Formalizing artisanal and small-scale gold mining : A grand challenge of the Minamata Convention

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2022-03-18

Prescott , G W , Baird , M , Geenen , S , Nkuba , B , Phelps , J & Webb , E L 2022 , ' Formalizing artisanal and small-scale gold mining : A grand challenge of the Minamata Convention ' , One Earth , vol. 5 , no. 3 , pp. 242-251 . https://doi.org/10.1016/j.oneear.2022.02.005

http://hdl.handle.net/10138/356289
https://doi.org/10.1016/j.oneear.2022.02.005

One Earth

Formalizing Artisanal and Small-scale Gold Mining: a Grand Challenge of the Minamata Convention

--Manuscript Draft--

Manuscript Number:	ONE-EARTH-D-21-00185R1
Full Title:	Formalizing Artisanal and Small-scale Gold Mining: a Grand Challenge of the Minamata Convention
Article Type:	Perspective
Keywords:	Artisanal and small-scale gold mining (ASGM); environmental health; extraction; Mercury; Trade-offs; formalization; environmental governance
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Abstract:	The global Artisanal and Small-scale Gold Mining (ASGM) sector is worth an estimated US$36 billion and employs over 20 million miners in the Global South. Over 2,000 tonnes of mercury per year are emitted into the atmosphere or released into land and water by ASGM activities, with downstream negative health effects for humans and wildlife. The 2013 Minamata Convention on Mercury seeks to reduce anthropogenic emissions and releases of mercury. As ASGM largely operates informally—that is, it is neither regulated nor protected by state laws—its formalization is recognized as a necessary step for balancing emissions reduction with improved livelihoods. The Convention mandates formalization of the sector in National Action Plans. We review past and ongoing efforts to reduce and eliminate mercury use in ASGM. We argue that top-down approaches to formalization that involve centralized creation of permits and environmental mitigation requirements are likely to exclude millions of miners, and that bottom-up approaches centered around working with existing miners are needed. Ongoing efforts to formalize ASGM, while nominally bottom-up, are frequently based on an incomplete understanding of informal ASGM dynamics, fail to include mining communities, and are led by the wrong government departments. If these shortcomings are not addressed, these projects risk repeating the failures of previous attempts to reform ASGM. In addition to reviewing these efforts, we estimate the scale of external investment needed to ensure positive health and environmental outcomes from reforming ASGM. Extrapolating from available budgets, the global five-year cost of this approach could be $355 million USD (upper and lower estimate bounds: $213–829 million) if scaled per country, or $808 million USD ($268 million–$2.17 billion) if scaled per miner. Consumers, large mining corporations, and/or governments will need to bear these costs.
Opposed Reviewers:	
Suggested Reviewers:	Sam Spiegel, PhD Senior Lecturer in International Development, The University of Edinburgh School of Social and Political Science sam.spiegel@ed.ac.uk Relevant subject expertise in formalization of Artisanal and Small-Scale Gold Mining.
	Steven Van Bockstael, PhD Assistant Professor Globalisation Studies and Humanitarian Action, University of

	Gronigen s.j.n.van.bockstael@rug.nl Relevant subject expertise in formalization of Artisanal and Small-Scale Gold Mining.
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Additional Information:	
Question	**Response**
Standardized datasets<p>A list of datatypes considered standardized under Cell Press policy is available here. Does this manuscript report new standardized datasets?	No
Original Code<p>Does this manuscript report original code?	No

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UNIVERSITÄT
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Faculty of Sciences

Institute of Plant Sciences

to
Dr. Lewis Collins
Editor-In-Chief
OneEarth
London, UK

Bern, 15th January 2022

Dear Dr. Collins,

We are delighted to resubmit **‘Formalizing Artisanal and Small-scale Gold Mining: a Grand Challenge of the Minamata Convention’** (ONE-EARTH-D-21-00185) for consideration as a ‘Perspective’ in *OneEarth.*

We are grateful for the thorough and constructive comments we received regarding our initial submission. As outlined in the response to reviewers, we have majorly revised the manuscript and implemented all suggested changes. As recommended by Reviewer 1, we have restructured the review to include a more explicitly historical overview of previous attempts to reform Artisanal and Small-Scale Gold Mining (ASGM), and to offer a more nuanced critique of ongoing formalization efforts. Reviewer 2 suggested minor revisions, which we have all implemented.

Since our initial submission, an additional four countries have published their national budgets for reforming ASGM. In addition to revising our manuscript according to reviewer recommendations, we have updated the data and global cost estimates accordingly. To our knowledge, this is the first estimate of the global costs of reforming ASGM to tackle mercury emissions in a socially equitable manner.

ASGM is the world’s largest source of mercury emissions but employs over 20 million miners globally. Reforming ASGM to reduce pollution while safeguarding livelihoods in an equitable way is a major global sustainability challenge. Our perspective makes a novel contribution in outlining what has gone wrong with previous and current attempts to reform ASGM, what approaches are needed instead, how much it might cost to successfully implement reforms worldwide, and who should pay for it. As such, we believe it will be highly relevant to the readership of OneEarth.

We have no competing interests or similar work under review elsewhere. Thank you for your kind consideration of our manuscript. I look forward to hearing from you.

Yours sincerely,

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Matthew Baird, Asian Research Institute for the Environment, Vermont Law School
Sara Geenen, University of Antwerp, Université Catholique de Bukavu
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Jacob Phelps, Lancaster University
Edward Webb, University of Helsinki.

Reviewers' Comments:

Reviewer #1: This paper reviews the challenges with implementing the Minamata Convention on Mercury. Specifically, it seeks to review the challenges with formalizing ASGM to reduce its environmental impacts and consider what a successful approach will likely entail. I do not think the paper does the title nor the objectives much justice because it falls short of achieving its objectives. In short, I believe that the piece does not really do a good job of fleshing out the most significant challenges with implementing the Convention. I urge the authors to consider a revision taking into account the following:

Response: We thank the reviewer for their detailed and constructive comments. We have implemented their suggested approach to revising the manuscript.

1. The introduction (first few paragraphs) explains that a lot of gold is mined on a large scale. This is superfluous and has nothing to do with the paper. The paper focuses on ASGM and should get right to the point. I strongly advise removing any unnecessary discussion on large-scale mining.

Response: We have removed references to large-scale mining, and the introduction now goes straight to ASGM.

2. The 'Barriers to operationalizing the Convention' section is really cavalierly assembled, I my view. I do not know how to go about revising this section but I will try and give some pointers. What the authors have done in this section is basically summarise a series of developments that have taken place in the mercury-ASGM space over a couple of decades but which occurred under very different circumstances and took place for very different reasons. If there is a silver lining with Minamata, it is that things are done - at least in theory - in a cohesive manner, typically under the auspices of NAPs. In the past, this was not the case (i.e. there being any truly decentralized efforts to tackle the mercury pollution problem in the sector). The various interventions mentioned in this section, including efforts to implement retorts as well as the Borax method, were largely implemented in isolation. The problem is that the authors briefly highlight the pros and cons of these interventions, giving the impression that they will feature as part of the extension element of the Minamata Convention, which is not the case. A better way of framing things is to examine critically the legacy of mercury management in ASGM in the developing world, and to then reflect on what this means for the architects of Minamata moving forward. The section, however, is not written like this. In other words this section needs to be framed in a way in which the reader is informed about field efforts of the past and to then be informed about what needs to be done in order to avoid these same problems moving forward. It begins with more concretely reviewing the work that has been carried out, pre-Minamata, including that undertaken as part of the Global Mercury Project. There was, of course, an element of randomness to this work (things like Borax, with the Danish Geological Survey, and coal-oil agglomeration with various UK universities were one-off exercises with no real donor backing). Retorts have been central to most mercury efforts from the outset, so perhaps building the discussion around this would be something to consider.

Response: We thank the reviewer for their feedback on the structure. In the previous version we highlighted the pros and cons of different interventions. We have now restructured it in line with the suggestion, and created a new section titled ‘Challenges encountered in previous attempts to reduce mercury emissions from ASGM'. Here, following Reviewer 1's suggestion, we review the pre-Minamata work on this (primarily the Global Mercury Project) and critically review why these projects did not accomplish their aims.

See L60–111 ('Challenges encountered in previous attempts to reduce mercury emissions from ASGM') for the revised version of this section.

3. On the section, 'The ineffectiveness of top-down approaches', the purpose of Minamata, through NAPs, is to tackle the challenge of mercury pollution (countries which have ratified the Convention where 'artisanal and small-scale gold mining (ASGM) and processing in its territory is more than insignificant' must produce a NAP) from the bottom up. So in a way, the convention is a response to hitherto ineffective top down approaches taken to address the mercury pollution problem at small scale gold mines. What was needed here was rather a more nuanced analysis of why the implementation of NAPs and fulfilment of their objectives, through implementing agencies and executing agencies, has proved so challenging. Hilson et al. (2018), for example, offer a glimpse of what is unfolding in Ghana, Sierra Leone, and Mali. Here, it is a case of the wrong government agency being empowered to oversee the tasks enshrined in NAPs. The actions carried out under the convention largely epitomise how ASM has been treated and viewed in policy making and donor circles forever. This is what I believe this section should focus on: specifically, reflecting on what is different as far as the convention is concerned in terms of delivering assistance to the sector as well as why the results could be the same if the blueprint laid out is not followed.

Response: We thank the reviewer for this suggestion. We agree that the Minamata Convention is a response to the failures of previous attempts to reduce mercury emissions from ASGM, and that it is important to discuss challenges in beginning to implement NAPs. We restructured this to keep one paragraph about why top-down approaches have failed (to inform readers who may be unfamiliar with the topic). We follow this with a brief explanation of bottom-up approaches and conclude with discussion of the existing challenges in NAP implementation and the risks of repeating strategic errors from previous formalization attempts.

In particular, we argue that while the NAPs are bottom-up in the sense of being drawn up by each signatory country, and explicitly recognizing the needs to include previously marginalized ASGM-miners and tailor plans to their situation, the implementation is often top-down and driven by government departments and external consultants rather than the mining communities. We draw on the unfolding examples in Ghana, Sierra Leone and Mali cited by the reviewer, to illustrate how strategic mistakes such as empowering the wrong government ministries, failing to work effectively across borders, and maintaining a bias towards large-scale mining, are threatening the implementation of NAPs. We conclude this section with by presenting the 'formalization bubble' strategy.

See L113–179 ('An Opportunity to develop better formalization approaches') for the revised version of this section.

4. The 'Who pays?' section is interesting. But I really think the authors have missed the boat a bit here by failing to capture how the GEF intends to go about helping countries meet their commitments to Minamata. There is, of course, a rigidity here which the authors surprisingly fail to acknowledge: the requirement for countries that have ratified the convention to pursue a core collection of mercury free alternatives. These alternatives are being piloted under

planetGOLD and GOLD+, championed as a panacea to the mercury pollution problem in ASGM. The problem is that these technologies are ill-suited to landscapes which have lengthy histories of mercury use. It is really surprising that rather than focus on the challenges with switching to these technologies, the authors have elected to chronicle things like borax and retorts.

Response: We thank the reviewer for raising this point. We added a discussion of the GEF projects, planetGOLD and GOLD+. (L299–313)

5. A final note one what is really missing from this manuscript: a serious engagement with the challenges of operationalizing Minamata through NAPs. Foremost among these are an issue which the authors broach (formalization) and the fact that governments, and by extension, executing and implementing agencies, are interpreting Minamata as an exercise aimed at eradicating mercury from the ASGM circuit altogether when it is about reducing and eliminating where possible its use. The former is quite significant because formalization is an issue which all governments with more than and 'insignificant ASGM sector' must seriously think through carefully. The paper needs to really critique formalization in the context of ASGM, which it does not. The latter is significant because working toward a strategy to eradicate is very different than working toward a strategy to minimize and eradicate where necessary.

In short, the paper needs a bit more nuance, in my view. It fails to really interrogate the bigger issues and challenges linked to Minamata as well as identify the roadblocks which lie ahead. The paper has potential, but requires an overhaul with the points raised in mind.

Response: We believe that with the revisions we have made, particularly in response to points 2-4, we have focused more directly on the challenges of operationalizing NAPs through Minamata. We have also added to the 'Future Directions' section (L328–337):

'The framing of the Minamata convention and the drafted National Action Plans suggest that policymakers will, at least on paper, heed these lessons. However, the framing of planetGOLD and early experiences from drafting of NAPs in Cambodia, Sierra Leone, Ghana, and Mali[55] suggest policy makers risk repeating the same mistakes: a bias towards large-scale mining, inadequate implementation, and one-size-fits-all technical solutions. It is encouraging that the political will in the Minamata Convention and GEF financing to back these reforms has been mobilized, but we urgently need to learn from past failures to ensure that we do not squander political will and money repeating similar mistakes.'

References

Hilson, G., Hu, Y., Kumah, C. Locating female 'Voices' in the Minamata Convention on Mercury in Sub-Saharan Africa: The case of Ghana (2020) Environmental Science and Policy, 107, pp. 123-136.

Hilson, G., Zolnikov, T.R., Ortiz, D.R., Kumah, C. Formalizing artisanal gold mining under the Minamata convention: Previewing the challenge in Sub-Saharan Africa (2018) Environmental Science and Policy, 85, pp. 123-131.

Hirons, M. How the Sustainable Development Goals risk undermining efforts to address environmental and social issues in the small-scale mining sector (2020) Environmental Science and Policy, 114, pp. 321-328.
Hilson, G. 'Formalization bubbles': A blueprint for sustainable artisanal and small-scale mining (ASM) in sub-Saharan Africa (2020) Extractive Industries and Society, 7 (4), pp. 1624-1638.
Maconachie, R., Conteh, F.M. Artisanal mining and the rationalisation of informality: critical reflections from Liberia (2020) Canadian Journal of Development Studies, 41 (3), pp. 432-449.
Byemba, G.K. Formalization of artisanal and small-scale mining in eastern Democratic Republic of the Congo: An opportunity for women in the new tin, tantalum, tungsten and gold (3TG) supply chain? (2020) Extractive Industries and Society, 7 (2), pp. 420-427.
Clifford, M.J. Future strategies for tackling mercury pollution in the artisanal gold mining sector: Making the Minamata Convention work (2014) Futures, 62, pp. 106-112.

Response: we thank Reviewer 1 for providing this detailed reference list and have cited these studies in the revision.

Reviewer #2: Review of the ms One Earth D-21-00185. Formalizing artisanal and small-scale gold mining: a grand challenge of the Minamata Convention

General Comments

This is an excellent review manuscript. The authors covered, in a very comprehensive way, all aspects of the main problems related to artisanal gold mining. The criticisms are well based on the literature and the suggestions are well taken. Below, I made some suggestions to improve the text, but all can be done in a minor revision. I congratulate the authors.

Response: We thank the reviewer for their detailed and constructive comments. We have implemented the suggested changes.

Specific Comments

In the Abstract: "The 2013 Minamata Convention on Mercury seeks to reduce anthropogenic emissions of mercury, 37% of which are generated by ASGM". It is important to highlight that 37% is just emissions. The mercury lost to the environment from ASGM comprise emissions (air) and releases to land+water which totals over 2000 tonnes/a. This latter is much higher than the emissions. For reference, see Martinez,G., Restrepo,O.J., Veiga,M.M.,(2021). The Myth of Gravity Concentration to Eliminate Mercury Use in Artisanal Gold Mining. The Extractive Industries and Society, v.8, p.477-485

Response: We now specify this more clearly in the abstract: 'The global Artisanal and Small-scale Gold Mining (ASGM) sector is worth an estimated US$36 billion and employs over 20 million miners in the Global South. Over 2,000 tonnes of mercury per year are emitted into the atmosphere or released into land and water by ASGM activities, with downstream negative health effects for humans and wildlife.'

Line 5: "Global gold production is increasing by >3,000 tonnes (~1.5%) per year". Actually, the gold production is not increasing and it is very stable for years around 3400-3500 tonnes/a due

to lack of new large deposits discovered by conventional mining corporations. According to the World Gold Council the primary gold mining production has been
Year tonnes of Gold
2020 3401
2019 3532
2018 3554
2017 3492
2016 3459
2015 3336

Response: We had meant that the amount of mined gold increases by >3,000 tonnes per year, in line with the World Gold Council figures you cited, not that the rate of increase is increasing—but we acknowledge that the phrasing was ambiguous. In any case, we have now removed this section of the abstract in line with Reviewer 1's recommendation to cut references to large-scale mining and begin the introduction with discussion of ASGM.

Line 15: The data from Seccatore et al (2014) is a bit outdated. It sees that the number of artisanal gold miners are nowadays above 20 million…see UNEP (2021). https://web.unep.org/globalmercurypartnership/our-work/artisanal-and-small-scale-gold-mining-asgm.

Response: We have revised the text as follows: 'The estimated number of ASGM miners increased from ~16 million in 2011 to over 20 million by 2020, with a corresponding increase in annual production from 380-450 tonnes of gold in 2010-2011 to almost 600 tonnes by 2020'. (L6–8)

We have updated the estimates in Table 2 and added the following text: 'As the numbers estimated by Seccatore et al. may be outdated and imprecise, we also show cost estimates if the total number of ASGM miners worldwide is 20,000,000 or 30,000,000.'

Line 42: Gold particles are not in SOLUTION but in SUSPENSION. I would say "Liberated gold particles in concentrates or whole ore are usually extracted by artisanal miners using mercury, which forms an amalgam that it is heated to evaporate the mercury leaving behind the gold".

Response: Thank you for the correction – we have adapted your suggested wording: 'Miners use mercury to extract liberated gold particles in concentrates or whole ore. The mercury forms an amalgam that miners can heat to evaporate the mercury, leaving behind the gold' (L28–30).

Line 46: Again, the 727 tonnes (please use metric tonnes and not short tons) refer only to Hg going to the atmosphere not the whole Hg lost with tailings (which is much larger than the losses to the air). It is better to use " …according to UNEP (2021), over 2000 tonnes of mercury is annually lost by artisanal gold miners worldwide"; UNEP - United Nations Environment Programme (2021). Artisanal and small-scale gold mining; global mercury partnership. https://web.unep.org/globalmercurypartnership/our-work/artisanal-and-small-scale-gold-mining-asgm.

Response: We have now written: ‘According to UNEP, over 2000 tonnes of mercury are annually emitted or released into the environment by ASGM miners worldwide’ (L32–L34)

Line 49: "In aquatic ecosystems, mercury is converted into methylmercury by bacteria, and this can accumulate in aquatic and terrestrial food chains with negative health consequences, including among humans where it is associated with neurological damage such as Chisso-Minamata disease". Be careful…there is no one evidence that the metallic mercury released by ASGM into aquatic environments can be transformed into methylmercury. This is a possibility but it was never proven. Therefore to compare with Chisso-Minamata incident is a very dramatic and unreal, Recently, authors found that when Hg is mixed with cyanide a complex is formed (Hg(CN)2) that can be bioacccumulated. See: Marshall,B.G., Veiga,M.M., Silva,H.A.M., Guimarães,J.R.D. (2020). Cyanide Contamination of the Puyango-Tumbes River Caused by Artisanal Gold Mining in Portovelo-Zaruma, Ecuador. Current Environmental and Health Reports v.7, p.303-310. https://doi.org/10.1007/s40572-020-00276-3

Response: We removed this reference and the text now reads ‘In aquatic ecosystems mercury can form compounds with cyanide $Hg(CN)_2$ which can bioaccumulate.’ (L35–36)

Line 52: " … neurodevelopmental abnormalities estimated to cost 1,310 disability adjusted life years and $77.4 million in lost economic productivity in 15 developing countries."
This is a weird stretch. The economic productivity of 500 tonnes/a of gold produced worldwide by ASGM is close to US$ 30 billion…the lost of productivity is insignificant. The neuro abnormalities caused by Hg inhalation in developing countries were never proven as the local health workers do not have training or equipment to assess mercury in the body of contaminated people. This 1310 number is just a speculation. The effects of Hg vapor on communities can be much higher but nobody knows the extent of this. Analyses of Hg in urine of citizens in developing countries show the bioaccumulation of Hg vapor. There are hundreds of paper on this. In the paper from Bermudez et al. (2004), the levels of Hg in urine of miners and communities in Venezuela are outstanding, as well as the neurological problems found by specific tests, but, nobody has numbers of people in fact affected by this misuse of mercury. I suggest to remove this bogus reference to number of people affected…this can be millions.
Bermudez,D., Veiga,M.M., Roeser,M., Pacheco-Ferreira,H., Pedroso,L.R.M., Voss,L., Penna,S., Maciel,W. (2004) Health Impact Diagnosis Due to Gold Mining Activities in "Bloque B" at El Callao, Bolivar State, Venezuela. 7th International Conference of Mercury as a Global Pollutant. Ljubljana, Slovenia, June 27-July 2, 2004. RMZ Materials and Geoenvironment, v.51, Part 1, p.352.

Response: Thank you for pointing this out, we have removed the reference to the study.

Line 102: "For example, borax-treatment was successful in the Philippines, but requires ores with low sulphide concentrations." To use borax, it is also required that the concentrate has high grades of gold, therefore this implies that a large part of the gold is lost in the concentration process. The method is useful for alluvial ores where gold is usually liberated and it has been used for centuries. See Veiga,M.M. and Gunson,A.J. (2020). Gravity Concentration in Artisanal Gold Mining. Minerals 10(11), 1026. 49p, https://doi.org/10.3390/min10111026

Response: we now write ‘For example, borax-treatment has been used for centuries but requires ores with low sulfide concentrations and high grades of gold due to the high rate of gold loss during the process’ (L92–95)

Line 140: I would add to the good points of the authors that formalization implies in Legalization + Training. No training has been introduced by Governments to push formalization. In fact, in countries where legal (pseudo-formalized) artisanal miners operate, the pollution is the same as of the informal miners. See: Veiga,M.M. and Marshall,B.G. (2019). The Colombian Artisanal Mining Sector: Where Formalization is a Heavy Burden. The Extractive Industries and Society, v.6, n.1, p.223-228.

In addition: Technological change to eliminate the use of Hg needs heavy investments that can be around US$ 40,000 per tonne of ore being processed per day. This is not a simple matter of changing behaviors.

Response: we have added 'A failure to adequately train artisanal miners in improved techniques has resulted in legal (pseudo-formalized) miners in Colombia polluting at equal rates to informal miners.' (L121–123)

Line 143: I would remove this reference to Suriname. At the time that Dr Heemskerk conducted this work the price of Hg was extremely low. After the Minamata Convention the price of mercury is the mines are very expensive reaching up to US$ 300/kg. Therefore Hg can represent today a large expense for the miners. We are doing right now field studied about this in Suriname.

Response: We have now removed this reference.

Line 181: "International Institute for Sustainable Development". Where? Australian? Please be a bit more specific.

Response: We have specified that it is IISD in Winnipeg (L134).

Line 198: I would remove the word "replace" at the end of the sentence (line 199). The low price of a shaking table is related to a homemade shaking table buy not a commercial one. See here: Veiga,M.M., Masson,P., Peron,D., Laflamme,A.C., Gagnon,R., Jimenez,G., Marshall,B.G. (2018). An Affordable Solution for Micro-miners in Colombia to Process Gold Ores without Mercury. J. Cleaner Production, v.205, p.905-1005.

Response: We have removed 'replace': 'For example, a retort might cost US$5-50 and a shaking table US$1,000-10,000.' (L188–189).

Line 219: Good approach to calculate the costs for the total elimination of Hg. Actually better numbers of gold production and mercury losses are here: Yoshimura,A., Suemasu,K., Veiga,M.M. (2021). Estimation of Mercury Losses and Gold Production by Artisanal and Small-scale Gold Mining (ASGM) in selected countries. J. Sustainable Metallurgy

The problem in this calculation is that there are different levels of artisanal miners: micro, small, medium, large. I would say that 90% of the miners are micro or small and 10% are medium and large. These latter are in Processing Centers and they do not want to change anything. The micro and small do not have skills to use the moneys you suggest to change anything. So this is a catch 22. Any additional $ given to Govts to resolve the problem will disappear in the corrupted and intricate systems of the developing countries. The UN and other agencies invest nearly US$ 200 million per year in projects to formalize artisanal miners and eliminate Hg. The results are minimum.

Response: Thank you for these excellent points. Although we appreciate the Yoshimura et al. reference, we are unsure how to scale the estimates of gold and mercury volumes into cost needed per country to eliminate mercury emissions. We are open to any suggestions for how to incorporate this into our global cost estimates.

We have, however, now added an important caveat to our estimates: 'It is also important to note that there is substantial heterogeneity within the informal ASGM sector, and the costs and challenges will not be evenly distributed per miner: micro- or small operations (the vast majority) lack skills and capital to adopt new technology, and large and medium operations may have the means and incentives to resist reform.' (L215–219).

Line 240: Please use more recent data from World Gold Council. The data from 2020 is not good as the pandemic affected the numbers. See for example:
In 2019 (from WGC, 2020):
* Jewelry = 2107 t (48,4%) (China, India main consumers)
* Investment= 1271,7 t (29,2%)
* Central Banks = 650,3 t (14,9%)
* Technology (electronics, dentist, etc.) = 326,6 t (7,50%)

Response: We have updated the figures: 'In 2019, the global gold market was dominated by jewelry (48.4%), investments (29.2%), central banks (14.9%) and technology (7.5%).' (L232–233)

Line 241: "In other words, the demand for gold is driven by elite and luxury consumers" This is a mistake. The poorest countries are those consuming more gold for jewelry. The main consumers are not only the elite but the poor people who don't have access to banks and buy jewels for savings. This is also a tradition in India, China and other Middle East countries.

Response: We have removed this and added 'Although the majority of global jewelry demand comes from China and India, and is driven partly by lack of access to banking, the top five per-capita gold-consuming countries for which data are available are Switzerland, UAE, Kuwait, Hong Kong SAR, and Germany. There are significant opportunities to shift burdens onto donor countries, ASGM country governments, multinational mining corporations, and end consumers.' (L233–238)

Line 288: The Fairmined and Fairtrade requirements are quite bureaucratic and demand legalization of the participants, therefore less than 1-2% of the artisanal miners in Latin America can participate. I do not agree that the ARM relaxed their environmental requirements as said in line 290. The ARM, as well as the FLO, requirements are in fact too hard to be followed by a significant amount of miners. There is no inspection or enforcement of the requirements. These initiatives are minuscule attempts to legalize ASGM. Without Hg and cyanide the gold recoveries will be very low. Which conventional mining company (out of 2000 in the world) does not use cyanide? Probably only Mineros S.A. that works with alluvial gold in Colombia. These requirements of no-chemicals in gold extraction is only a cosmetic for these fair trade organization since the gold recoveries will be extremely low. Artisanal miners know this and they play the game to have US$ 4000 for their kg of "clean" gold. Who knows if the miners are in fact following the regulations of the agreements?

Response: We have rewritten our description of this: ‘Fairtrade International (FLO) and Alliance for Responsible Mining (ARM) launched a ‘Fairtrade and Fairmined Gold’ Label in 2011, but the two standards diverged from and competed with each other. Risks involved in the implementation of such certification schemes include bureaucratic and technical barriers to participation, lack of enforcement and monitoring, no clear market for ‘responsible’ gold, and the passing of due diligence costs onto upstream actors.’ (L269–274)

Formalizing Artisanal and Small-scale Gold Mining: a Grand Challenge of the Minamata Convention

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Keywords: Artisanal and small-scale gold mining (ASGM); environmental health; extraction; mercury; trade-offs; formalization; environmental governance

Abstract

The global Artisanal and Small-scale Gold Mining (ASGM) sector is worth an estimated US$36 billion and employs over 20 million miners in the Global South. Over 2,000 tonnes of mercury per year are emitted into the atmosphere or released into land and water by ASGM activities, with downstream negative health effects for humans and wildlife. The 2013 Minamata Convention on Mercury seeks to reduce anthropogenic emissions and releases of mercury. As ASGM largely operates informally—that is, it is neither regulated nor protected by state laws—its formalization is recognized as a necessary step for balancing emissions reduction with improved livelihoods. The Convention mandates formalization of the sector in National Action Plans. We review past and ongoing efforts to reduce and eliminate mercury use in ASGM. We argue that top-down approaches to formalization that involve centralized creation of permits and environmental mitigation requirements are likely to exclude millions of miners, and that bottom-up approaches centered around working with existing miners are needed. Ongoing efforts to formalize ASGM, while nominally bottom-up, are frequently based on an incomplete understanding of informal ASGM dynamics, fail to include mining communities, and are led by the wrong government departments. If these shortcomings are not addressed, these projects risk repeating the failures of previous attempts to reform ASGM. In addition to reviewing these efforts, we estimate the scale of external investment needed to ensure positive health and environmental outcomes from reforming ASGM. Extrapolating from available budgets, the global five-year cost of this approach could be $355 million USD (upper and lower estimate bounds: $213–829 million) if scaled per country, or $808 million USD ($268 million–$2.17 billion) if scaled per miner. Consumers, large mining corporations, and/or governments will need to bear these costs.

Introduction

Over the past three decades, the global appetite for gold has continued to grow, driven by increased consumer demand from Asia and soaring investor demand following spiking gold prices.[1] Artisanal and Small-scale Gold Mining (ASGM) is prevalent in at least 64 countries (Figure 1). The estimated number of ASGM miners increased from ~16 million in 2011[2] to over 20 million by 2020[3], with a corresponding increase in annual production from 380-450 tonnes of gold in 2010-2011 to almost 600 tonnes by 2020[4]. The ASGM sector is worth an estimated US$36 billion[4] but remains largely informal globally—that is, it is not officially recognized or registered, and neither regulated nor protected by state laws. The persistence of informality has been attributed to bureaucratic, financial, and legal barriers[5–7], as well as the lack of incentives among ASGM miners, who commonly rely on traditional or customary land claims, to have their claims sanctioned by governments.[8–10] A structuralist perspective on informality highlights that the cheap and flexible labor force provided by ASGM miners is extremely useful to global capital.[1]

Informality lowers the barriers to entry[11] and encourages widespread participation in ASGM. As such, in many regions around the globe, ASGM activities have become the backbone of rural economies.[12–14] For millions of miners and their dependents, ASGM is the primary source of income[15]. For others, it is a complementary income source that helps them overcome periods of crisis or agricultural low seasons.[16,17] Unfortunately, the lack of oversight and protections arising from informality has underpinned and facilitated egregious human rights and environmental violations.[18–20] For instance, ASGM miners are particularly vulnerable to extortion and arrest.[17,21–23] Of the many environmental issues arising from ASGM, policy makers and researchers have largely focused on mercury pollution (Box 1).

Mercury use remains one of the simplest and most cost-effective ways to extract and concentrate gold by ASGM miners.[24,25] Miners use mercury to extract liberated gold particles in concentrates or whole ore. The mercury forms an amalgam that miners can heat to evaporate the mercury, leaving behind the gold.[24] Mercury lost when disposing of the amalgamating solution and mercury vaporized from the amalgam are the main sources of mercury emissions from ASGM activities. According to UNEP,[26] over 2,000 tonnes of mercury are emitted or released into the environment by ASGM miners worldwide. The inhalation of mercury vapor has negative health impacts on miners[27] and on people who live adjacent to gold workshops.[28] In aquatic ecosystems, mercury can form compounds with cyanide $Hg(CN)_2$, which can bioaccumulate.[29]

Reducing mercury emissions and releases from ASGM is thus central to the 2013 Minamata Convention on Mercury (Box 1),[30] which requires signatories to take tangible steps towards reducing mercury use across the mining sector. As the environmental problems associated with ASGM have been primarily attributed to pervasive informality, policymakers have increasingly focused on formalization as the fundamental strategy to reform ASGM.[7] Researchers and policymakers have argued that formalization will not only stimulate economic growth and increase tax revenues by giving ASGM miners strong property titles, but will also improve working conditions and promote better environmental management.[31–35] The Minamata Convention therefore requires any Party where “artisanal and small-scale gold mining and processing in its territory is more than insignificant” to develop a National Action Plan (NAP) that includes steps towards ASGM formalization (Article 7.3).[36,37] By January 2022, sixteen countries had published NAPs: Burkina Faso,[38] Burundi,[39] Central African Republic,[40] Democratic Republic of Congo[41] (Box 2), Ecuador,[42] Guinea,[43] Laos,[44] Madagascar,[45] Mali,[46] Mongolia,[47] Nigeria[48], Republic of Congo,[49] Senegal,[50] Sierra Leone,[51] Uganda,[52] and Zimbabwe[53] (Figure 1).

In this article, we review the challenges of formalizing ASGM to reduce its environmental impacts and consider what a successful approach will likely entail. This includes consideration of how to incentivize and support informal miners to participate in a reformed ASGM sector. We discuss the need for considerable financial investment to accompany formalization, for which a range of global stakeholders must bear increased responsibility.

Challenges encountered in previous attempts to reduce mercury emissions from ASGM

The nature of attempts to reduce mercury usage in ASGM, and the discourses used to underpin these reforms, has evolved over the past decades from isolated technical interventions to the full-scale formalization approaches mandated in the Minamata Convention.[54,55] The 1980s gold rush in the Amazon triggered a wave of baseline monitoring studies[56–58] that brought attention to mercury pollution as a consequence of ASGM. Subsequent research in the 1990s focused on building technical capacity.[55] In parallel, discourses on formalization in this period followed the more ‘legalistic’ lens popularized by De Soto, which emphasized the need to remove bureaucratic restrictions so that entrepreneurial small-scale miners could benefit from technical assistance and create more taxable revenue.[55,59,60]

The 2002-2007 GEF/UNEP/UNIDO Global Mercury Project (GMP), the most significant international effort before the Minamata Convention,[25,55] epitomized this period’s framing of the problem as primarily one of awareness and technical capacity. The GMP aimed to educate ASGM miners and communities about the hazards of mercury and propose technical solutions to avoid mercury usage in six pilot countries (Brazil, Indonesia, Laos, Sudan, Tanzania, and Zimbabwe).[61] The project educated 300 trainers, who in turn trained an estimated 30,000 ASGM miners and community members.[61] Meanwhile, technical interventions included the introduction of relatively simple technologies and practices, such as burning amalgam in retorts and installing fume hoods in gold shops, which can reduce vapor emissions by 90%[61]. In parallel, other isolated projects funded by the Geological Survey of Denmark and Greenland introduced an alternative to mercury amalgamation using borax in the Philippines, Tanzania, and Bolivia.[62,63] Despite these efforts, interventions centered on awareness and technical capacity did not lead to lasting changes. As Veiga and Fadina noted, ‘At the end of six years of this multimillion dollar UN project [the GMP], not many miners continued with the methods they had learned’.[25]

As acknowledged in a post-project appraisal, the GMP encountered difficulties that stemmed from the fact that ASGM is largely poverty-driven, and that most ASGM miners lack the financial means to prioritize long-term health and environmental concerns over short-term economic considerations even with training and education.[61] Furthermore, some alternatives to mercury amalgamation are only economically viable with certain ores. For example, borax-treatment has been used for centuries, but requires ores with low sulfide concentrations[63] and high grades of gold due to the high rate of gold loss during the process.[64] Moreover, lack of trust by miners towards researchers and authorities, the low profitability of these gold extraction techniques, and the absence of trainers to help when the new equipment breaks down have all contributed to the widespread failure to change mining practices.[25] Beyond these financial constraints, the educational and technical focus of the GMP was ultimately unsuccessful because of poor knowledge of governance dynamics and an inability to tackle the structural issues that have created a widespread informal ASGM sector. Deep structural issues that have hindered ASGM reform include policy biases towards large-scale mining and the persistence of elite patronage networks, whereby corrupt government officials have an economic incentive to ensure revenue streams by maintaining informality.[54,55,65–67]

Increasing awareness of the poverty-driven nature of ASGM led to a phase of discourse in the 2000s centered around livelihoods'.[55] Recasting ASGM as not simply an environmental problem, but also a vital livelihood in low-income communities and rural areas, particularly as a complement to subsistence agriculture[68–71], has influenced policy discourse to emphasize the need to formalize the sector not only for tax revenue and/or environmental compliance, but also to protect livelihoods.

An opportunity to develop better formalization approaches

Top-down, 'carrot and stick' approaches to formalization, in which miners have to jump through expensive bureaucratic hoops in order to achieve legal titles and access to technical and financial aid, have largely failed.[25,54,55] In Peru, slow permit allocation and weak enforcement undermined an attempt to formalize ASGM and restrict it to a 5,000 km^2 'mining corridor', and failed to prevent a dramatic increase in deforestation for mining outside of the designated mining corridor, including in protected area buffer zones and indigenous territories.[72] A failure to adequately train artisanal miners in improved techniques has resulted in legal (pseudo-formalized) miners in Colombia polluting at equal rates to those of informal miners.[73] And even in rare cases that are considered to be successful, such as that of Guyana where 88% of ASGM is formalized, exclusionary dynamics and elite capture are prevalent.[73] The use of military and police violence to enforce restrictions on informal mining has led to human rights abuses[23] and failed to tackle environmental problems.[17,74] These examples show that a narrow focus on titling by no means guarantees that environmental regulations will be followed, as this requires money, training and incentives, and enforcement.[75] And even where formalization has occurred, formal ASGM operations are frequently found to rely on informal labour.[76]

There is widespread consensus in policy and academic circles that comprehensive bottom-up approaches are needed.[33,77] According to the International Institute for Sustainable Development (Winnipeg), bottom-up approaches are characterized by direct engagement with ASGM miners and tailoring the process to the specific complexities of each case.[77,78] For example, a formalization process in Mali started by recognizing traditional patterns of organizing gold miners instead of creating new cooperatives in a top-down manner, and making barriers low so that miners only had to apply for a $8 'gold-washing' (i.e. gold panning) card.[79] Formalization efforts in Mongolia have created space in the legal-regulatory framework for diverse institutional arrangements, recognizing not only registered companies, but also unregistered partnerships and miners' NGOs. [33]

In response to the failures of previous mercury reduction strategies, the Minamata Convention recognizes the need for a comprehensive approach to tackling mercury emissions that includes formalizing ASGM. While the process may appear bottom-up because each signatory country develops their own NAP, and the wording of the NAPs recognizes the need to include previously marginalized ASGM miners, the process of drafting and implementing the NAPs has echoed some of the previous problems with top-down approaches. The drafting of the NAPs has been delegated to consultants who may have consulted mining communities to a larger or lesser extent, but this does not mean that the mining communities have played an active role in drafting the NAPs. As such, the process has been driven by government agencies and consultants rather than mining communities.

In addition to the process being implemented *de facto* top-down by government ministries, implementation has been led by ministries lacking knowledge of and power over mining dynamics. While NAP implementation might ideally be a collaboration across multiple ministries, including the mining, environmental, labor, and health ministries, NAP implementation has mostly been delegated to environmental ministries that in some cases (e.g. Ghana and Sierra Leone) have little knowledge of informal mining dynamics, e.g. concerning the participation of women in the informal ASGM sector.[78,80] Furthermore, they typically have no power over permit allocation, inhibiting effective action and creating inter-ministerial conflict.[55]

Early indications from the development of NAPs offer warnings that strategic mistakes with previous formalization processes are being repeated, and in particular that structural barriers to formalization are not being eliminated. The aim to totally eliminate mercury instead of eliminating and reducing mercury use where necessary is impractical in light of the economic constraints micro-ASGM miners face. A bias towards allocating the best and largest mining concessions to large-scale mining continues to be a problem in countries such as Cambodia and Ghana,[55,81] making it unclear where governments will allocate viable space for a formalized ASGM sector. In writing separate NAPs at a country-level, countries are missing opportunities for cross-regional collaboration to tackle the illegal trade in gold and mercury.[55] Given the daunting scale of the challenge—in particular, the need to understand complex governance dynamics across vast scales—Hilson has proposed the ‘formalization bubble’ approach[54]. This strategy remains to be tested empirically, but would start with small, contained pilot sites, anchored around ASGM miners who are already licensed, as a way to effectively concentrate the spread of technical capacity and access to finance. By concentrating stakeholders, the strategy aims to generate accountability amongst stakeholders and thus reduce the risk of elite capture.[54]

Comprehensive bottom-up approaches have a high price tag

Comprehensive bottom-up ASGM formalization must deliver measures such as registration, environmental and social impact assessment, training and capacity building, monitoring, enforcement, and restoration needed to improve socio-environmental impacts. Since ASGM miners largely lack related financial and technical capacity,[33] assessment and compliance costs need to be funded from other sources. Up-front subsidies for replacement of equipment are also required. For example, a retort might cost US$5-50 and a shaking table US$1,000-10,000.[82] In many ASGM contexts, miners take their ore to independent processing centers for amalgamation and concentration. Developing cleaner processing facilities for these processors will require an investment of around US$10,000 per tonne of gold ore processed.[83] Similarly, site restoration is essential after the mine loses viability for ASGM. Woody biomass recovery rates on abandoned gold mining sites in Guyana were among the lowest ever recovered for tropical forests.[84] Restoration is thus also costly: restoration of gold mines in Peru cost an estimated $1,662–3,464 per hectare in the first year.[85] Unlike well-funded multinational companies with the legal obligations, resources, and expertise to restore large-scale mining sites, informal ASGM miners typically lack the capacity to successfully restore mining sites, leaving sites vulnerable to abandonment rather than rehabilitation.

The best available data sources for the likely active costs of this comprehensive global approach are the five-year budgets in the National Action Plans submitted by signatories to the Minamata Convention (Table 1). Actions taken to register and organize ASGM, interventions to eliminate the use of mercury in ASGM, and measures to promote public health and protect women of child-bearing age and children from the harmful effects of mercury are the dominant costs (Figure 2). We extrapolated from the median costs per country for the available NAP budgets, and used the lower and upper quartile values of these costs (Tables 1–2) as lower and upper bounds on the global five-year cost to extend calculations to the 64 countries with documented ASGM sectors (Figure 1). We repeated the calculation on a per miner basis (Table 2), using bounded estimates of 20-30 million ASGM miners worldwide.[3,4] We estimate a total five-year active cost of $355 million USD (upper and lower estimate bounds: $213–829 million) if scaled per country, or $808 million USD ($268 million–$2.17 billion) if scaled per miner (Table 2). Since we only have data for 16 countries (out of 64 with significant ASGM sectors), and there are huge uncertainties about the number of ASGM miners worldwide due widespread informality, these estimates are necessarily crude. It is also important to note that there is substantial heterogeneity within the informal ASGM sector, and that the costs and challenges will not be evenly distributed per miner: micro- or small operations, which comprise the vast majority of the sector, lack the skills and capital needed to adopt new technology, and large and medium operations may have the means and incentives to resist reform. However, these numbers suggest the approximate scale of funding needed to implement comprehensive bottom-up approaches to reforming ASGM worldwide.

Who pays?

Donor agencies and governments have identified the social and environmental costs of informal ASGM as major problems to tackle. Reforming ASGM to address these problems, whether through top-down or bottom-up formalization, presents significant new costs. There is increasing recognition that other stakeholders, particularly industry, governments, and consumers from the Global North, must assume greater financial responsibility for the impacts and regulation of ASGM activities.[86]

In 2019, the global gold market was dominated by jewelry (48.4%), investments (29.2%), central banks (14.9%) and technology (7.5%)[87]. Although the majority of global jewelry demand comes from China and India, and is driven partly by lack of access to banking, the top five per-capita gold-consuming countries for which data are available are Switzerland, UAE, Kuwait, Hong Kong SAR, and Germany[87]. There are significant opportunities to shift burdens onto donor countries, ASGM country governments, multinational mining corporations, and end consumers.

In principle, the revenue raised from royalties and taxes placed onto a new, large, formalized ASGM sector could stimulate economic growth and provide sufficient revenue to cover the costs of formalization. However, high up-front costs, taxes, and other fees could deter informal miners from engaging with the formalization process. Alternatively, governments could shift the financial burden onto other actors by taxing gold exports, raising taxes and royalties from the formal sector, using funds from the national budget (e.g. from the Ministry of Mines or equivalent), and encouraging partnerships between informal miners and large corporations.[33]

As larger corporations have greater capacity than informal ASGM miners use mercury-free gold mining processes, corporate-ASGM partnerships could be a potential solution. For example, a Colombian mining company (Mineros S.A) operating on the Bonanza Gold Mine ran a partnership with 2,000 ASGM miners whereby the company instituted a mercury-free processing plant for them.[25] Cases in which informal ASGM activities occur on land on which formal leases have expired, as in Northern Myanmar, may be particularly suited to such an arrangement.[17] A possible policy tool for funding this arrangement might include an expansion of the fiduciary mechanisms currently used to guarantee successful post-mine restoration.[88] For example, in Western Australia, mining companies pay an annual levy to a publicly held Mining Restoration Fund, which is used to reclaim historic mine sites and pay for restoration if a company is unable to do so. These mechanisms could be extended to funding ASGM partnerships, requiring companies to pay into a central fund used to support ASGM formalization, and/or to postpone the restoration if ASGM occurs on the site after completion of the company's license.

Market incentives for miners who better comply with standards can also help to improve compliance. There exist several transnational governance schemes to regulate the global mining industry. Some focus on specific issues like transparency in revenue sharing (e.g., Extractive Industries Transparency Initiative) while others are concerned with a broad range of social and environmental sustainability issues (e.g., International Council on Mining and Minerals).[89] Fairtrade International (FLO) and Alliance for Responsible Mining (ARM) launched a 'Fairtrade and Fairmined Gold' Label in 2011,[90] but the two standards diverged from and competed with each other.[91] Risks involved in the implementation of such certification schemes include bureaucratic and technical barriers to participation, lack of enforcement and monitoring, no clear market for 'responsible' gold[91], and the passing of due diligence costs onto upstream actors.[92–94]

The difficulties encountered thus far in providing market incentives through certification suggest that tougher approaches may be needed to ensure that the high-income consumers, investors, and companies who ultimately benefit the most from global gold mining share the burden of paying for its environmental and social costs. Requiring the adoption of environmental and humanitarian standards by major importers through regulation, following the example of FLEGT for timber imports to the EU[95] and the Roundtable on Sustainable Palm Oil,[96] could be a step in the right direction. The main challenges lie in ensuring that the benefits of compliance outweigh the costs, particularly for the poor,[97] and that they are not undermined by market competition from miners operating under less stringent standards.[91] Further leverage points for enforcing greater environmental and social standards in publicly listed companies that mine, trade, or use gold could include pressure from lenders, sustainability reporting mechanisms in stock exchanges, and shareholder activism.[98]

International development funds could be used to provide support and environmental oversight for a formalized ASGM sector, analogous to the use of development funds to help exporting countries formalize their timber market in order to comply with the European Union Timber Regulation (EUTR).[99] Public subsidy through taxes and international development agencies may face challenges, since it could be seen as a public subsidy of private polluting enterprises, the costs of which the public bear. A complete financial accounting that takes into consideration not only the cost of formalization, but also the savings from avoiding future health and environmental costs, could make such investments more attractive.

Of the options discussed above, it is international development funding that has gathered the most traction so far, particularly through the Global Environmental Facility (GEF)[100,101]. The GEF-funded planetGOLD (US$ 180 million[102]) and GOLD+ (phase 2 of planetGOLD; US$ 417 million including co-financing[103]) have provided funds for countries to develop and implement their NAPs, including technical solutions to reduce mercury usage, formalize ASGM, and provide financial assistance and access to formal markets for formalized ASGM miners. Early achievements of planetGOLD (listed in the project's 2019/20 annual progress report[100]) include designing a mercury-free processing plant in Burkina Faso, forming an agreement with the Alliance for Responsible Mining to carry out formalization activities in Colombia, training 70 women miners in mercury-free techniques in Ecuador, and obtaining certification for 'El Dorado Gold' for mercury-free gold in Guyana. As noted above, these steps are individually promising. But however effective they may be in isolation, if they are implemented unsystematically or inappropriately, these massive investments may not deliver the intended systematic reform, as happened with the 2002-2007 GEF/UNEP/UNIDO Global Mercury Project.

Future Directions

Policy makers have made little progress in formalizing ASGM despite an increasing acknowledgement of its importance. Top-down command-and-control approaches to formalization are ineffective, and narrow approaches that focus on titling are insufficient to address the complex social and environmental concerns associated with informal ASGM. More comprehensive, bottom-up approaches to formalization are needed, but these require training, appropriate incentives, and monitoring and are thus costly. Moreover, such approaches risk placing undue burdens on poor miners in ways that are likely inequitable and undermining. Supporting a comprehensive, inclusive, and effective formalization strategy requires candidly confronting the financial and moral burdens of reforming ASGM. As it stands, upstream supply chain actors have borne not just the social and environmental costs of mining gold, but also the costs of formalization. We have approximated the scale of active costs to improve social and environmental standards in ASGM formalization strategies. The framing of the Minamata convention and the drafted National Action Plans suggest that policymakers will, at least on paper, heed these lessons. However, the framing of planetGOLD and early experiences from drafting of NAPs in Cambodia, Sierra Leone, Ghana, and Mali[55] suggest that policy makers risk repeating the same mistakes: a bias towards large-scale mining, inadequate implementation, and one-size-fits-all technical solutions. It is encouraging that the political will in the Minamata Convention and GEF financing to back these reforms has been mobilized, but we urgently need to learn from past failures to ensure that we do not squander political will and money repeating similar mistakes.

Competing Interests

The authors declare no competing interests.

Author contributions

Original conceptualization: GWP and ELW; Methodology: GWP; Writing: GWP, MB, SG, BN, JP, ELW; Visualization: GWP; Funding Acquisition: SG and ELW.

Acknowledgements

The research was funded by a Singapore Ministry of Education grant (MOE2015-T2-1-131) and an MOE Tier 1 grant to ELW. We thank S Sahla, DR Williams, and two anonymous reviewers for thoughtful commentary on the manuscript. We partially relied on data gathered in the research project G056718N funded by the Research Foundation Flanders (FWO).

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Box texts

Box 1. The Minamata Convention on Mercury

Mercury emissions have increased dramatically since the industrial revolution. Mercury concentration has doubled in the surface layers of the oceans and increased 12-fold in Arctic marine mammals.[104] Elemental mercury, emitted directly into water or deposited from the atmosphere, is converted by bacteria into methylmercury. An accumulation of methylmercury can cause severe neurological disorders. The Minamata Convention is named after a Japanese city where residents developed severe neurological disorders (now named Chisso-Minamata disease) after eating seafood that had accumulated mercury following decades of industrial emissions of mercury into the neighboring bay.

The Minamata Convention on Mercury[37] deals with all anthropogenic sources of mercury, including coal burning, cement production, and disposal of consumer products containing mercury (e.g., batteries, thermometers). The treaty aims to phase out the global trade in mercury; the manufacture, import and export of mercury-containing products (Annexe A); the elimination of mercury from several manufacturing processes (Annexe B); and to implement safer ways of disposing and storing of mercury. It also sets out to regulate ASGM (Annexe C), the largest anthropogenic mercury emission source, by educating mining communities about health risks, substituting mercury amalgamation-based gold extraction methods and, pertinently for our review, 'Steps to facilitate the formalization or regulation of the artisanal and small-scale gold mining sector'.[105,106]

Box 2. Case study: gold mining, mercury, and formalization in the Congo

The Democratic Republic of the Congo (DRC), as one of the signatories to the Minamata Convention, has developed a National Action Plan targeting ASGM formalization as one of the most important tools to curb mercury use.[41] Although the government has been involved in several formalization efforts before, the top-down approach and limited enforcement have rendered these barely effective.[60] The most extreme effort was the ban on all artisanal mining in the Eastern provinces in 2010-2011, which led to severe economic and social backlashes such as decreased income, school drop-outs, malnutrition, and untreated illnesses.[60] When ASGM activities were allowed again mid-2011, the requirement to group into cooperatives led to elite capture, leaving those at the bottom of the labour hierarchy worse off.[107] Meanwhile, non-governmental initiatives have been confronted with black market prices that are impossible to compete with.[108]

However, despite the limited formalization of ASGM, miners' commonly shared knowledge has significantly reduced mercury use. Indeed, techniques that are highly recommended by the Minamata convention are already widespread in DRC. These include using mercury on concentrates rather than whole ores and using leaves with trichomes to recapture mercury during the burning phase. Despite these techniques being less efficient than shaking tables and retorts, they have resulted in an average mercury-gold ratio of 1.8, which is one of the lowest in the world, totaling around 3 tonnes of mercury annually for 12 tonnes of artisanal gold production.[109] Adopting the more efficient shaking tables and retorts would require higher upfront costs and continued training. If not cared for by large-scale mining corporations and consumers from the Global North, these costs would be borne by individual ASGM miners and/or their already struggling cooperatives.

Tables

Table 1. Total 5-year costs of National Action Plans (NAPs) to meet the Minamata Convention for countries with available budgets[38–53] (Figures 1–2). Estimates for size of the ASGM sector from Seccatore *et al.*,[2] except for Burkina Faso,[38] Democratic Republic of Congo,[41] Nigeria,[48] and Mongolia[47].

Country	**National Action Plan budget (USD)**	**ASGM miners**	**Cost per miner (USD)**
Burkina Faso	5,075,000.00	146,196	34.71
Burundi	3,327,000.00	91,000	36.56
Central African Republic	795,400.00	291,000	2.73
Democratic Republic of Congo	19,660,000.00	250,000	78.64
Ecuador	5,665,629.00	128,000	44.26
Guinea	3,130,000.00	250,000	12.52
Lao PDR	5,805,000	NA	NA
Madagascar	7,019,000.00	437,000	16.06
Mali	2,420,800.00	361,000	6.71
Mongolia	5,170,550.29	65,000	79.55
Nigeria	47,177,681.95	259,012	182.14
Republic of Congo	5,433,200.00	NA	NA
Senegal	13,561,508.43	15,000	904.10
Sierra Leone	22,385,000.00	437,000	51.22
Uganda	11,145,785.94	218,000	51.13
Zimbabwe	3,328,000.00	509,000	6.54
Grand Total	166,449,605.81	3,457, 208	48.15
Median (per NAP)	5,549,414.50	250,000	40.41

Table 2. Extrapolated global costs of meeting the Minamata Convention over the next 5 years in the 58 countries included in a 2014 estimate of the size of the global ASGM sector[2], plus another 6 countries with documented ASGM sectors (Cambodia, Côte d'Ivoire, Lao PDR, Nigeria, Myanmar, Republic of Congo). Given the scarcity of data on both costs and the size of the ASGM sector (Table 1), these are necessarily imprecise estimates aiming to give an approximate sense of the possible scale of global costs for a concerted effort to formalize ASGM and mitigate the worst impacts of mercury. As the size of the global ASGM sector is unknown but estimated to be over 20 million[4], we estimated the cost for the lower bound of 20 million ASGM miners and the upper bound of 30 million ASGM miners.

Summary statistic used	Cost per country (USD)	Multiplier	Multiplier value	Global Cost (USD)
Median	5,549,414.50	Countries	64	355,162,528.00
Lower Quartile	3'327'500.00	Countries	64	212,960,000.00
Upper Quartile	12'957'577.81	Countries	64	829,284,979.73
Median	40.41	Miners	20,000,000	808,200,000.00
Lower Quartile	13.41	Miners	20,000,000	268,108,924.49
Upper Quartile	72.47	Miners	20,000,000	1,449,325,194.54
Median	40.41	Miners	30,000,000	1,212,300,000.00
Lower Quartile	13.41	Miners	30,000,000	402,163,386.73
Upper Quartile	72.47	Miners	30,000,000	2,173,987,791.81

Figure legends

Figure 1. Worldwide distribution of documented ASGM sectors and countries with available National Action Plan budgets (as of January 2022) that we used to estimate the global costs of comprehensive formalization strategies[37] (Table 1). Legend: countries with documented ASGM sectors (yellow), countries with published NAP budgets (blue).

Figure 2. Breakdown of costs reported in the five-year budgets for National Action budgets[38–53] of sixteen countries (Table 1). 'Formalization' covers measures directly taken to organize and register informal ASGM miners, and to expand legal frameworks to include them.

Figure

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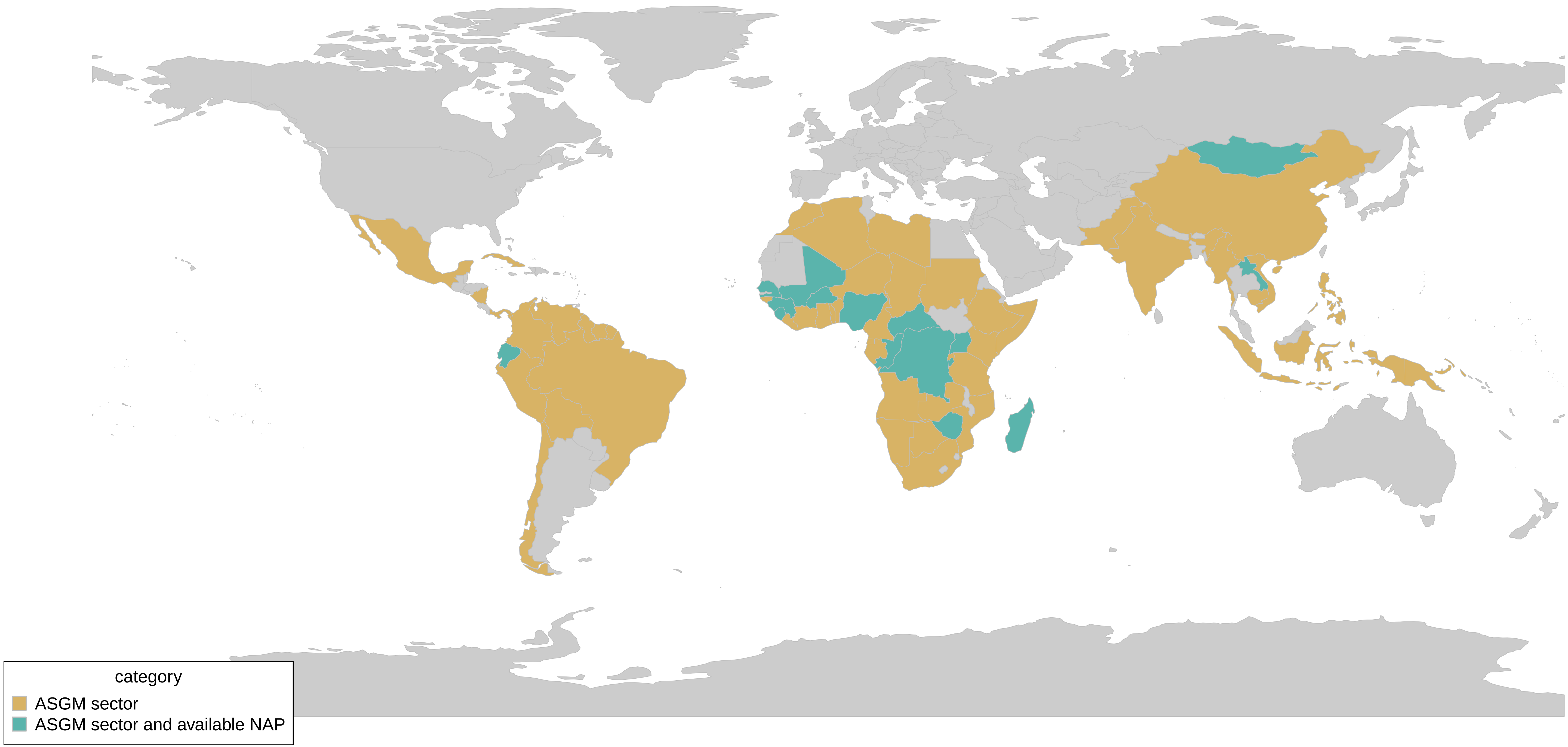

Figure

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