledge of local people on effects of mercury

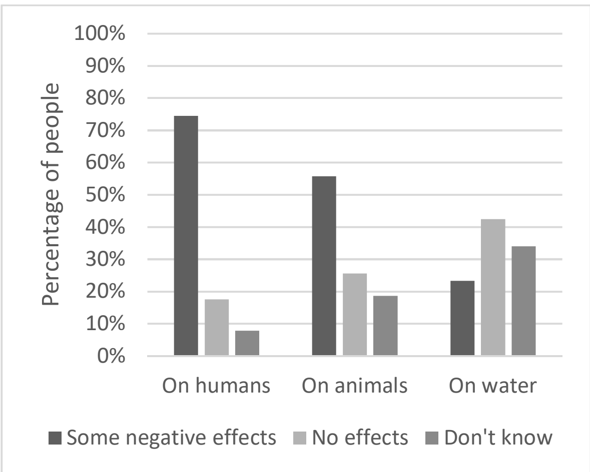


Fig. 11: Knowledge of local people on effects of acids

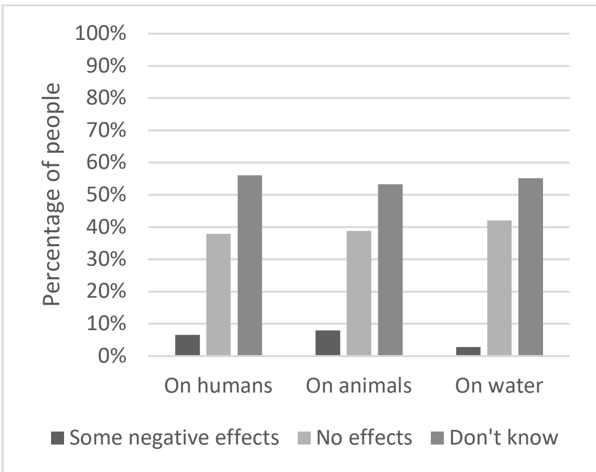


Fig. 12: Knowledge of local people on effects of cyanide

We hypothesize that miners are better informed about deforestation, erosion and river siltation because these effects are more visible, and acid pollution because of its strong unpleasant smell and the brown fumes evolving from the vial when the acid is heated. The effects of mercury and cyanide pollution are not directly visible (cyanide is not yet being used in Kamituga) and are hard to identify. In addition, some campaigns have raised awareness on deforestation and erosion, while there have been no campaigns on the effects of cyanide or mercury. Even Banro's environmental department works on reforestation (they report having planted over 1500 trees in the last two years, as part of their legal requirement to restore the area in its previous state), while regarding mercury, they argue not to be responsible for mitigating the harm done by artisanal miners.

Moreover, the lack of reported cases of mercury intoxication limits the awareness. Our discussions with both the Kamituga hospital and health administration revealed that no case of death or disease due to mercury intoxication has been reported. This is not to say that there have been no cases though. It is very well possible that there have been some unreported cases, because the patients either did not get to the hospital (which happens very frequently in the region due to health structures' accessibility and people's poverty (Dandoulakis *et al.*, 2015)) or they did, but had their symptoms mistaken for other neural, cardiac, respiratory, gastro-intestinal or embryological disorders (Lech, 2015). Interestingly, witchcraft is the most common explanation for babies born with malformations or deaths with mercury-like symptoms. A study shows that being accused of witchcraft is the biggest problem bereaved people face in D.R.Congo when no clear cause of death is found (Katambwa, 2016).

We also analysed the effect of access to news and social media. A first finding is that the population of Kamituga has quite good access to news media. More than half of the people own a radio in their household, and people who do not own their own radio can still listen to one at their work place, since it is a very common practice to play the radio all day long while working. Others use their phone's radio to access information. Very few people have access to TV and internet, or are a member of an association (which is another possible way of accessing information through networking) (Appendix 3). After running a principal component analysis (PCA) of these different parameters to get the integrated access to information parameter, correlation analyses showed no relationship between the access people have to news and social media, and their knowledge on mercury impacts on human health (Appendix 4).

Unfortunately, even though mercury is not visible in the environment and is not well publicized either, it actually is a chemical time bomb, as Stigliani stated back in 1991. Exposure to mercury is a silent threat to the environment (due to its physiological perturbation of many aquatic species) as well as human life (because of its effects on the central nervous system, heart, lungs, kidney and immune system, and on foetal growth). It indeed has the potential to harm almost every organ and body system (Kim *et al.*, 2016; Turaga *et al.*, 2014; Rice *et al.*, 2014; Gibb and O'Leary, 2014).

3.3.2. Perceptions on the trade-off between environment and economy

Regarding the appreciation of the economic and environmental impact of mining, our respondents generally stated that there is a positive impact of artisanal mining on the local economy (Fig.13), this proportion being higher still among respondents living closer to gold mines. Most people who live far from the mines (like in Kele) do not report a significant positive impact of mining activities.

Nevertheless, disregarding the economic benefits, most people acknowledge that artisanal mining is harmful to the environment (Fig. 14). Surprisingly, they also admit that large-scale mining would harm the environment less than artisanal mining does (despite its limited economic benefits to them). This suggests that they are indeed conscious of how much harm artisanal mining does to the environment. The inhabitants of Kele are again the ones who showed the highest perceptions of the negative impact of artisanal mining to the environment. This would be due to their higher dependence on agriculture. Similar perception have been found in Peru, where locals perceived the environmental impact of large-scale mining to be lower, and the contribution to the national economy higher, but still rejected it and supported artisanal mining instead, since artisanal mining was more favourable to their social order and income of the poorest inhabitants (Toledo-Orozco and Veiga, 2018).

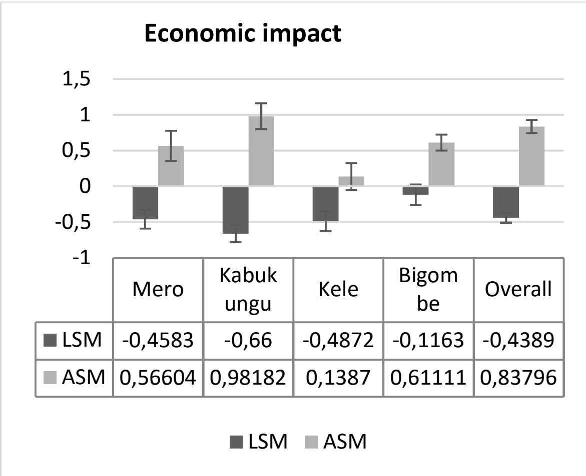


Fig. 13: Appreciation of the economic impact of LSM and ASM (very bad=-2, bad=-1, none=0, good=1 and very good=2)

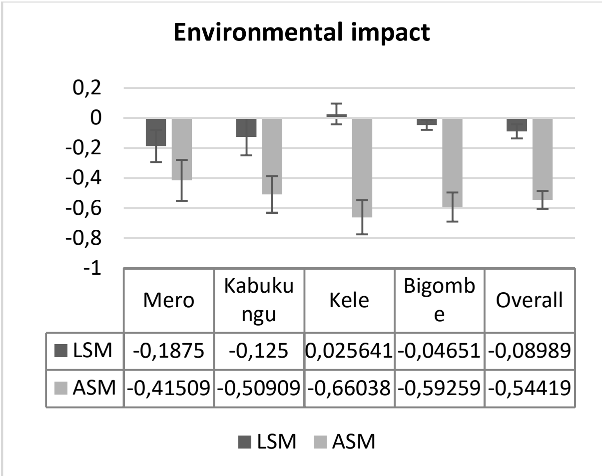


Fig. 14: Appreciation of the environmental impact of LSM and ASM (very bad=-2, bad=-1, none=0, good=1 and very good=2)

When people had to consider the overall picture, and faced a dilemma of either abandoning mining activities and losing the mining-generated income, or continuing to support mining activities and damage the environment while putting their family health at risk, most people would prefer giving up on mining income. However, this opinion was not equally expressed in different neighbourhoods. In neighbourhoods closer to and highly dependent on mining activities (Mero and Kabukungu), there was less propensity towards the possibility of giving up on mining income, in contrast to areas where people are more involved in agriculture (Kele and Bigombe) (Fig. 15).

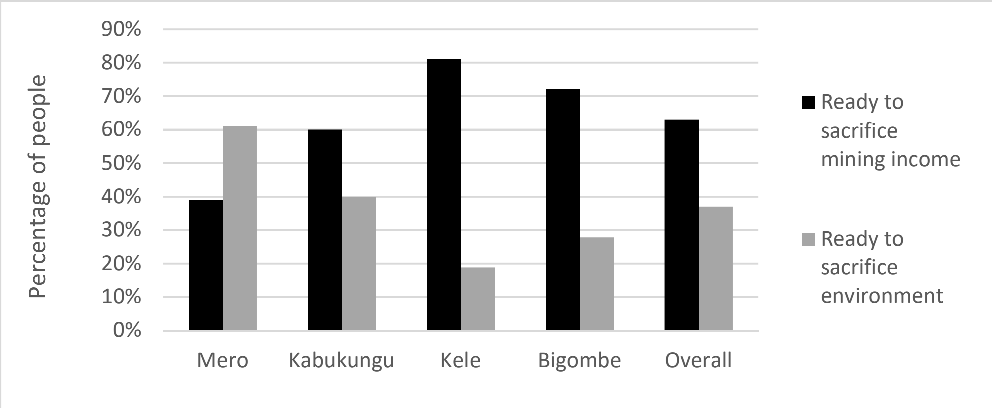


Fig. 15: Choice between mining income and environment and health protection

The perception of environment and health issues does not solely depend on the neighbourhoods. It is also based on individual characteristics such as age, profession, time spent in the mining town, level of stability in the town (ownership of a house) and access to information.

Chi-square analyses did not show significant differences between population groups, so as to identify which categories of people were more likely to give up on mining. This is likely due to the fact that the sample size was limited. However, from cross-table analyses we could observe differences in behaviour between different age groups and family sizes. The people who were most willing to give up on mining were aged between 40 and 64 (Fig.16), with a household size between 2 and 9 (meaning people who were single or those who had a family of more than 7 children were more focused on keeping their income) (see appendix 5). This was most likely due to the fact that between 40 and 64, most people have children under their care and are most careful about anything that may affect children's health. However, people with families of 10 or more people agreed less to ending mining activities, since they are under so much financial pressure to survive, that they feel threatened by any change of livelihood. Regarding types of jobs, farmers showed a higher concern for the environment than people from other sectors. Miners, wage workers and unemployed showed less propensity to save the environment by giving up on mining income (Fig. 17).

In their study focusing on miners' perspectives towards relocation and reorientation to other livelihood activities, Stoop *et al.* (2016) demonstrated that if artisanal mining was no longer possible in Kamituga, half of the miners would opt to leave Kamituga and continue mining elsewhere. Moreover, they estimated that on average, miners were willing to engage in alternative activities if they were to earn least 15 USD per day. This shows how difficult it is to have miners change their job, since a job with a monthly salary of 330 USD (supposing they work 22 days) for an unskilled or low-skilled worker is very hard to find in the DRC, where the current GDP is 441 USD per capita per year and 90.5% of the population earns less than 3.1 USD per day (Economic focus, 2018; UNDP, 2018).

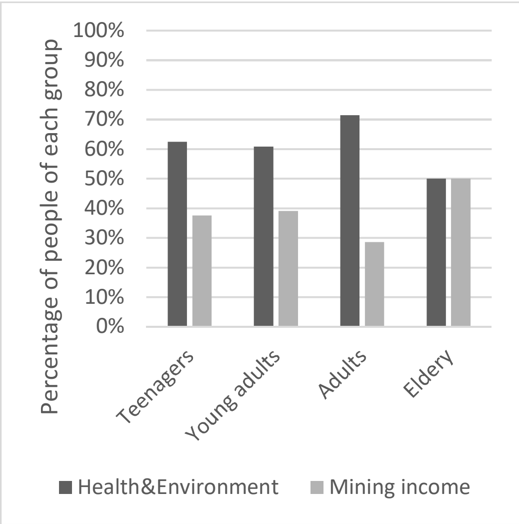


Fig. 16: Willingness to save the environment of different age groups

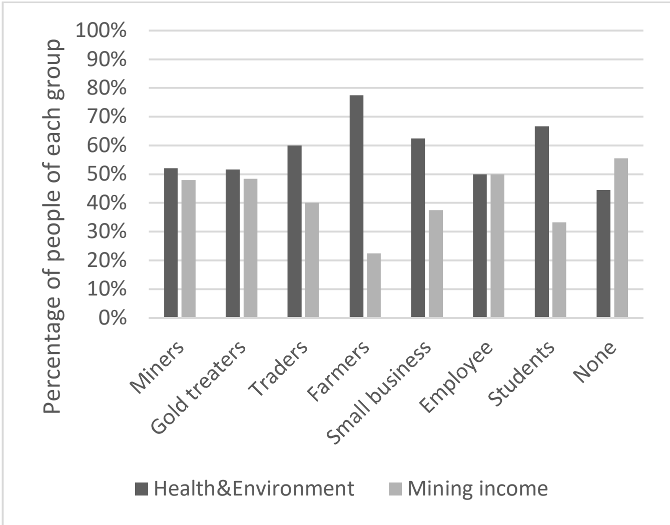


Fig. 17: Willingness to save the environment of people from different professions

4. Conclusion

In the Democratic Republic of the Congo, mercury is rendered invisible in several ways. It has been rendered invisible in research, which tends to focus on the country's immense socio-economic and security problems. Its use has not been comprehensively documented in the gold mines. Furthermore, it seems to be an invisible threat for local communities. The extensive scientific documentation on mercury's harmful effects on human health and the environment does not seem to trickle down to the people directly concerned. Our survey results have shown that Congolese communities living around gold mines are more concerned about the effects of deforestation, erosion, river siltation and acid pollution, rather than the effects of mercury and cyanide pollution which are not directly visible and thus harder to identify. These findings are further complicated by the fact that respondents who are the most dependent on mining activities, are the least willing to give up potential short term (economic) benefits for longer term (environmental and health) gains.

The Congolese mining regulations forbid the use of mercury outside licensed plants, but the regulations are not enforced because of two main reasons. First, public and technical services that are mandated to protect the environment face financial, material, technical and human constraints. Second, there is very little information about the specific potential effects of mercury pollution. Neither the key stakeholders in the mining sector, nor the miners themselves or the population living around the mines, have appropriate information. However, the risk of pollution is very real: our participatory mapping exercise has revealed that mercury is not so much used in the gold mines themselves, but rather in and around the miners' houses. This situation poses a risk for three rivers with catchments that overlap with areas where mercury is used. Further research in this area will evaluate the level of pollution as well as its impact on the environment and human health.

At the international level, efforts have been made to reduce the use of mercury, such as the Minamata Convention. These regulations are now being adopted at the national level, with the DRC participating in the Minamata Convention and preparing national action plans. While applauding these efforts, we want to flag a major risk. Forbidding the use of mercury without putting in place any support strategies, would most certainly affect artisanal miners in a negative way. It risks having the same consequences as the ban on artisanal mining that occurred in 2010-2011 or the obligation to gather in cooperatives (De Haan and Geenen, 2016), namely the exclusion of the most marginalized miners and a move towards more clandestine gold production. The best policy option would be to raise awareness and train miners and other stakeholders on cleaner practices, but also to equip artisanal miners with the skills to manage mercury in a more responsible way or to use density-based techniques. This task falls within the responsibility of SAEMAPE. However, since the financial and technical resources of this department are limited, donors and international NGOs should also engage in this activity. In this sense, we call for more cooperation across scales (local, national and international), so that interventions, e.g. on mercury use and trade, policy formulation and enforcement, community awareness, etc., can be more effective, but also better adapted to local realities (Li *et al.*, 2017; Zhang *et al.*, 2018). Such interventions should also take into account the intimate interconnections between the environmental, economic, social and political spheres, as well as the interdependence of different natural resources, such as minerals, water and land.

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