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Item 4 (b) of the provisional agenda\*\*

**Matters for consideration or action by the Conference of  
the Parties: artisanal and small-scale gold mining**

## **Guidance document on the management of artisanal and small-scale gold mining tailings**

### **Note by the secretariat**

As is mentioned in the note by the secretariat on the matter (UNEP/MC/COP.4/6), a technical document on the management of tailings from artisanal and small-scale gold mining (ASGM) was developed by the secretariat in cooperation with the ASGM partnership area of the Global Mercury Partnership, as a basis for a new chapter on this topic for inclusion in the guidance document for the preparation of a national action plan to reduce and, where feasible, eliminate mercury use in artisanal and small-scale gold mining. The technical document is set out as the annex to the present note and has not been formally edited.

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\* The resumed fourth meeting of the Conference of the Parties to the Minamata Convention on Mercury is to convene in person in Bali, Indonesia, and is tentatively scheduled for the first quarter of 2022.

\*\* UNEP/MC/COP.4/1.



**Annex**



# **SOUND TAILINGS MANAGEMENT IN ARTISANAL AND SMALL-SCALE GOLD MINING**

## **Technical Document**

United Nations Environment Programme

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# EXECUTIVE SUMMARY

Tailings are the waste material left over after a portion of the valuable components have been removed from the ore. Comprised mainly of crushed and milled rock and water, they may also contain chemical reagents, such as mercury and/or cyanide, used in gold extraction. Due to inefficiencies in ore processing, some artisanal and small-scale gold mining (ASGM) tailings contain significant amounts of unrecovered gold and may subsequently be reprocessed to recover it. Cyanide leaching in tailings to which mercury has been added without first removing the mercury is one of the worst practices as defined by Annex C of the Minamata Convention because it leads to generation of mercury-cyanide complexes that are highly mobile in the environment and bioavailable.

Sound management of tailings is often neglected in ASGM settings. Tailings may be left behind without proper stabilization or containment measures after the operations cease or move to new locations. This poses a risk to the environment and human health, especially if tailings contain residual mercury (or other toxic materials) that can evaporate into the atmosphere as elemental mercury or leach into surface and ground water and contaminate soils. The impacts include increased mercury emissions to the atmosphere; water and sediment contamination with mercury (including the formation of methylmercury) and other heavy metals; acid rock drainage; and dust emissions. This may lead to direct exposure to mercury of nearby communities. Moreover, physical failure of ASGM tailings ponds and dams can greatly damage the surrounding environment and pose further risk to human health.

As such, the Third Conference of the Parties of the Minamata Convention requested the Secretariat, in cooperation with the Global Mercury Partnership, to improve the guidance on the preparation of national action plans for ASGM in regards to management of tailings from such mining.

This technical document provides an overview of the available knowledge on the management of mercury-containing tailings generated from the ongoing ASGM practices. Furthermore, based on experiences and specific case studies gathered from mining sites worldwide, each section outlines relevant recommendations for the sound management of tailings along the mining life cycle. Overarching and specific recommendations (per chapter) are summarized below:

## Overarching recommendations

- The best way to manage mercury-contaminated ASGM tailings is not to generate them in the first place, or generate much less of them. Utilizing mercury-free ore processing methods will ensure that tailings do not contain added mercury. Applying sound management practices to non-mercury-contaminated tailings is less challenging compared to mercury-contaminated tailings. If mercury is used, limiting amalgamation to concentrates (rather than the whole ore), combined with keeping the two waste streams (prior to addition of mercury and post-mercury) separate, will greatly reduce the quantity of mercury-contaminated tailings and make management easier.
- Mercury-contaminated tailings that still contain economically viable quantities of gold are commonly generated in ASGM settings. In addition, legacy stockpiles of such tailings exist in ASGM areas throughout the world, some dating back decades or more. Applying cyanide to

mercury-containing tailings for gold recovery is a worst practice and should not be permitted. Mercury must first be removed. Potential removal methods can be based on thermal, adsorption (e.g. metal plates), and gravimetric methods. Extreme care should be taken in any subsequent use of cyanide, best done by organized and trained miners that can comply with chemical management protocols<sup>1</sup>.

- Basic best practices of sound management of tailings should be followed, especially for tailings containing mercury or other contaminants. These include:
  - Keep mercury-contaminated and non-mercury-contaminated tailings separated throughout storage, transport, reprocessing and disposal. Do not mix them.
  - Never discharge tailings into a water body or an area susceptible to flooding.
  - Store tailings in a sound manner. Practices depend on site conditions, but basic principles include ensuring groundwater or surface water do not migrate from the tailings structure to the environment, tailings ponds are structurally sound and dust emission is suppressed.
  - Make sure that the tailings are stored and disposed of away from the local communities.
  - Inform the community about the presence of mercury-contaminated tailings and the associated risk through signs or other means of communication. Limit access of people or animals to tailings structures by fencing.
  - Local or national governments should make efforts to record the location of mercury-contaminated tailings for future risk reduction and remedial actions.

### Specific recommendations

Specific recommendations and best practices in ASGM tailings management to be considered while designing required strategies under the NAP are mapped and presented in the table below and in the Annex.

**Table i. Specific recommendations for the sound management of tailings (per chapter)**

Chapters	Recommendations
<b>OVERALL CONSIDERATIONS FOR ASGM TAILINGS MANAGEMENT</b> As with any intervention in ASGM, it is vital to understand the local political, socio-economic, and environmental context of the ASGM, including formal status and organization, power dynamics, and roles of stakeholders along the value chain of tailings.	
<b>BASICS OF TAILINGS MANAGEMENT</b> (Chapter 3)	Best practices to minimize generation of mercury-containing tailings <ul style="list-style-type: none"> <li>• Avoid the generation of mercury-rich tailings by switching to mercury-free technologies. Utilizing mercury-free ore processing methods (see Section 5.5 of NAP guidance document<sup>2</sup>) will ensure that tailings do not contain added mercury. Applying</li> </ul>

<sup>1</sup> More information on safe cyanide use in ASGM context are presented in the report “Best Management Practices for Cyanide Use in the Small-Scale Gold Mining Sector”, published by the planetGOLD Programme (in preparation)

<sup>2</sup> <https://web.unep.org/globalmercurypartnership/nap-guidance-document>

	<p>sound management practices to mercury-free tailings is less challenging than with mercury-contaminated tailings.</p> <ul style="list-style-type: none"> <li>• If amalgamation is used, avoid adding mercury to the whole ore (a worst practice) and instead concentrate gold from the ore before amalgamation. Properly applied, concentrating the ore can also increase gold recovery.</li> <li>• Keep mercury-contaminated tailings separate from other tailings throughout the entire process, including during generation, storage, transport and reprocessing of tailings.</li> </ul> <p>Characterization of potential contaminants in the tailings and their risks</p> <ul style="list-style-type: none"> <li>• In order to plan for treatment, disposal or reprocessing of ASGM tailings, it is necessary to first determine some of their key characteristics. These include: <ul style="list-style-type: none"> <li>○ Are they contaminated with mercury? <ul style="list-style-type: none"> <li>▪ If the tailings were generated from whole ore amalgamation operations or without specific tailings separation practices, they should be assumed to contain mercury, as amalgamation results in residual mercury in the tailings. Mercury flour can also sometimes be observed by inspecting tailings closely or using a hand lens.</li> <li>▪ If the origin of the tailings is unknown, sampling and analysis can be used to determine if they are mercury-contaminated. Field screening for mercury in tailings can also be conducted using a portable atomic absorption spectrometer, X-ray fluorescence device or gas detector tubes. Samples of tailings can be collected and sent to a lab for analysis of total mercury content as well as other constituents</li> </ul> </li> <li>○ Other important tailings characteristics are grain size, mineralogy, presence of cyanide, sulfides or other potentially hazardous substances (such as arsenic, lead or cadmium), and residual gold content.</li> </ul> </li> </ul>
<p>MERCURY AND GOLD RECOVERY FROM TAILINGS (Chapter 4)</p>	<p>Options for mercury recovery from tailings, including prior to reprocessing for gold recovery</p> <ul style="list-style-type: none"> <li>• Mercury-contaminated tailings should never be reprocessed for gold recovery using cyanide leaching without first removing the mercury. This can lead to severe harm to human health and the environment and hence it is considered a worst practice under the Minamata Convention.</li> </ul>

	<ul style="list-style-type: none"> <li>• Wastewater should be separated from solids in tailings in order to apply the most suitable treatment to each phase.</li> <li>• Prior to reprocessing of mercury-contaminated tailings, mercury must first be removed<sup>3</sup>. Due to the variable nature of ASGM tailings, there is no single procedure to recover mercury from tailings which fits all circumstances. Instead, it is necessary to examine the most economically, technically, and socially acceptable method for the conditions at each ASGM site. Potential methods that miners can consider to remove mercury from tailings include: <ul style="list-style-type: none"> <li>○ Adsorption on metal plates (e.g. copper, silver or tin);</li> <li>○ Thermal treatment that volatilizes elemental mercury which can then be condensed and recovered;</li> <li>○ Gravimetric methods that take advantage of the high density of mercury relative to other minerals in the tailings;</li> <li>○ Other methods, including foam flotation, distillation and combined use of activated carbon and electrodeposition.</li> </ul> </li> <li>• Extreme care should be taken in any subsequent use of cyanide, best done by organized and trained operators in compliance with sound chemical management protocols.</li> <li>• ASGM miners, local and national authorities should collaborate to allow for collection, transportation, storage and safe disposal of the mercury recovered.</li> <li>• Implement occupational exposure monitoring for people involved in the mercury recovery process.</li> </ul> <p>Gold recovery: considerations for safe use of cyanide</p> <ul style="list-style-type: none"> <li>• Never apply cyanide to mercury-contaminated tailings. This is considered a worst practice under the Minamata Convention.</li> <li>• Cyanide leaching can be used to extract residual gold from tailings produced from mercury-free operations, or where the mercury has been removed.</li> <li>• The improper use of cyanide is extremely dangerous to human health and the environment, with risks of serious injury or death.</li> <li>• Cyanide should only be used by organized and trained miners that can comply with chemical management protocols to ensure occupational health and safety as well as protect the environment.</li> <li>• Where cyanide is a lawful alternative processing method, the NAP can consider including strategies for training ASGM miners (and other relevant stakeholders) on the sound management and use of cyanide.</li> </ul>

<sup>3</sup> The trace residual amount of mercury that may remain in the tailings should be defined by relevant authorities, taking into account the subsequent reprocessing methods and control measures, so that there are no adverse impacts to human health and the environment. Further guidance on how to evaluate the process is provided in chapter 4.2.

<p>DISPOSAL, ECOLOGICAL RESTORATION AND MONITORING OF MERCURY CONTAMINATED TAILINGS (Chapter 5)</p>	<p>Considerations for design, construction, storage and disposal of final ASGM tailings</p> <ul style="list-style-type: none"> <li>• In the processing area, install concrete walls or chemically resistant liners in the tailings containment ponds to stabilize the small volume of mercury-contaminated tailings and prevent mercury leaks.</li> <li>• Promote the use of impermeable lining systems or concrete to avoid leaching into groundwater. Cover tailings structures with impermeable material to prevent rainwater infiltration and dust emissions.</li> <li>• Ensure that inert materials are used for the construction of physical barriers for tailings storage, not the mercury-contaminated tailings themselves.</li> <li>• Ensure that tailings structures are constructed well away from rivers and or other waterbodies and outside of flood plains.</li> <li>• Choose a location away from community settlements, grazing and farming areas to minimize exposure</li> <li>• Ensure tailings structures are clearly marked and fenced so that local people know to stay away (and keep animals away).</li> <li>• Inclusion of tailings structures (data on location, land deed, size, type of tailings, land and contaminants) in a national database is recommended as it can help monitoring and land use planning.</li> <li>• If possible, select a centralized site for disposal in collaboration with local and national authorities, who can provide the relevant environmental, hydrological and geotechnical information to ensure safe and secure disposal.</li> <li>• If transport of tailings is necessary, care must be taken to avoid spilling mercury-contaminated materials (e.g. using lining and covers on trucks).</li> <li>• In alluvial mining, tailings are commonly generated directly adjacent to waterbodies. Special care must be taken not to dump the tailings that contain mercury back into streams or in flood-prone areas. Tailings should be transported to a secure area way from riverbanks for treatment and disposal.</li> </ul> <p>Considerations for ecological restoration</p> <ul style="list-style-type: none"> <li>• After tailings structures and other ASGM works are no longer in use, restore the surface grading and revegetate the land to reduce erosion. Ideally revegetation would also restore lost habitat or productive use to the site.</li> <li>• Consult with the ASGM community and apply knowledge and local experiences to succeed in the restoration approach. The most sustainable approach will be the one that best serves the needs of the local community.</li> <li>• Stimulate ASGM community commitment to restoration plans by engaging them actively in the restoration activities (ideally community engagement should be already taking place during operation of the ASGM site) and organizing educational sessions focused on the benefits of restoration and future restored land use possibilities.</li> </ul>
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	<ul style="list-style-type: none"> <li>• While designing a restoration strategy for the specific site and tailings material, elaborate plans based on the information obtained through site and tailings characterization, if it was conducted.</li> <li>• In line with Article 12 of the Minamata Convention, Parties/countries should develop appropriate strategies for identifying and assessing sites containing mercury-contaminated tailings for future risk reduction and remedial actions.</li> </ul> <p>Considerations for monitoring and tracking of mercury contaminated tailings</p> <ul style="list-style-type: none"> <li>• While deciding on the monitoring strategy, it is essential to apply baseline information obtained through tailings analysis and characterization, including data on mercury and any other contaminant presence and levels in the tailings.</li> <li>• Remote sensing methods, using satellite imagery, might be used to identify and track progress of the existing tailings, especially in the alluvial ASGM settings.</li> <li>• Geospatial tools, e.g. GIS, may be used to keep track of the locations and characteristics of mercury contaminated tailings.</li> <li>• Periodic sampling and characterization of the tailings could be envisioned, to track any potential physical or chemical changes to the tailings material, including level and speciation of mercury.</li> </ul>
<p>LEGAL ASPECTS AND GOVERNANCE (Chapter 6)</p>	<p>Considerations for improving tailings management through legal aspects and governance</p> <ul style="list-style-type: none"> <li>• Governments should involve and consult ASGM miners in all steps of tailings management planning.</li> <li>• Formalization or regulation of the sector are key to ensure good governance of tailings management. Especially in small-scale hard-rock mining contexts, if the responsibility of tailings management is passed from one actor to another (from miner to processing plant owner) it is essential to agree on a common approach while designing tailings management solutions.</li> <li>• Allocate financial mechanisms and responsibilities to ensure the sound management of tailings along the value chain, through mine closure, restoration, and monitoring.</li> <li>• Review legal and regulatory frameworks, identify gaps and propose improvements directly related to the governance of tailings management in ASGM, such as: <ul style="list-style-type: none"> <li>○ Define the responsibility of mining permit owners to dispose of mine tailings and in an environmentally sound manner.</li> <li>○ Facilitate collaborative approaches among miners and investors to create financial mechanisms to support environmentally-sound gold recovery from ASGM tailings and effective application of regulations.</li> </ul> </li> </ul>

<p>PROVIDING INFORMATION AND ENGAGING COMMUNITIES (Chapter 7)</p>	<p>Considerations for providing information and engaging communities in tailings management:</p> <ul style="list-style-type: none"> <li>• Inform the community about the presence of mercury-contaminates tailings and the associated risk through signs, meetings, or other means of communication.</li> <li>• Engage all relevant actors and affected communities in the planning and execution of mercury-contaminated tailings management (ensuring participatory process).</li> <li>• Disseminate information about mercury pollution and mitigation programs in affected communities.</li> <li>• Design and conduct educational programs, facilitating ASGM miners' opportunities to present ideas and models for their organization to implement acceptable practices for tailings management.</li> <li>• Ensure the engagement of indigenous populations, including from territories in conflict, in the decision-making process for a sound management of tailings aiming at the protection of human health and the environment.</li> </ul>
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# 1. INTRODUCTION

## 1.1. Background

Artisanal and small-scale gold mining, commonly referred to as ASGM, is crucial to the livelihood of millions of people in over 80 countries, mainly in rural areas with limited alternative economic prospects. It is increasingly recognized as an opportunity to alleviate poverty and contribute to national, regional and local development. With the right support, the ASGM sector has the potential to transition to more responsible and cleaner production methods. Responsibly managing each processing step, including the management of tailings, can help minimize its impacts on human health and the environment.

The Global Industry Standard on Tailings Management defines tailings as “a by-product of mining, consisting of the processed rock, sediments or soil left over from the separation of the commodities of value from the rock, sediments or soil within which they occur<sup>4</sup>.” In the context of this document, tailings are the waste material left over after the valuable components have been removed from the ore. Comprised mainly of crushed and milled rock, and water, they may also contain chemical reagents, in case of ASGM often mercury and/or cyanide, used in the extraction of the mineral. Due to the informal, seasonal, and migratory nature of many ASGM operations, the final steps in the ore processing lifecycle – safe disposal of amalgamation tailings – is not often applied. The tailings are often left behind without proper stabilization or containment measures and the operations then move to more profitable locations. This poses a great risk to the environment and human health, especially if tailings contain residual mercury or other toxic materials that can leach into surface and ground water and contaminate soils. The impacts range from direct exposure to pollution from run off (other metals associated with the ore or leaching agents, such as acids, cyanide etc.) to dust emissions (exposure to silica dust etc.). Moreover, flooding of ASGM tailings ponds can greatly damage the surrounding environment and pose a risk to human health. Within ASGM communities, the unsound management of mercury contaminated tailings might result in higher exposure of vulnerable populations such as children and women of childbearing age.

ASGM miners often use mercury to separate gold from other minerals. In fact, the sector is the largest source of mercury emissions to the air globally, with annual emission of 838 tonnes, and 1,220 tonnes of mercury was estimated in 2015 to be released into water and land, twice as much as release of mercury onto water from other sectors (UNEP, 2019). Miners frequently use rudimentary methods and lack access to technology and process optimization. Adding mercury to the ore without concentrating the ore results in particularly large amounts of mercury-contaminated tailings. The process, known as whole ore amalgamation, is recognized as one of the worst practices under the Minamata Convention on Mercury. The miners often do not capture all the gold from the ore and ASGM tailings sometimes contain economically viable concentrations of gold. In contrast to large-scale operations, where tailings

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<sup>4</sup> <https://globaltailingsreview.org/about-tailings/>

are seen mainly as a final waste material, in the ASGM context, tailings can also be a resource for reprocessing. The management of mercury-contaminated tailings is of particular concern when cyanide is used to extract the remaining gold from those tailings. In the presence of cyanide, the mercury is transformed more rapidly into its oxidized form, available for the microorganisms to transform it further into methylmercury in favorable conditions (Seney et al., 2020). Methylmercury is toxic and accumulates in the aquatic biota and further in the food chain. This behavior makes cyanide leaching of mercury-contaminated materials another worst practice targeted for elimination under the Minamata Convention.

Mercury amalgamation has been in use for centuries and great amounts of abandoned tailings are frequently contaminated with mercury. If gold is to be recovered from mercury-contaminated tailings from previous operations, or for those ongoing operations still using mercury, mercury must be removed from the tailings prior to cyanide leaching. However, in most ASGM conditions, mercury is not removed due to (i) lack of technical knowledge or awareness, (ii) economic reasons, or (iii) lack of regulations or enforcement. As such, the best solution for managing mercury-contaminated tailings is to avoid generating them in the first place. That is why eliminating practices like whole ore amalgamation is critical. A first step could be to concentrate the ore before the amalgamation process. With amalgamation applied to concentrated ore, the quantity of material contaminated with mercury is reduced, which represent a great improvement in comparison to the application of whole ore amalgamation. The process should be accompanied by use of mercury vapour capturing device, e.g. retorts, to avoid exposure of miners to mercury vapours during amalgam burning.

Finally, reclamation of the tailings' impoundments (as well as other parts of the mining and processing sites) is often needed in order to restore the landscape after the mining operations cease. In large scale operations, proper tailings management, including reclamation and restoration, must be planned before any operation begins. In the ASGM context, the miners often do not proceed with a plan. As a result, operators rarely consider the final stage of tailings management due to the nature of the sector, i.e. informality, low awareness levels of the environmental and health impacts of mercury, low levels of accountability or ownership for the land and the dependency on renting processing centers to recover the minerals from their ore.

## **1.2. ASGM tailings management and the Minamata Convention**

Article 7 of the Minamata Convention requires each Party to the Convention which identifies the presence of ASGM in its territory as more than insignificant to develop and implement a National Action Plan (NAP) to reduce, and where feasible, eliminate mercury use in the ASGM sector. Each NAP must include a particular set of strategies, as described in the Annex C of the Convention.

The sound management of tailings in ASGM is necessary to fully develop and implement many of the strategies, in particular “Strategies for promoting the reduction of emissions and releases of, and exposure to, mercury in artisanal and small-scale gold mining and processing, including mercury-free methods” and “Strategies to prevent the exposure of vulnerable populations, particularly children and women of child-bearing age, especially pregnant women, to mercury used in artisanal and small-scale gold mining”. As such, countries that are developing NAPs for ASGM may wish to include measures to manage ASGM tailings linked to the above-mentioned strategies or in a standalone strategy. Key

recommendations and best practices in ASGM tailings management to be considered while designing required strategies under the NAP are mapped and presented in the Annex of this document.

### 1.3. Objective of the technical document

The Third Conference of the Parties of the Minamata Convention requested the Secretariat, in cooperation with the Global Mercury Partnership<sup>5</sup> to improve the guidance on the preparation of national action plans for ASGM<sup>6</sup> regarding management of tailings from such mining. The revised version of the NAP guidance is to be presented for consideration and possible adoption by the Conference at its fourth meeting.

The objective of the document is to provide information and practical guidance on tailings management along their lifecycle, from safe storage, through mercury and gold recovery, reprocessing, safe disposal and reclamation and monitoring, in the specific context of ASGM. Furthermore, as the document is intended to inform the development and implementation of the NAP for ASGM under the Minamata Convention on Mercury with respect to tailings management, the focus is placed on sound management of tailings contaminated with mercury.

### 1.4. Scope and definitions

Under the framework of Article 7 of the Minamata Convention on mercury use in ASGM<sup>7</sup>, this technical document focuses on the management of tailings containing mercury resulting from ongoing ASGM activities, and that could either be reprocessed or safely disposed of. Unless reprocessed under current ASGM operations, tailings from legacy sites are not within the scope of this document. The management of legacy and abandoned tailings contaminated with mercury falls under Article 12 on contaminated sites, and its related guidance adopted during the third meeting of the Conference of the Parties<sup>8</sup>. Nevertheless, some of the tools and recommendations provided here might be also applicable for the legacy and abandoned tailings.

In view of the often-poor management of tailings in ASGM and the resulting impact on the environment and human health (Figure 1A), the document is centered around the necessary elements and considerations for improved sound management of tailings in ASGM throughout the life cycle (Figure 1B.).

Specifically, the document provides: (i) general considerations for tailings management in the context of ASGM; (ii) basic best practices on mercury-contaminated tailings management and safe storage; (iii) review of available methods to recover mercury and gold from ASGM tailings; iv) considerations for the final disposal, reclamation and monitoring; (v) considerations for management and governance aspects, and (vi) considerations for providing information and engaging ASGM communities.

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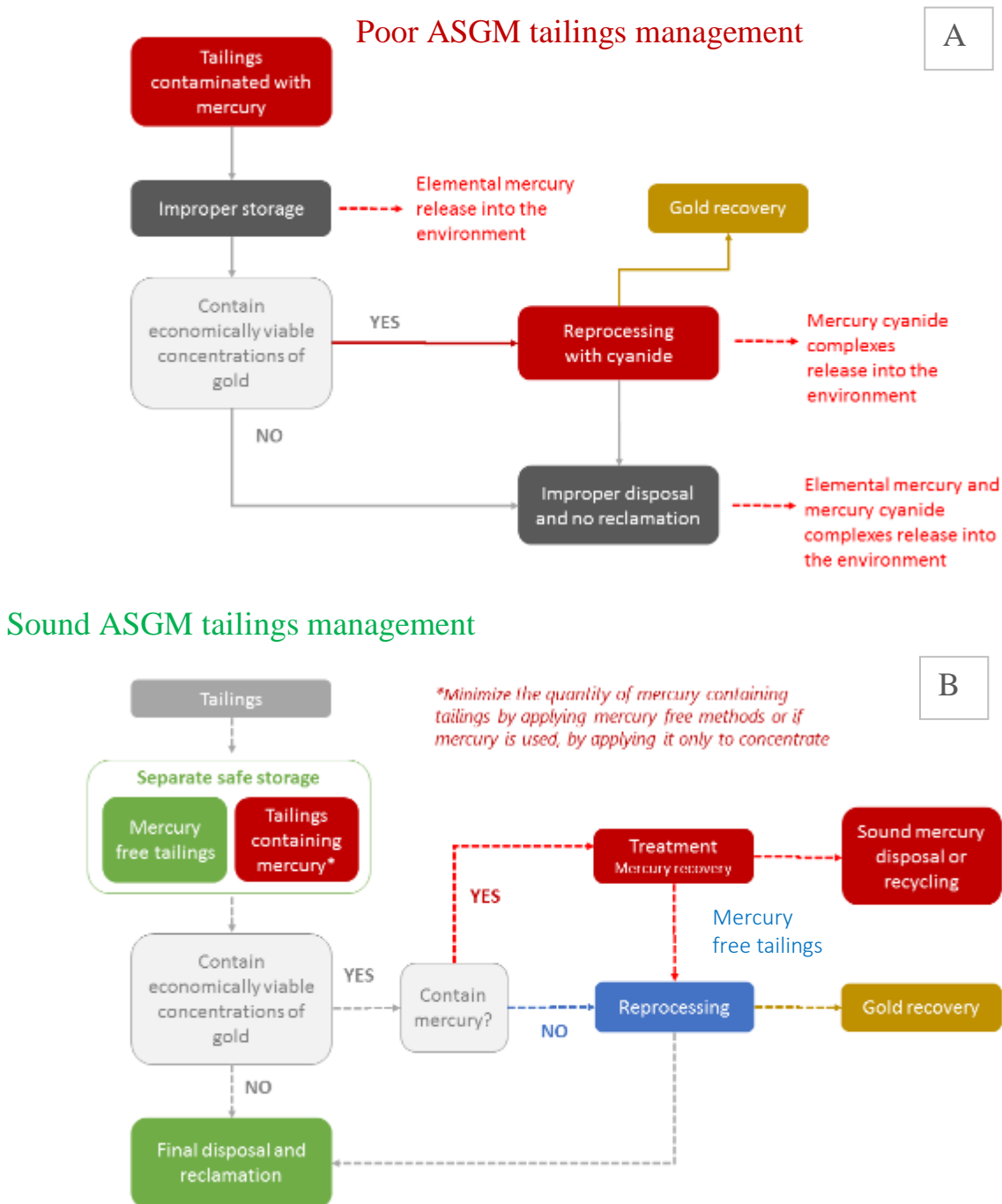
<sup>5</sup>[http://www.mercuryconvention.org/Portals/11/documents/News/ES\\_COP3\\_follow\\_up\\_decisions.pdf](http://www.mercuryconvention.org/Portals/11/documents/News/ES_COP3_follow_up_decisions.pdf)

<sup>6</sup><https://web.unep.org/globalmercurypartnership/nap-guidance-document>

<sup>7</sup> The Conference of the Parties will consider the relevance of thresholds for ASGM tailings under Article 11 of the Convention at the fourth meeting in 2021.

<sup>8</sup> [http://www.mercuryconvention.org/Portals/11/documents/forms-guidance/English/UNEP-MC-COP-3-8Rev1-Guidance\\_ContaminatedSites.English.pdf](http://www.mercuryconvention.org/Portals/11/documents/forms-guidance/English/UNEP-MC-COP-3-8Rev1-Guidance_ContaminatedSites.English.pdf)

Key elements and definitions of ASGM tailings management are featured in Figure 1 and Table 1.



**Figure 1.** Poor tailings management (A) vs sound management of ASGM tailings (B)

**Table 1.** Main definitions related to the sound management of ASGM tailings

<b>Cyanidation</b>	Hydrometallurgical technique for extracting gold from low-grade ore by converting the gold to a water-soluble coordination complex. It is the most commonly used leaching process for gold extraction (Rubo et al., 2006).
<b>Formalization</b>	Process that seeks to integrate the ASGM sector into the formal economy, society and regulatory system. It is a process that ensures that ASGM actors are licensed and organized in representative entities that represent their needs; policies are implemented, monitored, and enforced; and ASGM actors receive technical, administrative and financial support that empowers them to adhere to requirements prescribed by national regulations <sup>9</sup> .
<b>Gold recovery</b>	Processes or techniques to extract gold from the ore, sediment or other materials. This may include a combination of comminution, mineral processing, hydrometallurgical, and pyrometallurgical processes.
<b>Governance</b>	Coordination, collaboration and understanding between all actors for effective mining waste management.
<b>Mercury compounds</b>	Any substance consisting of atoms of mercury and one or more atoms of other chemical elements that can be separated into different components only by chemical reactions. <sup>10</sup>
<b>Mercury recovery</b>	Methods to remove and recover the residual mercury from the tailings that are a product of mercury amalgamation. Mercury must be removed from tailings prior to reprocessing with cyanide to avoid further mercury contamination.
<b>Mercury waste</b>	Substances or objects: (a) consisting of mercury or mercury compounds; (b) containing mercury or mercury compounds; or (c) contaminated with mercury or mercury compounds, in a quantity above the relevant thresholds defined by the Conference of the Parties, in collaboration with the relevant bodies of the Basel Convention in a harmonized manner, that are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law or Minamata Convention. <sup>11</sup>
<b>Reclamation</b>	Activities to restore or re-create the natural landscape after the mining operations cease. These might include for example habitat restoration, planting trees and vegetation.

<sup>9</sup> <https://web.unep.org/globalmercurypartnership/handbook-developing-national-asgm-formalization-strategies-within-national-action-plans>

<sup>10</sup> Definition based on Article 2 of the Minamata Convention

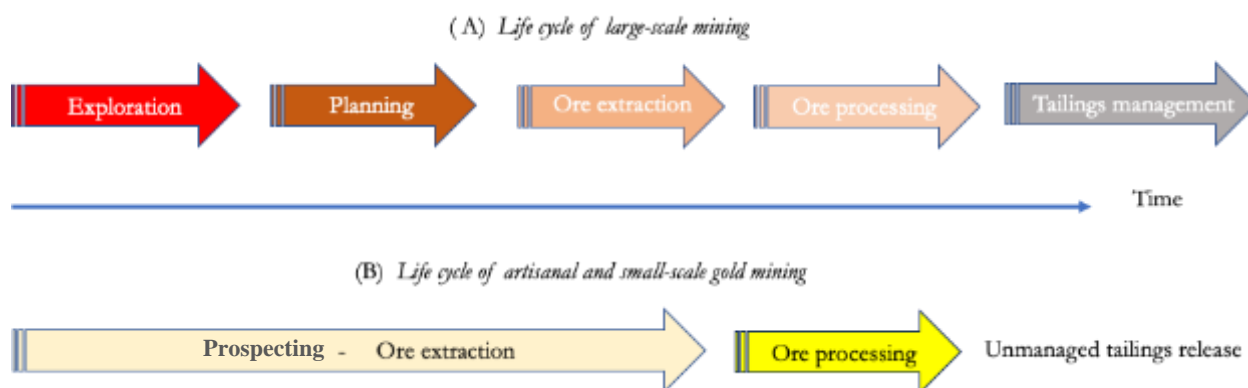
<sup>11</sup> Definition based on Article 11 of the Minamata Convention

<b>Remediation</b>	Actions, including appropriate decontamination techniques, undertaken for reducing and/or removing pollution from contaminated air, soil and water (ground and surface water) caused by mining operations, in order to protect human health and the environment against harmful effects.
<b>Safe disposal</b>	Physical measures to contain and stabilize the tailings, including for example construction of tailings ponds, neutralization of effluents, and monitoring of tailings facilities.
<b>Tailings</b>	Waste material left over after the valuable component has been removed from the ore. Comprised mainly of crushed and milled rock and water, they may also contain chemical reagents, in case of ASGM often mercury and/or cyanide, used in extracting the mineral.
<b>Tailings reprocessing</b>	Additional treatment of ASGM tailings still containing economically viable concentrations of gold and other valuable minerals with cyanide, or other leaching agents, to recover the residual gold.

## 2. CONSIDERATIONS FOR TAILING MANAGEMENT IN THE CONTEXT OF ASGM

### 2.1. Organizational level and social considerations

In contrast to large-scale mining (LSM) that is well structured through the strategic planning phase, exploration, ore extraction, processing, tailings management and closure phases, ASGM is characterized by a relatively lower level of organization, and limited technical capacity, resulting in challenges when applying appropriate tailings management solutions. The sector often misses the strategic planning phase, with a mining life cycle restricted to prospecting, ore extraction and processing, through which miners recover gold, often causing environmental contamination. Figure 2 presents the life cycle of both LSM and ASGM.



**Figure 2.** The mine life cycle of large-scale mining (A) vs life cycle of the artisanal and small-scale gold mining (B)

While LSM processes the ore in a single structured company, most ASGM operations usually involve multiple stakeholders playing different roles. For example, a concessionaire owns the mining title, the miner extracts the ore, the processing center owner facilitates ore processing, and finally other miners purchase and reprocess the produced tailings. The arrangements under which tailings are produced and sold are essential to consider for a sound management of tailings in the ASGM sector.

In terms of organization of work, the ASGM sector is varied. For example, miners might work on an individual basis, within communities or in remote areas. Others work in abandoned mines or make arrangements with the title owner in a concessional area. Finally, miners also work in small associations, in many cases under an informal social organization, with clear distribution of roles among members of the group. In terms of actors in ASGM sector, title owners might employ the miners to extract minerals under their concession. The miners who extract the ore might sell the ore to the processing center. Afterwards, the tailings might be sold to external buyers who reprocess the tailings to recover gold and other minerals.

In many regions worldwide, gold mining is performed year-round as an artisanal operation established for subsistence. However, in other areas, the ASGM miners work seasonally, for example in sub-Saharan countries, where people combine mining activity with agriculture for their subsistence (Hilson and Garforth, 2012). The information about tailings management in seasonal ASGM is limited. Generally, the miners extract the ore without any plan and control, disposing of the tailings in the surrounding environments where they practice gold recovery.

Alongside these various organizations and informality context, in many regions, ASGM miners and owners of processing centers hold short time permits, which do not allow them to make planning or investment in their small operations. For example, in Ecuador, the processing centers' owners justify the low investment in tailings management by the lack of long-term permits (Vangsnes, 2018). Moreover, many ASGM activities occur in areas previously explored or worked by medium, or large-scale mining companies.

The lack of planning, often linked to the low level of organization, poor knowledge and understanding of gold deposits as well as geological information, leads to unsound tailings management in the ASGM sector. Additionally, tailings are often perceived as waste that do not have added value, meaning that managing tailings is an extra cost that does not generate any income for miners that are already struggling to make ends meet.

## **2.2. ASGM operational models and technical considerations**

### **Alluvial ASGM**

In alluvial and colluvial gold deposits, the miners work close to riverbanks and adjacent land (Figure 3). The miners often use elementary sluice boxes in the riverbed and excavators to extract the ore. The sluice box remains the most economical technique of recovering gold in ASGM alluvial mining. The most equipped ASGM miners use hydraulic mining technology to extract the gold from surface alluvial deposits and dredging at the rivers' bed. In alluvial mining, the miners process the ore in the extraction site, and tailings are released around the riverbanks, creating severe environmental impacts (e.g., Corpus et al., 2011; Hilson and Vieira, 2007).



**Figure 3.** Different modes of work in alluvial and colluvial ASGM. A) panning in the river, Tanzania (B) single sluice box, Ghana (Hausermann et al., 2020) C) single sluice box in Ecuador D) dredge, Ecuador E) Zig Zag sluice box in Ecuador, F) Zig Zag sluice box in Guyana.

Under the operating model of alluvial ASGM, the miners usually release the tailings in open spaces around the mine operation. This operational mode poses high health and environmental risks by producing tailings contaminated with mercury if no control and containment measures are applied.

### Hard rock ASGM

In hard rock ASGM mining, extracted ore from the underground operations (Figure 4) is often transported to the processing centers containing essential equipment such as crushers and drums, to crush and mill the ore, or advanced processing centers that can include cyanidation and flotation equipment. Sometimes, processing centers might also provide amalgamation services. Alternatively, some hard rock operations feature processing on site, following extraction. Generally, the miners crush, mill and concentrate the ore to recover the gold. To process the ore, miners use different equipment, for example Jaw crusher and stamp mill in Zimbabwe, ball mills in Indonesia, Philippines and Tanzania, "cocos" and "chanchas" in Colombia, Peru and Ecuador, "quimbaletes" in Peru, and "rastras" in Honduras and Nicaragua (illustrated in Figure 5) (e.g., Murao et al., 2019, Veiga et al. 2014). The above-mentioned practices are often associated with low gold recovery due to the lack of ore characterization, including particle size, that is linked to inefficiency of the processes. Other miners grind ore manually using mortars and pestles, for example in Guinea, West Africa<sup>12</sup>. In the most developed ASGM areas, the ore processing services include cyanide leaching systems and froth flotation techniques.

<sup>12</sup> Video available: <https://iwlearn.net/media/videos/14876> - The footage presented in this video was filmed in April of 2006 by Marcello Veiga on a mission to Guinea sponsored by the Blacksmith Institute and UNIDO. It presents the methods being used in Guinea to mine for ore and concentrate gold.



**Figure 4.** In underground mining, the ASGM miners make underground shafts while looking for veins.



**Figure 5.** A) The "quimbaletes" Peru B) "Rastras" Nicaragua and Honduras C) "Cocos" Colombia; used to crush and mill the ore and proceed to amalgamation for gold recovery.

Due to the inefficiency of the techniques applied in ASGM, amalgamation tailings often contain an economically valuable amount of gold (e.g., up to 30ppm: Murao et al., 2002a) (especially fine or associated gold) that was not captured during previous steps (gravimetric method and amalgamation) and may be repossessed with cyanide or other techniques to capture the remaining gold.

Miners may leave the tailings in the processing center as a form of payment or sell the material to another individual. Sometimes, small-scale gold mining companies buy mercury-contaminated tailings to leach with cyanide (Veiga et al., 2014). The miners commonly stock the tailings until they have enough material for a cyanide leaching batch. The cyanidation is carried out by using either vat leaching, or agitated tank leaching systems. When miners sell the amalgamated tailings to other people, tracking of tailings becomes difficult. The buyers may process the tailings with cyanide, and those contaminated tailings are disposed of in the next processing center.

As illustrated in Figure 6, miners in Burkina Faso accumulate left-over material before it is being processed. (Lanzano and Arnaldi di Balme, 2021). In Ecuador, ASGM miners also reprocess tailings and wasted ores. In Latin America, this role is often performed by women who live close to mining

areas, collecting or working in low-grade abandoned small pieces of mine waste rock, using mercury to recover the gold (Velásquez-López et al., 2020).



**Figure 6.** Mercury-contaminated tailings are exposed to cyanide leaching. Burkina Faso (Left), ASGM; Ecuador (right).

Similarly, in Peru, the women miners often extract gold from the abandoned mines without proper mine waste management and limited opportunity to engage in small-scale operations (Solidaridad y Red Social, 2017). The material is processed in a processing center using mercury to recover the gold which results in generation of mercury-contaminated tailings (Lanzano and Arnaldi di Balme, 2021, Velasquez et al. 2020) The use of mercury in the process affects women (Murao et al., 2002b), especially those of childbearing age, who are the most vulnerable to mercury's adverse effects.

In both alluvial and underground mining, the miners can first characterize the ore to understand the particle size (for example by performing simple tests that determine the most suitable time for milling) and other geochemical parameters, that are essential to improve efficiency of the applied milling and concentration methods. Gravity concentration is performed to reduce the mass volume of the ore and to reduce amount of mercury use (if concentrate amalgamation is performed). Following these steps, the miners can produce mercury free tailings (if no mercury was used) or a lower amount of mercury-contaminated tailings (if the tailings are kept separated), which in turn facilitates easier handling, management and disposal of produced tailings.

## 2.3. Lessons learned from large-scale mining

UNEP, in partnership with the International Council on Mining and Metals, published a set of guidelines for the sound management of tailings in the LSM context – in the form of the *Tailings Standard*.<sup>13</sup> Although the Tailings Standard document is tailored to LSM operations, it constitutes a good starting reference, as several initial steps could be adequately replicated or adjusted for the ASGM sector. This chapter reviews the main principles addressed by the Tailings Standard document (summarized in the Table 2). Specific guidelines and recommendations for the ASGM sector are presented in the following chapters of this document.

<sup>13</sup> [https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard\\_EN.pdf](https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard_EN.pdf)

The Tailings Standard document reviews and offers recommendations as well for the non-technical topics on tailings management, such as governance, and public participation and communication. Indeed, prior to addressing technical issues related to design, operation, and tailings management, the Tailings Standard document emphasizes the following points relevant for ASGM:

- The importance of assessing the whole mining operations, engaging the entire community in each territory, and recognizing the affected communities' right to participate in tailings management's overall life cycle.
- The importance of addressing tailings management as an interdisciplinary process.
- The relevance of implementing governance in tailings management, aiming to establish policies, systems, and accountabilities for tailings' safe management and development of standardized practices in the ASGM sector.
- The value of a structured tailings management project, which starts with a planning phase and ends with the closure of operations.

Building on lessons learned from LSM, the ASGM miners should follow a process of organization, education and formalization associated with mercury elimination to manage mercury-free tailings in an organized mining structure. One of the main findings from LSM is the importance of discussing the role of the state and stakeholders in tailings management for all scales of mining.

**Table 2:** Tailings Standard Document principles for the management of tailings

<ul style="list-style-type: none"> <li>• <b>Principle 1: Develop and maintain an updated knowledge base to support tailings management across the ASGM tailings lifecycle.</b></li> <li>• <b>Principle 2: Integrate the social, economic, environmental, and technical information to select the site and the technologies to minimize the risk of disposal of mercury-contaminated tailings.</b></li> </ul>	
<b>TOPIC II: AFFECTED COMMUNITIES</b>	<ul style="list-style-type: none"> <li>• <b>Principle 3:</b> Respect the rights of project-affected people and enable their participation in decisions that affect them at all stages of the mercury-contaminated tailings lifecycle.</li> </ul>
<b>TOPIC III: DESIGN, CONSTRUCTION, OPERATION AND MONITORING OF THE TAILINGS FACILITY</b>	<ul style="list-style-type: none"> <li>• <b>Principle 4:</b> Design, construct, operate and manage the tailings holding tanks and ponds on the presumption that the consequences of failure classification are 'Extreme'.</li> <li>• <b>Principle 5:</b> Develop a robust design that integrates the knowledge base and minimizes the risk of failure for all stages of the ASGM tailings lifecycle, particularly residues containing mercury.</li> <li>• <b>Principle 6:</b> Adopt design criteria that minimize the risk of mercury in the tailings.</li> <li>• <b>Principle 7:</b> Build and operate the tailings containments to minimize risk.</li> <li>• <b>Principle 8:</b> Design, implement and operate monitoring systems in surrounded communities.</li> </ul>
<b>TOPIC IV: MANAGEMENT AND GOVERNANCE</b>	<ul style="list-style-type: none"> <li>• <b>Principle 9:</b> Elevate decision-making responsibility for mercury-contaminated tailings management with a 'Very High' or 'Extreme' Consequence Classification.</li> </ul>

	<ul style="list-style-type: none"> <li>• <b>Principle 10:</b> Establish roles, functions, accountabilities, and remuneration systems to support the integrity of the tailings produced in ASGM operations.</li> <li>• <b>Principle 11:</b> Establish and implement levels of review as part of solid quality and risk management system for all stages of the tailings lifecycle.</li> <li>• <b>Principle 12:</b> Appoint and empower miners in the tailings' management approach.</li> <li>• <b>Principle 13:</b> Develop an organizational culture that promotes learning and early problem recognition during the management of mercury-contaminated tailings.</li> <li>• <b>Principle 14:</b> Respond promptly to concerns, complaints and grievances during tailings lifecycle.</li> </ul>
<b>TOPIC V: EMERGENCY RESPONSE AND LONG-TERM RECOVERY</b>	<ul style="list-style-type: none"> <li>• <b>Principle 15:</b> Prepare for an emergency response to tailings management failures and support local-level emergency preparedness and response using best-practice methodologies.</li> <li>• <b>Principle 16:</b> Prepare for long-term recovery in the event of catastrophic failures in ponds holding mercury-contaminated tailings.</li> </ul>
<b>TOPIC VI: PUBLIC DISCLOSURE AND ACCESS TO INFORMATION</b>	<ul style="list-style-type: none"> <li>• <b>Principle 17:</b> Provide public access to information on tailings management decisions, risks and impacts, management and mitigation plans, and performance monitoring of all stages of tailings lifecycle.</li> </ul>

## Recommendations

### Overall considerations for the sound management of ASGM tailings are as follows:

- Understand the political, socio-economic and environmental context of the ASGM in your country, including for example the labor model and organizational level, power dynamics and roles of stakeholders along the value chain of tailings.
- Adjust and apply lessons learned and recommendations from large scale mining as outlined in the industry accepted– *Tailings' Standard*.
- Introduce and promote mine planning as a critical step for tailings management through the entire ASGM life cycle

## 3. BASICS OF TAILINGS MANAGEMENT

### 3.1. Amalgamation process and tailings production

ASGM miners often apply amalgamation without knowledge and understanding of the type of ore they are treating. During the amalgamation process, miners add mercury either to the whole ore (whole ore amalgamation) or to a smaller amount of previously concentrated gold (amalgamation of concentrate).

In the concentrate amalgamation scenario, the volume of mercury-containing tailings produced is low in comparison to whole ore amalgamation, where the mass of mercury-contaminated tailings is similar to the ore processed.

As concentrate amalgamation produces a lower volume of mercury-containing tailings, it is easier to manipulate the residue either in the processing center or store it in another place until further treatment or disposal. When the miners apply whole ore amalgamation, they create a large volume of mercury rich tailings, which is more difficult to manage. In the worst-case scenario, they could directly be discharged into the surrounding environment. In many ASGM areas, the common practice is the reprocessing of amalgamation tailings with cyanide, which worsens the impacts on human health and the environment due to improper storage, unsafe transportation between mining and processing sites, and chemical complexes generated through the mixing of mercury and cyanide, leading to mercury transformation and its releases in tailings solutions (Velásquez-López et al., 2011).

### 3.2. Best practices to minimize generation of mercury-containing tailings

Eliminating mercury in ASGM is a long-term process that depends on, *inter alia*, availability of technology, formalization level, capital investment and labour division. Amalgamation of concentrate is a first step to reduce the use of mercury and the generation of mercury-containing tailings since the mercury is added to a much lower mass of ore. However, miners' practices in many parts of the world still generate significant amounts of mercury contaminated tailings. For example, Lanzano and Arnaldi di Balme (2021) reported that after crushing and milling the ore, miners in Burkina Faso produce a large quantity of leftovers contaminated with mercury. Similarly, in Colombia, tailings containing mercury were documented under the Pure Earth and US Department of State project *Promoting Responsible Recovery and Handling of Mercury from Contaminated Artisanal Gold Mining Tailings in Colombia*. Table 4 summarizes the mercury levels found in the ASGM tailings all over the world.

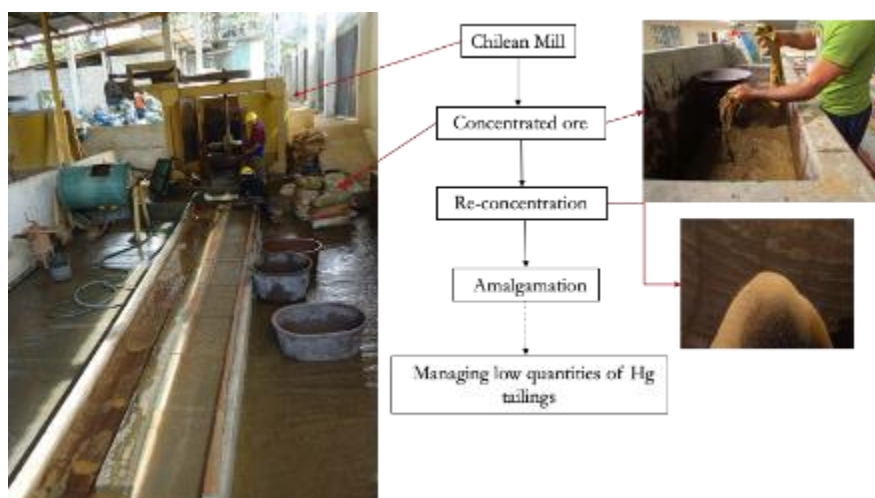
To improve the ore concentration process, several techniques are available. In hard rock mining, firstly, characterizing the ore and understanding the gold particle size present in ore, followed by tailored milling and a more efficient gravity concentration methods is necessary.

### **Crushing and concentrating the ore using chilean mills**

For example, Chilean mills allow the miners to crush the ore while concentrating it simultaneously (Velásquez-López et al., 2020). The Chilean Mill, as shown in Figure 7, allows grinding the material while collecting inside the mill the coarse gold. With this device, the miners can separate the milled ore at the end of the milling process, following the below steps:

- The miners place the concentrated ore in cement tanks close to the Chilean Mill.
- The first product is further re-concentrated by panning or centrifuges depending on the miners' skills and knowledge.
- The re-concentrated material is then amalgamated.

With this device, the miners reduce the material's mass volume that will finally be treated with mercury. The tailings passing through the sluice box contain fine unliberated gold, which usually miners cannot be recovered by gravity concentration and mercury.



**Figure 7.** Chilean mill processing center and illustrative guide showing the form by which miners obtain concentrates. The Chilean Mill, which consists of heavy iron wheels that rotate inside the mill. The ground material is released through a nylon screen. While the ground material is released through the sluice boxes, wool carpets are used to get the concentrated. The miner washes the wool carpet to get the first concentrate. A second step of concentration by hand panning results in a rich concentrate of gold.

Depending on the type of ore, the volume of concentrates obtained in the Chilean mill represents approximately 0.1 % of the total amount of ore milled in batches (Velásquez-López et al. 2010). If subjected to amalgamation, this concentrated ore produces a lower volume of amalgamation tailings.

In alluvial mining, miners use sluice boxes with centrifuges, shaking tables or any type of gravity concentrating equipment. After initial concentration, the material can be upgraded to a final concentrate by simple hand screening and sorting following panning to recover coarse gold particles. The process of panning is time-consuming but often performed in both alluvial and hard rock ASGM, notably because it is the cheapest option to concentrate the gold in ASGM.

### **Direct Smelting**

*The use of the chemical fluxes, for example borax, when the ore is sufficiently concentrated, facilitates the melting process and gold refining. In ASGM, the miners take the final concentrate to smelt directly to produce gold ingots, a common practice used by ASGM miners in gold refining. The Peruvian ASGM miners found that the concentration using sluice boxes is a critical step to reduce mercury use while minimizing the production of mercury-contaminated tailings. The miners apply the smelting process to the concentrate using a flux to facilitate the extraction of impurities. The effectiveness of the method depends directly on the efficacy of the ore's initial treatment containing gold, i.e. gravity concentration and gold liberation. Field observations in Ecuador reveal skilled ASGM miners practicing this technique. In addition, direct smelting has been suggested in alluvial mining after gold concentration (Vieira, 2006).*

Applying appropriate technologies for reducing the volume of mercury-containing tailings produced represents the first step in the sound management of tailings. The management of the low volume of mercury-containing tailings produced through concentrate amalgamation should be prioritized. If whole ore amalgamation is performed at the site, all the tailings produced should be assumed to contain mercury and appropriate storage and disposal solutions should be identified.

If concentrate amalgamation is practiced, separate storage for the mercury free tailings must be ensured. For example, clearly mark and inform all the ASGM users about the tailings ponds that are designated to receive the mercury free tailings and prepare or construct in advance the storage solution for the low amount of mercury-containing tailings (more information on storage solution are provided in chapter 5.1). This way the mixing of mercury-containing material with mercury free tailings can be avoided, and in turn generation of high volume of contaminated material that is hazardous for human health and the environment spared.

## **Recommendations**

### **Best practices to minimize generation of mercury-containing tailings**

- Avoid the generation of mercury-rich tailings by switching to mercury-free technologies. Utilizing mercury-free ore processing methods (see Section 5.5 of NAP guidance document<sup>14</sup>) will ensure that tailings do not contain added mercury. Applying sound management practices to mercury-free tailings is less challenging than with mercury-contaminated tailings.
- If amalgamation is used, avoid adding mercury to the whole ore (a worst practice) and instead concentrate gold from the ore before amalgamation. Properly applied, concentrating the ore can also increase gold recovery.
- Avoid mixing mercury-contaminated tailings with other tailings throughout the entire process, including during generation, storage, transport and reprocessing of tailings.

<sup>14</sup> <https://web.unep.org/globalmercurypartnership/nap-guidance-document>

### 3.3. Mercury content and characterization of tailings

#### 3.3.1. Mercury content in ASGM tailings

Mercury in tailings can be found in its elemental form or as salt complex. It is present in both wastewater and solid phase, highlighting a need for mercury characterization in both aquatic and solid phase of the tailings. Since tailings might be reprocessed with cyanide or undergo flotation methods, mercury might form complexes with cyanide making it more bioavailable or creating ligands with other organic compounds which also affect mercury behaviour.

Existing studies have reported mercury concentrations in ASGM tailings ranging from 0.0040 to 5000 mg/kg, depending on the type of extraction process which includes the possible mixing of mercury-contaminated tailings with other mercury free tailings. Table 3 provides a summary of available information on mercury concentration in ASGM tailings.

**Table 3.** Reported mercury concentration in ASGM tailings

Type of sample and location	Hg content in tailings	Source
Solid phase		
Tailings assessed from ASGM sites across Ghana	0.011 to 19.23 mg/kg	Basu et al., 2015
Tailings from ASGM, Tanzania	165-232mg/kg	Ministry of the Environment, Japan, 2001
Amalgamation tailings, Tanzania	1414 mg/kg	Van Straaten, 2000
Tailings, Camarines Norte, Philippines	0.22-120 ppm	Murao et al., 2019
Amalgamation tailings, Colombia	5000 mg/kg	Cordy et al., 2011
Amalgam whole ore in “rastras”, Nicaragua	10.3 mg/kg	Veiga et al., 2014
Amalgamation tailings, Indonesia	3000 mg/kg	Krisnayanti et al., 2012
Amalgamation solid tailings, Philippines	10.94 mg/kg	Samaniego et al., 2018
Cyanidation tailings, Indonesia	1600 mg/kg	Krisnayanti et al., 2012
Whole ore amalgamation, Ecuador	430 ± 90 mg/kg	Velásquez-López et al., 2010
Left over a milling process, Ecuador	380 ± 140 mg/kg	Velásquez-López et al., 2010
Gravity concentrate, Ecuador	360 ± 140 mg/kg	Velásquez-López et al., 2010
Entering cyanidation, Ecuador	166 mg/kg	Velásquez-López et al., 2011

Cyanidation tailings (solids) Merryl Crowe type, Ecuador	0.0093 mg/kg	Velásquez-López et al., 2011
Cyanidation tailings (solids) Merryl Carbon in pulp, Ecuador	0.021 mg/kg	Velásquez-López et al., 2011
Tailings' pile, Brazil	12.30 mg/kg	De Andrade Lima et al., 2008
Several samples from ASGM tailings in Nicaragua	10-40 mg/kg	Appel, 2015
Kambele, East Cameroon (CREPD 2020)	>60 mg/kg	CREPD: <a href="http://www.crepdcameroun.org">www.crepdcameroun.org</a>
Tailings, Colombia	>170 mg/Kg	Pure Earth Promoting Responsible Recovery and Handling of Mercury from Contaminated Artisanal Gold Mining Tailings in Colombia. <a href="https://www.pureearth.org/colombia-proyecto-de-recuperacion-de-mercurio-en-relaves/">https://www.pureearth.org/colombia-proyecto-de-recuperacion-de-mercurio-en-relaves/</a>
Liquid phase		
Amalgamation wastewater tailings, Philippines	0.18 mg/L	Samaniego et al, 2018
Cyanidation tailings (solution) Merryl Crowe type, Ecuador	0.0051 mg/L	Velásquez-López et al., 2011
Cyanidation tailings (solution) carbon in Pulp, Ecuador	0.0040 mg/L	Velásquez-López et al., 2011

Tailings' geochemical characteristics have tremendous implications on the degree of impacts on the ecosystem and human health. For example, sulphides, which are associated with acid mine drainage, can affect mercury mobility. An acidic condition of tailings can also affect the physical and chemical properties, such as the particles pH and morphology.

### 3.3.2. Characterization of ASGM tailings

Characterizing tailings is not a common practice among ASGM miners. The variety of techniques used for gold extraction and actors involved throughout the tailings life cycle may create diverse tailings characteristics, even in the same ASGM community. Therefore, understanding the characteristics of mercury-contaminated tailings, including sampling and chemical and mineralogical characterization, is crucial for selecting adequate tailings management strategies, such as mercury removal methods and tailings disposal.

#### Sampling

In ASGM, miners might extract the gold and release the tailings in the surrounding environments; or move mercury-contaminated tailings from one place to another. In both situations, tracking the tailings and sampling may be challenging. However, it is essential to comprehend the possible changes in tailing characteristics, total mercury content and the form in which it is present.

Challenging field conditions such as steep slopes, heavy rain or hostile relationships at ASGM sites often do not allow to follow lengthy experimental protocols. Handy apparatuses such as handheld X-ray fluorescence (XRF) analyzer and detector tubes might be used for on-site measurement. They can also assist with the decision on choosing the most representative sample for more detailed analysis.

ASGM miners can analyze the tailings obtained in their operations by applying a simple (one time) sample technique, a composite (multiple), or discrete sampling protocol and adjusting the method to a specific work scenario in the target ASGM site. Generally, a single sampling location will not accurately reflect the mercury content of tailings. A mixture of individual samples collected over a specific period of time (e.g., 24 hours for a daily processing method) represent a composite sample. The composite samples are mixed and taken to the laboratory for their corresponding analysis. The water or solution characteristics in a composite sample represent conditions in the sampled flow during that time period. The discrete sampling consists of taking one or more small volume sub-samples from a tailings' container. The number of discrete samples, like with composite samples, will depend on the variability, extent and accessibility of the tailings. Cost is also a consideration, especially if an off-site laboratory analysis is needed, as analysis of multiple samples is more expensive than analysis of a single (or several) composite sample (Pure Earth, 2021b).

Mercury levels in a tailing pile or pond are likely to vary, sometimes significantly. Mercury may settle or infiltrate in tailings materials differently and evaporate from shallow tailings areas in high temperature areas. It is important to find and note the variation in mercury levels through the sampling strategy (usually through multiple point samples or multiple composite samples) so that the appropriate actions can be taken and areas with higher contamination can be prioritized (Pure Earth, 2021b). For example, in the case of concentrated amalgamation, because the total amount of tailings produced is essentially equivalent to the concentrate material processed, a discrete sample (small volume sub-sample) can be taken from final tailings produced after amalgamation of concentrates.

The implementation of a sampling protocol in Ecuador and Colombia is presented in the box below.

***Tailings characterization in Ecuador***

*In the TransMAPE project in Ecuador, the project aimed to assess the most common processing method employed by hard-rock ASGM operations in Southern Ecuador and track different tailings produced at the site (Velásquez-López et al., 2020). The researchers, accompanied by the miners, implemented a pilot sampling before conducting the sampling procedure. The sampling protocol included the composite interval samples from the milling process and discrete sampling strategy. The composite sampling included a mix of samples taken overtime throughout several phases of the milling process. For example, for the milling process that lasted for about 24 hours, this involved taking multiple samples over that period. Discrete samples were taken in different spatial points of the surface of the holding tailings container's structure.*

***Tailings characterization in Colombia***

*In another work, Baena et al. (2020) described sampling methods developed in several ASGM mine tailings piles in Colombia. The first method consisted of taking subsamples from different points on the tailings' piles using a hand sampler up to a maximum depth of 15 cm. Then, all subsamples were mixed to obtain a final sample. The second method involved taking subsamples from the sacks where ASGM miners usually store the amalgamation tailings. All subsamples were mixed, to get a final sample.*

The methodological approaches recommended for characterization of mercury-contaminated tailings should include sampling, handling and analysis of metallurgical samples as follows:

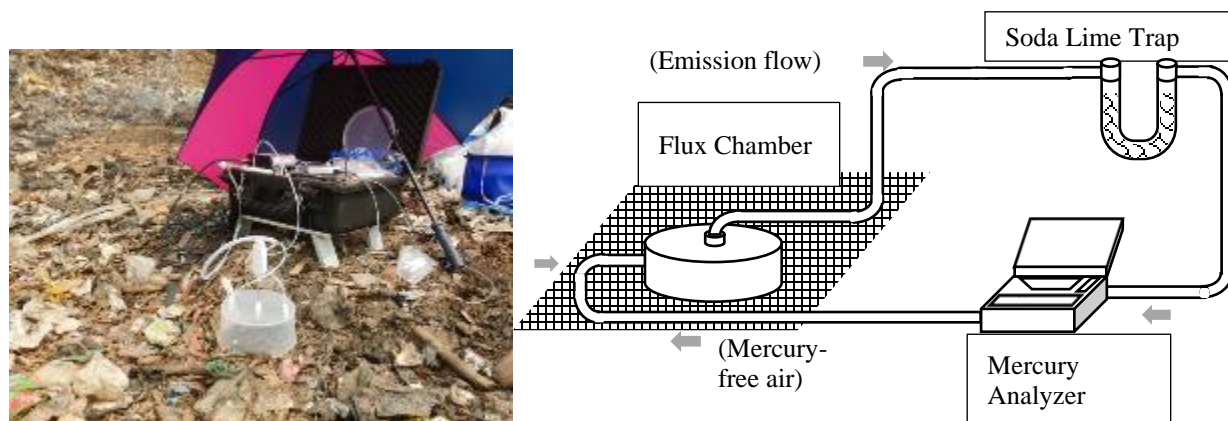
- Choose field methods for representative sampling depending on the type of ASGM operations.
- Understand in-situ physicochemical conditions, such as water/solid content of tailings, presence of other minerals (such as iron etc.).
- Implement adequate methods for labelling, storage and transportation of samples.
- Assess the need and requirements for the laboratory analysis before taking samples.
- Collect reference (control) samples.

The sampling team should design a sampling protocol that takes into account the main type of processing methods where miners use mercury. The team should develop sampling protocols in a flexible and adaptable manner to suit particular aspects of the field's operations and challenges according to site characteristics. For example, Figure 8, demonstrates a case where sampling was undertaken both at the entrance and discharge of a Chilean mill based on the specificities of the site analyzed.



**Figure 8.** Sampling the head ore at the milling process entrance in a Chilean mill (right) and sampling the slurry at the discharge of the mill (left). The team must follow the miner's procedures and adapt the sampling according to each ASGM site's operational mode.

Another possibility include measuring mercury content in soil gas that can assess the characteristics of ASGM tailing sites quickly and without excavation. Different from soil mercury sampling, which can only analyze the mercury level on the soil surface, evaporated underground mercury diffuses through the soil cavity and will be detected on the surface. Thus, by comparing the mercury levels with the background sites, the extent of the tailing disposal and its mercury contamination level can be estimated. Or, if no difference on mercury level in the soil gas between a tailing site and the surroundings is observed, we may conclude that mercury was not used for the previous mining activity. The mercury in soil gas can be analyzed by putting a flux chamber on the soil surface and sucking the air into a mercury analyzer (Figure 9). This method cannot determine the exact mercury concentration level in the tailings, but it can map out the concentration profile in the tailing site and its surroundings easily and quickly.



**Figure 9.** Picture and diagram demonstrating the mercury analyzer in soil gas.

Beyond technical considerations, the following key organizational aspects for sampling tailings in ASGM sites should be considered:

- Identify critical safety, ethical, logistical and technical aspects of sampling operations;
- Liaise with partner operations for a participatory sampling;
- Map health and safety concern for the sampling team;

The sampling protocol should address each of these steps in a participatory approach, including the miners and other local ASGM actors.

### **Chemical and mineralogical characterization**

Following the sampling the collected samples should be further analyzed for their chemical content, including mercury, other heavy metals of interests (for example lead, arsenic, zinc) and gold. Complementary to the chemical characterization, a characterization of the mineralogical composition of tailings is also important in decision making for their management.

The mercury present in tailings can be present in the three oxidation states, metallic mercury [Hg(0)], mercurous mercury [Hg(I)] and mercuric mercury [Hg(II)] forming inorganic salts, such as chlorides, nitrates, sulfates, and other organometallic compounds (Cortés Castillo, 2017). It is recommended to start with determination of total mercury at first and perform analytical determination of mercury speciation, if necessary (Pure Earth, 2021b). Methods to determine mercury speciation in solids include among others: pyrolytic and chemical extractions, extended X-ray adsorption fine structure spectroscopy or Solid-phase-Hg-thermo-desorption (UNEP, 2010).

Typically, to evaluate concentrations of gold in the tailings, the miners use simple panning techniques. It is also possible to approximate mercury content in the tailings this way, but it is not possible to quantify it through observations and panning.

The tailings can be analyzed with several techniques to identify mercury content and minerals present in the tailings. Mercury analyses could be conducted with the following direct methods using either portable equipment, or in specialized laboratories:

- The LUMEX<sup>15</sup>, or Nippon Instruments Corporation (NIC), portable spectrophotometer can be used for quick field analysis.
- In laboratories, the determination and quantification of the levels of mercury and other metals in the tailings are performed using several types of analytical equipment such as Inductively coupled plasma mass spectrometry (ICP-MS), or Atomic absorption spectrophotometry (AAS).
- High-performance liquid chromatography (HPLC) coupled with vapour generation atomic fluorescence spectrometry (VGAFS) are also applied for the determination of mercury species (Sanchez-Rodas et al., 2010).

In order to determine the gold content in tailings a fire assay test is recommended (Baena et al. 2020). This method consists of fusing the sample with the help of reagents (lead oxide) and fluxes and performing chemical analysis or gravimetric determination, depending on the final conditions of the sample. The sample must be previously prepared by pulverization and fusion occurs in a crucible by subjecting the prepared sample to direct heat (between 900 °C and 1000 °C). Although precise and gold industry accepted standard, the method might be time consuming and out of reach for most ASGM miners.

Alternatively, miners can use colorimetry method that can be also performed directly in field. To determine micro-quantities of gold in tailings, the material is treated with cyanide solution, followed

<sup>15</sup> <https://www.lumexinstruments.com/catalog/atomic-absorption-spectrometry/ra-915m.php>

by precipitation with zinc. The precipitate is dissolved, and color is developed using the stannous chloride method (Pure Earth, 2021b). The method must be performed under controlled conditions (in a secure container or vessel) to prevent release of potentially formed mercury-cyanide complexes if tailings contain mercury as well.

The mineralogical characterization of tailings is usually performed by two types of analysis: X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD). In addition, it is recommended to carry out other types of tests such as particle size distribution, release tests, determination of relative hardness, etc. (Pure Earth, 2021b).

Table 4 summarizes available techniques for the analysis and characterization of ASGM tailings.

**Table 4.** Equipment for ASGM tailings characterization and mercury analysis

Equipment	Description
<b>Gas detector tube</b>	For reconnaissance survey. Low-cost tube to detect mercury from air, soil and water around the tailings (GASTEC website). Detection range is 1-20mg/L for soil and 0.05-13.2 mg/m <sup>3</sup> for air.
<b>Handheld XRF</b>	For screening of hot spots. Minimum detection limit for handheld XRF is typically around a few ppm (OLYMPUS website).
<b>Inductively coupled plasma mass spectrometry (ICP-MS)</b>	High-cost scientific instrument used to analyze the present inorganic elements in tailings samples. This technique can determine the majority of elements recognized in the periodic table including mercury. <b>Samples:</b> solid (soil, rock and sediments) and liquid <b>Detection limit:</b> 0.001 ppb (Passariello et al., 1996).
<b>Atomic absorption spectrometry (AAS)</b>	The cold vapour atomic adsorption is the most commonly analytical technique used for the quantitative determination of total mercury in any sample matrix. <b>Samples:</b> solid (soil, rock and sediments) and liquid <b>Detection limit:</b> 2 ppb.
<b>RA 915+ LUMEX spectrophotometer</b>	A low-cost effective monitoring equipment. It is a portable equipment that operates under the characteristic of atomic desorption helping to determine total mercury in air, water, and soil. The portable spectrophotometer offers the opportunity to get results in fresh samples and real time from a specific site which in turns helps decision making for treatment and remediation. <b>Samples:</b> air, water and soil <b>Detection limit</b> for solid samples (soil, rock and sediment) 0.5 ppb (LUMEX instruments)
<b>EMP-GOLD+ NIC spectrophotometer</b>	A low-cost, field portable battery operated, effective monitoring equipment for mercury flux in soil gas to survey for mercury pollution in both surface and deeper depth ground. Measuring principle using atomic absorption spectrometry, it can also be used for monitoring mercury in ambient and

	workplace air. Couple with a simple AQUA reducing kit, capable to measuring mercury in aqueous samples at-site. <b>Samples:</b> soil gas, air and water <b>Detection limit</b> for air 0.1 ug/m <sup>3</sup> (direct); 0.3 ng/m <sup>3</sup> (gold-amalgam mode) and water samples 0.01ppb (direct); 0.0002ppb (gold-amalgam mode)
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Determining the chemical and mineralogical composition of the ASGM tailings is essential to understand the chemical changes occurring in the tailings through mineral processing. Understanding the chemical characteristic is critical as well for choosing adequate treatment (for example mercury removal), management and final disposal of tailings. Furthermore, because ASGM tailings are slurries composed of solid and liquid phase, when sampling and analyzing the tailings, it is crucial to separate the solid material and liquid solution to understand the contaminants' pathway in various media. After confirming gold and mercury content in the tailings through sampling and analysis, the miners may decide to dispose or reprocess the tailings.

## Recommendations

### Characterization of potential contaminants in the tailings and their risks

- In order to plan for treatment, disposal or reprocessing of ASGM tailings, it is necessary to first determine some of their key characteristics. These include:
  - Are they contaminated with mercury?
    - If the tailings were generated from amalgamation operations without specific tailings separation practices, they should be assumed to contain mercury, as amalgamation results in residual mercury in the tailings. Mercury flour can also sometimes be observed by inspecting tailings closely or using a hand lens.
    - If the origin of the tailings is unknown, sampling and analysis can be used to determine if they are mercury-contaminated. Field screening for mercury in tailings can also be conducted using a portable atomic absorption spectrometer or X-ray fluorescence device. Samples of tailings can be collected and sent to a lab for analysis of total mercury content as well as other constituents.
  - Other important tailings characteristics are grain size, minerology, presence of cyanide or other hazardous substances (such as arsenic), and residual gold content.

## 4. Mercury and gold recovery from tailings

Because most amalgamation tailings still contain valuable gold, the miners often proceed to recover gold from those mercury-contaminated tailings. Gold recovery from tailings can be performed using various methods, including roasting, pressure leaching, bioleaching, flotation, gravitational techniques, or heap leaching. The most common method involves the use of cyanide as a leaching agent. This is recognized as a worst practice by the Minamata Convention as it leads to generation of mercury-cyanide complexes that are highly mobile in the environment and bioavailable. Moreover, mercury present in the tailings may affect cost and efficiency of the gold recovery. This section i) presents the interactions of mercury with gold when the worst practice of cyanidation of mercury-containing tailings occurs, ii) reviews options for mercury recovery from tailings prior to gold extraction, and iii) discusses the options for best practices in cyanidation of mercury free tailings.

### 4.1. Mercury-cyanide interactions

When cyanide is applied to mercury-containing tailings (worst practice according to the Minamata Convention on Mercury) mercury and other heavy metals present in the ore can be mobilized and contaminate the surrounding environment. When mercury interacts with cyanide, it forms cyano complexes such as  $\text{Hg}(\text{CN})_2$  and  $\text{Hg}(\text{CN})_4$  which are released with the tailings. These chemical complexes are part of the weak acid dissociation (WAD) compounds formed in the cyanide leaching system. At lower pH levels, the  $\text{Hg}(\text{CN})_2$  becomes the most predominant species (Flying and Mc Gill, 1995). As a result of the combination of mercury and cyanide in the gold processing, the tailings are contaminated with mercury and the metal is dissolved in cyanide solutions. Soluble mercury is released with the tailings solutions and disposed in the tailings ponds or released to the surrounding environment.

**The process of mixing mercury and cyanide constitutes a dangerous and inefficient practice in ASGM gold recovery causing several economic and environmental problems:**

- The presence of mercury in the cyanide leaching systems increases the cyanide consumption and decreases the selectivity of gold and silver which affects the efficiency and increasing the cost of gold recovery.
- The cyanide leaching of mercury-contaminated tailings leads to the creation of dissolved mercury compounds that can be transformed more easily into its bioavailable form (Marshall et al., 2020).
- The released cyanide mercury compounds are more toxic (Seney et al., 2020), can cause a quicker spread of contamination, and accumulation in the food chain.

Other disadvantages of the presence of mercury in tailings that are reprocessed for gold recovery can be summarized as follows:

- In many ASGM sites the miners perform cyanidation extracting the gold with zinc. In these circumstances, mercury reduces the gold cementation with zinc, affecting the efficiency of gold recovery. Part of the mercury and gold is released with the tailings' solution (Velasquez-López et al., 2011).

- The presence of high concentrations of mercury retards cyanidation (Wickens, 2001). Many ASGM miners experienced this issue, causing frustration due to the system's lack of understanding, decreasing cost and effectiveness.
- The fact that cyanide forms complexes with other metals, such as mercury, partially accounts for cyanide consumption in gold extraction circuits, which generate tailings that may be difficult to treat (Miller et al., 1996).

To achieve an efficient gold recovery from tailings, it is critical to remove mercury before the cyanide leaching (for more details see chapter 4.2”).



**Figure 10.** Fresh and dry tailings after a cyanidation leaching process. Mercury droplets can be seen in the tailings.

## 4.2. Options for mercury removal from tailings, including prior to reprocessing for gold recovery

Prior to reprocessing of mercury-contaminated tailings, mercury must be first removed. The best practice to manage mercury-contaminated tailings, as previously highlighted, is to reduce the generation of mercury-containing tailings in first place through the practice of concentrate amalgamation or eliminate it altogether by using mercury-free methods. The treatment of lower volume of mercury-containing tailings is more efficient, and economically advantageous. In contrast, storing and treating large quantities of mercury-containing tailings is challenging and more expensive.

Industrial technologies to remove mercury from soils and tailings have been documented by the Office of Superfund Remediation and Technology Innovation of the US Environmental Protection Agency (US EPA, 2007), including processes such as soil washing, stabilization and thermal treatment (an overview of the industrial techniques is provided in Annex). Although these are industrial techniques, which may be expensive and are intended for the treatment of large quantities of tailings industrial mining produces, some could be adapted and applied to the ASGM context, where lower quantities of tailings are involved.

Technologies to remove mercury from the tailings need to be adapted to the nature and reality of ASGM. Due to the variable nature of ASGM tailings, there is no single procedure to recover mercury

from tailings which fits all circumstances. Instead, it is necessary to examine the most economically, technically, and socially acceptable methods for the conditions at each ASGM site. In some instances, it may not be technically and economically feasible to remove mercury from tailings, in which case the tailings need to be disposed of in an environmentally sound manner.

Practical and less expensive approaches, that have been tested in the field to remove mercury from tailings in ASGM are summarized below. Further information, including technical datasheets, on methods that recover mercury from tailings generated by ASGM, are presented in "Technical Report on Mercury Recovery from Tailings"<sup>16</sup>, part of the project "Promoting Responsible Recovery and Handling of Mercury from Contaminated Artisanal Gold Mining Tailings in Colombia," implemented by Pure Earth and financed by the U.S. Department of State (DOS). Further testing and research might be needed to adjust the proposed approaches to the local ASGM context.

### **Metal plates**

This technique involves the use of metal coated plates that captures the mercury from the tailings material. The plates can be constructed from or coated with copper, silver, tin, zinc or mixtures of those. The use of coarse material, such as sandpaper is recommended in the design of plates. Before use, the plates are entirely cleaned with nitric acid. Afterwards the plates are treated with metallic mercury forming a thin coating of amalgam. The plates can be assembled in zigzag or cascade forming several plates stacked at an inclined angle, one plate on top of the next in a continuous flow (Figure 11). The tailings with mercury are flushed down the plates, and mercury is captured by sticking to the coating. The mercury deposited on the plates can be removed by scrapping the surface. The efficiency of the mercury removal depends on speciation of mercury in the tailings which in turn can be influenced by the age of the tailings. For example, an oxidized form of mercury (HgO), more commonly present in older tailings does not firmly attach on the metallic surface forming a thin layer of mercury oxide, which must be removed by heavy shaking or adding reagents such as hydrogen peroxide to improve the efficiency of the method. Once mercury is removed, it can be mixed with cement and sulfur to "solidify it" (Figure 12). (Marcello Veiga, *personal communication*)

The technology has been piloted in countries such as Venezuela, Costa Rica and Brazil with excellent results, removing almost 95% of the mercury present in tailings (Figure 11).

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<sup>16</sup> [https://www.pureearth.org/wp-content/uploads/2021/06/TC\\_Tecnologias\\_Recuperaci%C3%B3n\\_21102019\\_English\\_Final\\_Draft.pdf](https://www.pureearth.org/wp-content/uploads/2021/06/TC_Tecnologias_Recuperaci%C3%B3n_21102019_English_Final_Draft.pdf)



**Figure 11.** Various design model of the metal coated plates to remove mercury from tailings. A) Cu-Sn-Ag-Hg plates manufactured by two Brazilian companies: Goldtech Rio-Sul, B) laboratory prototype of zigzag configured plates in Venezuela C) Cascade configured Ag-Cu plates in Venezuela. (source: Marcello Veiga)



**Figure 12.** Mercury solidification with cement and sulfur in Costa Rica. (source: Marcello Veiga)

### ***Copper plates in Colombia***<sup>17</sup>

*The pilot field tests for mercury recovery in tailings generated by ASGM were carried out within the framework of the project: “Promoting Responsible Recovery and Handling of Mercury from Contaminated Artisanal Gold Mining Tailings in Colombia”, which is executed by Pure Earth and funded by the United States Department of State (DOS), with the National Center for Cleaner Production and Environmental Technologies (CNPMLTA) as a strategic partner for technical support.*

*The general objective of the project is to reduce the amount of mercury in tailings associated with ASGM activities in Colombia. Copper plates were chosen as a pilot technique. Laboratory tests that were followed by three filed pilot tests, aimed to finetune the conditions under which copper plates were sued to enhance their effectiveness (Figure 13). The efficiency of mercury recovery on the plates ranged around 60%, based on XRF equipment. Key lessons learned are summarized below:*

<sup>17</sup> Read more about the pilot field test in Pure Earth reports, available at:  
<https://www.pureearth.org/colombia-proyecto-de-recuperacion-de-mercurio-en-relaves/>

- Using tin plates (tin-leaf) instead of copper plates, might give more stability to the silver (Ag) on the surface and thus achieve greater mercury recovery.
- The age of the tailings might have influence on the efficiency of the plates – resulting in quicker oxidation of plate when older tailings are passed<sup>18</sup>. The use of the shaking table before passing through the copper plates has shown an increase in the recovery of mercury present in the tailings. Another complementary alternative could be the use of centrifugal separators.
- To further improve the efficiency of the plates it is recommended to use cascade type of design, could increase this residence time, and therefore the effectiveness of the technique.



**Figure 13.** Improving the use of copper plates for the recovery of mercury from contaminated tailings in Colombia  
Source: Pure Earth, 2020

### Foam Flotation

This technique involves an appropriate combination of reagents to recover not only mercury, but also gold and silver through the foam flotation process. This technology involves the construction of a plant with a flotation column and the transport of tailings to the plant. The field test showed efficiency of mercury recover up to 75%, and gold and silver recover up to 90% ((Bustamante et al., 2019). Although the technology has some efficiency, the process of pre-treating the tailings is an important aspect to evaluate in the technique's implementation viability, since it can significantly increase the costs of treatment.

### Activated Carbon and Electrodeposition

This technology includes the combination of several methods tested independently that are in the adaptation and testing stage. The technology is primarily designed for the recovery of residual gold in tailings from artisanal mining and not for mercury recovery purposes. However, its adaptation to mercury recovery is extremely viable. The test system captured metal with activated carbon that takes approximately 2 hours. The de-absorption process of metals is a slow operation that takes around 36 hours. This is accompanied by an electrodeposition process that causes a precipitation of the compound of interest (Au - Hg) according to the voltage supplied in the solution. The model of the plant used for this process can be found in Figure 14. (Pure Earth, 2021a)

<sup>18</sup> One hypothesis is the high presence of oxides with other metals that are present in such tailings due to long periods of time spent outdoors before reprocessing. (Pure Earth 2021a)



Figure 14. Activated Carbon and Electrodeposition Plant

### Distillation

The method uses a vacuum distillation that has been primarily applied for the extraction of mercury from fluorescent lights. According to laboratory tests carried out by the work team that developed this technology it was possible to determine that the 1 hour of operation, at temperature between 200 and 500 ° C, recovers 80-95% mercury. The simplicity of the technique enables it to be applied to materials such as mining tailings. The advantages of thermal distillation process are that it enables the recovery of metallic mercury, and it does not require personal specialization or additional chemicals. On the other hand, the disadvantages are the high-energy cost and the lack of simultaneous Au recovery. (Pure Earth, 2021a).

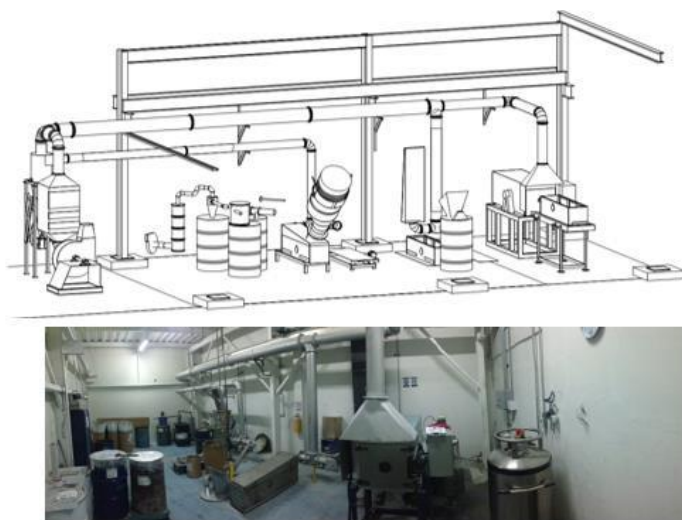


Figure 15. Design and Distillation Process of the Existing Plant (Source: Pure Earth, 2021a).

### ***Thermal treatment to recover mercury from tailings***

This method consists of heating the tailings to evaporate mercury. A demonstration project showed an average of 84% of mercury removal after thermal treatment of 24 hours and 250 C (Annicaert, 2013). The method requires pre-treatment of tailings to lower moisture content and careful

management of reactor. According to the author, the operating cost associated with thermal treatment depends strongly on the time and temperature needed to treat a given quantity of tailings. The volatility of mercury makes it possible to transfer it from the solid phase in the tailings to the gas phase by heating at a relatively low temperature compared to other metals. As mercury occurs in different species, the recovery by thermal treatment occurs at different temperatures according to the tailings' speciation. This option must be performed under controlled environment with application of necessary safeguards and secure systems to capture mercury vapor to avoid any unintentional emissions of mercury. An example of the application of thermal treatment is in-situ smart burners technology (Pure Earth, 2021a).

### **Gravimetric methods**

As mercury is relatively heavier than other minerals another possible method to recover mercury from ASGM tailings is applying gravimetric techniques. Nevertheless, there is little experimental data and information available on the efficiency of the method. As such, further investigation is required to understand the effectiveness of gravimetric techniques and application of other alternatives methods to recover mercury from tailings produced in ASGM.

#### ***Improved gravimetric concentration (Pure Earth 2021a)***

*This technology was developed in Honduras by the company Raptor Mining. Demonstration test recovered mercury from mining tailings by means of centrifugal, gravimetric and thermal processes and resulted in a recovery percentage of 97% (field test with intentional additional on mercury). Operating the system is environmentally friendly and requires basic supplies such as water and electricity. The technology can be portably mounted on a pilot scale to recovery mercury and decontaminate sites that have been closed or are designated for the purpose of responsible mining. However, the process is covered by a patent, so it can only be implemented through Raptor Mining.*

For the above-mentioned mercury removal techniques, it is crucial to understand the tailings chemical and physical characteristics before deciding on the best mercury removal techniques. The particle size, moisture content, and the presence of other organic compounds are some of the main factors that may affect the performance of the treatment. For example, mercury forms complexes with sulphur to form insoluble and steady compounds (Miller et al., 1996), and the presence of other minerals such as sulphides may influence the recovery. Similarly, the pH of the media, presence of other contaminants are the major factors that may affect the recoverable treatment in liquid or tailings solutions (US EPA, 2007).

Acknowledging that adequate removal of mercury from tailings might not be technically possible using currently available technologies, the relevant authorities may need to define the trace residual amount of mercury that may remain in the tailings, taking into account the subsequent reprocessing methods and control measures, in order to minimize adverse impacts to human health and the environment. Due to the variability of ASGM practices and physical, chemical and mineralogical conditions at mining sites, it is not possible to define a specific concentration or a threshold that fits all cases. Instead, governments may wish to follow a risk-based assessment to evaluate the situation. The risk assessment may include:

- i. **Measurements of mercury present in the tailings before and after the application of mercury removal methods:** Information on sampling and measurements of mercury content in tailings are provided in chapter 3.3. “Mercury content and characterization of tailings”.
- ii. **Evaluation of the potential for releases** of any remaining mercury in the tailings during and after reprocessing. The type of reprocessing method chosen has a major impact on the release and mobility of mercury from tailings into the environment, with cyanide leaching posing particular risks, as described in this document. Besides reprocessing methods and applied control measures, factors such as vegetation, climate, vicinity of the water streams or bodies should be considered as they might influence the fate and mobility of mercury.
- iii. **Evaluation of the potential impacts** on human health and surrounding ecosystems (for example presence of nearby vulnerable communities or critical ecosystems that would be harmed by exposure to mercury). The assessment of impacts might be quantitative, by undertaking sampling and measurements, or qualitative by documenting visible impacts.

Risk assessments should be based on the best possible knowledge and data. Nevertheless, in the context of the ASGM it might not be possible to obtain all the relevant information. Therefore, the uncertainties and knowledge gaps should be clearly highlighted while communicating the result of risk assessment<sup>19</sup> and taken into account when defining the technical and regulatory requirements for the mercury removal techniques and possible remaining trace mercury content in the tailings prior to reprocessing.

### Storage of recovered mercury

Once mercury is recovered from the tailings its safe storage must be ensured. Personal protective equipment, such as masks, respirators, and gloves must be provided while handling recovered mercury. The storage container must be airtight, the material must be non-reactive for mercury, for example carbon steel, and must have the ability to withstand the weight. A protective coating must be applied (e.g. epoxy-type paint) against exterior corrosion. Consider using small container, less than 3 liters, which are easier to transport.



**Figure 16.** Examples of the mercury containers for temporal storage. Source: UNEP, 2019.

Each container of mercury must be labeled with the proper safety instructions in line with the local regulations. The transport to the mercury waste to the storage facility must be carefully planned and follow security measures, such as use of secure vehicle, clear signs and labeling, and include emergency plans and kits in case of spillage. The storage area should be secure and have sufficient

<sup>19</sup> <https://www.epa.gov/risk/about-risk-assessment>

space for the placement, inspection, and recovery of mercury containers in an easy and accessible way. The area must be ventilated and have fire protection measures (UNEP, 2019).<sup>20</sup>

## Recommendations

### Options for mercury recovery from tailings, including prior to reprocessing for gold recovery

- Mercury-contaminated tailings should never be reprocessed for gold recovery using cyanide leaching. This can lead to severe harm to human health and the environment and hence it is considered a worst practice under the Minamata Convention.
- Wastewater should be separated from solids in tailings in order to apply the most suitable treatment to each phase.
- Prior to reprocessing of mercury-contaminated tailings, mercury must first be removed. Due to the variable nature of ASGM tailings, there is no single procedure to recover mercury from tailings which fits all circumstances. Instead, it is necessary to examine the most economically, technically, and socially acceptable method for the conditions at each ASGM site. Potential methodologies that miners can consider to remove mercury from tailings include:
  - Metal plates (e.g. copper) can remove mercury from tailings
  - Thermal treatment volatilizes elemental mercury which can then be condensed and recovered
  - Gravimetric methods that take advantage of the high density of mercury relative to other minerals in the tailings
  - Other methods that can be adapted for the ASGM setting, e.g. foam flotation, activated carbon and electrodeposition or distillation.
- Extreme care should be taken in any subsequent use of cyanide, best done by organized and trained miners that can comply with chemical management protocols.
- ASGM miners, local and national authorities should collaborate to allow for collection, storage and safe disposal of the mercury recovered.

## 4.3. Gold recovery: considerations for safe use of cyanide

Once mercury has been removed from amalgamation tailings ASGM<sup>21</sup>, miners have the option to use cyanide for gold recovery. Sound chemicals management systems, combined with environmental, health, and safety management systems that accommodate national regulations and enforcement, are preconditions for its safe and responsible use.

The principal reasons for the prominent use of cyanide in ASGM include its wide availability, and its ability to capture fine gold and silver particles. The leaching method used in the ASGM sector depends on knowledge and availability of resources at the site. As discussed in previous sections, generally,

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<sup>20</sup> Further details and case study with recommendations for the mercury waste storage in the context of Colombia are available in UNEP, 2019, *Guía para el manejo y almacenamiento de mercurio*, available at: [https://wedocs.unep.org/bitstream/handle/20.500.11822/33418/Guia\\_hg.pdf?sequence=1&isAllowed=y](https://wedocs.unep.org/bitstream/handle/20.500.11822/33418/Guia_hg.pdf?sequence=1&isAllowed=y)

the miners operate cyanidation through vat leaching or by using agitated tanks. In many ASGM regions, the vat leaching is performed in structures called percolation ponds. In others, miners use agitation tanks with zinc precipitation for gold recovery after cyanide leaching (Figures 17 and 18). The most progressive technology observed in ASGM is the Carbon in Pulp (CIP) process, similar to the Carbon in Leach (CIL) technology illustrated in Figure 19. It is essential to assess each ASM community's cyanide leaching process to understand the critical aspects in order to find the appropriate way to optimize the techniques.

Further information on safe use of cyanide in ASGM context can be found in the planetGOLD and Pact report entitled “Best Management Practices for Cyanide Use in the Small-Scale Gold Mining Sector” (Stapper et al. 2021, *in preparation*). The report provides an overview of cyanide practices used in the ASGM sector and offers high-level guidance on minimum requirements for safe and responsible use of cyanide in ASGM.



**Figure 17.** The vat leaching systems using trucks to transport tailings in Burkina Faso (Photo PACT). In these systems, the process of cyanidation lasts for about 20 to 40 days.



**Figure 18.** Merrill Crowe cyanidation process in three steps (Portovelo-Zaruma mining district Ecuador). CN agitation tank for leaching. After decantation the solution flows to the decantation tank. The solution passes through the zinc shavings which captures the leached gold. The barren solution is collected in the tailings' solution tank. The barren solution is returned to the leaching tank to continue the process of gold leaching.



**Figure 19.** Carbon in leach (CIL) cyanidation tanks varies from 25 to 60 tones of capacity. The process of gold leaching lasts for about 24 hours. Following gold leaching, the pulp flows into the carbon in pulp circuit. The carbon is collected in a rolled screen discharging the tailings in the form of pulp to the tailings pond. The CIL systems practiced in ASGM are similar to Carbon in Pulp with the difference that leaching and extraction occurs simultaneously in the CIP tank. Portovelo-Zaruma ASGM mining district Ecuador.

#### **4.4. Adapting the cyanide code to the ASGM context and optimization of the process**

The Cyanide Code is a voluntary program for gold mining companies and the organizations producing and transporting the cyanide used in gold mining. The Code focuses exclusively on the best practices and safe management of cyanide from manufacturing through transportation and during the use in the mining operation. The Code guides the secure management of cyanide in the mining operation. In LSM, the companies that adopt the Cyanide Code are audited by independent third-party professional health, safety and environmental and technical experts to guarantee compliance with the program's requirements. Those operations that meet the Cyanide Code requirements are certified and authorized to display a unique trademarked symbol signifying their certification<sup>22</sup>. The full application of the Cyanide Code reduced the incidence of environmental incidents involving cyanide in large scale mining.

The use of the cyanide code in ASGM could help reduce the adverse cyanide impacts on the environment and human health. However, due to the nature of ASGM, the interest and the cost of participation of ASGM communities to enter the program can be prohibitive. Importantly, since the cyanide code certifies miners for the safe use of cyanide, mercury must be first eliminated from the

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<sup>22</sup> [www.cyanidecode.org](http://www.cyanidecode.org).

processes of gold recovery. While mercury is in use and mercury-contaminated tailings are mixed with cyanide, the use of code will not be possible.

The effective use of the cyanide code relies, among others, on the consideration of the following social, technical and economic aspects in enabling ASGM communities to join the Cyanide Code:

- A collaborative approach among the mining community to implements code of conduct for safety cyanide handling and storage.
- Since miners pay to be part of its adherence to the Code, external economic support might be needed to help ASGM miners adhere to the code.
- Use of the cyanide code for formalized small-scale miners, and those mining associations that have eliminated mercury are the most likely scenarios. Government support to organize, educate, formalize, regulate mining communities are also important steps to implement best cyanide management and control of cyanide in the tailings through the cyanide code.

## Recommendations

### Gold recovery: considerations for safe use of cyanide

- **Never apply cyanide to mercury-contaminated tailings. This is considered a worst practice under the Minamata Convention.**
- Cyanide leaching can be used to extract residual gold from tailings produced from mercury-free operations, or where the mercury has been removed.
- The improper use of cyanide is extremely dangerous to human health and the environment, with risks of serious injury or death.
- Cyanide should only be used by organized and trained miners that can comply with chemical management protocols to ensure occupational health and safety as well as protect the environment.
- Where cyanide is a lawful alternative processing method, the NAP can consider including strategies for training ASGM miners (and other relevant stakeholders) on the sound management and use of cyanide.

## 5. DISPOSAL, ECOLOGICAL RESTORATION AND MONITORING OF MERCURY CONTAMINATED TAILINGS

### 5.1. Options for tailings disposal

To safely dispose of mercury-contaminated tailings miners can consider various on-site and off-site options. In most ASGM regions, the tailings are dumped on site in open areas, referred to as tailings ponds, changing the site's landscape and modifying its condition. The tailings ponds often receive a mix of tailings from different types of processing systems including tailings containing mercury. The on-site option might include immobilization and stabilization of the tailings ponds followed by revegetation and or remediation (see chapter 5.2 for further information). The off-site options, that require transfer of tailing material into designated and controlled location/vessel, might be considered if the volume of the mercury-containing tailings is low or the mercury content of the tailings is particularly high.



**Figure 20.** Tailings transportation in Colombia. Source : Pure Earth, 2020.

Key factors influencing the planning for mercury-contaminated tailings disposal include the quantity of tailings produced and the practices ASGM miners use to produce the tailings that in turn influence the chemical characteristics of the tailings. Often, the ASGM miners mix amalgamated tailings with mercury-free tailings increasing the volume of mercury-contaminated tailings. Therefore, as

highlighted before, it is a best practice to store separately the low volume of mercury-containing tailing. This approach allows for easier management and disposal of mercury contaminated tailings. Figure 21 below illustrates examples of storage solutions for mercury contaminated tailings at ASGM sites.



**Figure 21.** Examples of storage solutions of mercury-contaminated tailings in ASGM: A) deposition in open area, B) deposition in separated holding tanks, C) deposition in earthen tailings ponds, D) tailings accumulated in piles; E) tailings piled in sacks, F) tailings deposited in inadequate tailings ponds, G) tailings scattered in the environment. Source (D-G Pictures): Pure Earth – 2021b.

### Storage tanks

Depending on the volume of tailings produced, small containments or holding tanks can be used to temporarily store tailings. For example, if an artisanal miner processes 250 kg of ore, after concentration and addition of the mercury only to the obtained concentrate, the volume of mercury-contaminated tailings would be less than 1 kg. Ideally, the storage tanks should be made out of steel material and be stored in a secure place in the processing center over a fixed period of time (before final safe disposal of mercury contaminated waste). This requires supervision and maintenance. The storage of tailings containing mercury inside the processing center requires protection against accidental spills and disturbances to avoid adverse effects on human health and the environment. The

stored mercury-contaminated tailings should be protected from direct exposure to rain, sun, wind, flooding, and external environmental conditions. If the tailings are considered hazardous waste in a country, adequate procedures and compliance with the local regulations must be ensured.

### **Tailings ponds**

In the context of ASGM, tailings are often released to nearby environments or in the best cases disposed in small tailings ponds. As illustrated in Figure 22, tailings ponds are small containments that the miners or owners of processing centers put in place in their mine processing facility. Estimating quantity of tailings to be disposed dictates the decision on the tailings pond's size and overall strategy for tailing's storage.



**Figure 22.** Tailings ponds to collect mercury-containing tailings mixed with other type of metallurgical residues.

In many cases the containment is constructed using the tailings produced in their facilities. However, due to the nature of mercury contamination of ASGM tailings, the miners should avoid this practice. Mercury-contaminated tailings should never be used to construct barriers for tailing containment. In such cases, it is recommended to use inert material or rock to build the tailings storage ponds. The embankment is built around the whole area of the tailings pond. The tailings are disposed of inside the embankment, forming a pool in the tailings pond central part. The pond should be constructed ensuring its stability.

Figure 23 provides examples of tailings ponds that are constructed next to the riverside or sidehill or near water streams and highlights the flows of the design.



**Figure 23.** Tailings pond located next to the waterside and in a narrow terrain of an ASGM mining community (left picture). The topography of the area has some implications in selecting the site for large quantities of tailings disposal (right picture). The following problems can be anticipated: a) The walls of the tailings' storage consist of mine tailings. b) The containment wall is too close to the river with an enormous risk of contamination by liquefaction. c) There is a high risk of containment failure by an overflow of the river or a break due to high rainfall. Another important issue is the seepage and leakage through the bottom of the pond, dust emissions, and direct exposure of the nearby communities.

### Considerations for tailings disposal

Best practices and guideline for the tailings disposal in the context of large-scale mining, including design, construction and monitoring of the tailing facility, are document in various publications, including for example:

- UNEP *Global industry Standard on Tailings Management*<sup>23</sup>
- U.S. Environmental Protection Agency *Design And Evaluation Of Tailings Dams*<sup>24</sup>
- European Commission *Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries*<sup>25</sup>

The section below outlines key recommendations and considerations for the tailings disposal in the context of ASGM, based on the lessons learned from the LSM and taking into consideration limitations and characteristics of small-scale mining.

Although many miners work under an informal framework, the tailings pond design for final disposal of ASGM tailings must follow the specific characteristics of the mining operation, national guidelines and environmental regulations<sup>26</sup>. It is essential to ensure that the tailings management plan is linked to the type of treated ore, extraction process, efficiency of extracting process which influence chemical

<sup>23</sup>UNEP, 2020, available at <https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard-on-tailings-management.pdf>

<sup>24</sup> U.S. Environmental Protection Agency, 1994, available at <https://archive.epa.gov/epawaste/nonhaz/industrial/special/web/pdf/tailings.pdf>

<sup>25</sup> European Commission, 2018, available at <https://publications.jrc.ec.europa.eu/repository/handle/JRC109657>

<sup>26</sup>[https://unece.org/DAM/env/documents/2018/TEIA/UNECE\\_pilot\\_project\\_in\\_Kazakhstan/1326665\\_ECE\\_TMF\\_Publication\\_ENG.pdf](https://unece.org/DAM/env/documents/2018/TEIA/UNECE_pilot_project_in_Kazakhstan/1326665_ECE_TMF_Publication_ENG.pdf)

characteristics of tailings (see chapter 3). Such information will help decide on the embankment types. According to The Global Industry Standard on Tailings Management<sup>27</sup>, which focuses on medium and large-scale mining, the tailings facility's construction must include necessary geological studies. For the small-scale industry, it is recommended, to include evaluation of the site's geotechnical conditions (including for example assessment of site underlying geology, susceptibility to earthquake and landslide and impacts of climate on site stability) to ensure the storage facility's physical stability. Besides, it is crucial to assess the waste material's physical-chemical characteristics, underground water and surface water streams in the area, and local information about weather patterns. If possible, it is recommended as well to survey and understand the regional land planning before deciding on the construction of a tailings pond, even for small tailings ponds. Land planning and zoning for ASGM organization and tailings management, including the development of new mining areas and processing centers, may be highly beneficial. Creating exclusive zones for processing centers and tailings management would allow for safe tailings disposal and environmental management in the community. Planning the design of tailings disposal facility requires a good estimation of the mineralogical resource of the ASGM site to start the land selection, geological and geotechnical studies, provision of water and electricity for the tailing's disposal.

Because of mercury presence in the ASGM tailings, it is crucial to ensure a secure tailings pond design. It is essential to know the physical and chemical characteristics of tailings such as grain size, sulphide and cyanide presence. It is recommended to use impermeable barriers, geosynthetic, composite lining system (geomembrane-geosynthetic clay liner) or concrete tanks, to avoid leakage of harmful elements and prevent environmental damage. Tailings should be also covered with impermeable material to prevent rainwater infiltration and dust emissions. Since ASGM tailings are contaminated with mercury, the concrete barriers of the tailings ponds should be built using borrowed material. Furthermore, tailings facilities should be located away from community settlements, grazing and farming areas to avoid exposure of the vulnerable populations. The tailings structures must be clearly marked and fenced so that local people know to stay away (and keep animals away).

A secure tailings pond implies financial resources for the design and construction, and management of the tailings' ponds. Often miners or processors do not have the economic capability for designing and building a safe storage pond. Hence, a collaborative approach is recommended to secure necessary funds and buy-in from all involved parties through mining associations or other community-based approaches. In some cases, this would not be a simple solution because it needs an agreement between all ASGM miners or processing center owners. A thorough understanding of key stakeholders' roles, responsibilities and interactions within the ASGM community is essential to design and agree on the tailings storage and disposal system. It is also necessary to understand the labour model or business characteristics between miners and processing center owners regarding tailings transfers and ownership.

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<sup>27</sup> <https://globaltailingsreview.org/global-industry-standard/>



**Figure 24.** A) an artisanal tailings pond covered with liner at the base to prevent leakage. B) Tailings disposal in cement ponds.

### **Tailings transportation**

In many areas, the miners transport the tailings to dumping sites or disposal ponds away from the processing site. In other instances, the ASGM miners store the mercury-contaminated tailings temporarily. When they accumulate an adequate amount, the tailings are transported to another processing plant or for disposal (Veiga et al 2014; Lanzano and Arnaldi di Balmi 2021). The transportation of large quantities of mercury rich tailings must be avoided by eliminating generation of high quantities of mercury-containing tailings in the first place (by switching to concentrate amalgamation, and separate storage of mercury-containing tailings). Even in low quantity of tailings, this transport must be carefully performed avoiding dispersion of the material during tailings transport.

When concentrate amalgamation is performed, the quantity of mercury contaminated tailings is significantly lower. The miners could transport those tailings placing all mercury-containing material in a container with a tight-fitting lid, e.g. plastic bins with a lid (recommended for tailings with higher percentage of humidity) (Pure Earth, 2021b). Miners must be careful when transporting the tailings, even the ones without mercury. If possible, trucks with safety procedures could be arranged to avoid leakage and spills along the way. Consideration such as, proper labeling of the vehicle carrying hazardous material containing mercury, legal permits according to the local requirements and driver training so he or she is aware of danger and emergency response, should be considered while planning for tailings transportation (Pure Earth, 2021b).

### **Water management**

Water content and tailings solutions are essential elements in the ASGM tailing's management due to the potential presence of mercury and cyanide in tailings solutions and potential implications on natural streams or communities if not controlled in a sound manner. The water released during the process of amalgamation must be stored separately avoiding mixing with clean water and the release of the wastewater into the soil or streams. The presence of water in the tailings also affects transportation.

Small-scale miners might consider implementation of wastewater treatment in the processing plant to eliminate harmful elements such as mercury and cyanide from tailings solutions. This in situ treatment can be applied in the processing system before transporting the solid tailings. Small-scale miners can also consider the opportunity to implement filters pressure to remove water from the sludge. For example, in Ecuador, a small-scale mining association implemented high-pressure filters to dewater the tailings produced in a processing center, and safely disposed of solid tailings in a mountainous

area (Yaguana and Dominguez, 2009). Another option to reduce water in the tailings is to construct sedimentation ponds (Figure 25).



**Figure 25.** Concrete tailings ponds to separate solids from liquids. The system also facilitates the separation of different types of tailings. The tailings are drained into ponds to settle the solids allowing the liquid to pass through.

## Recommendations

### Considerations for design, construction, storage and disposal of final ASGM tailings

- In the processing area, install concrete walls or chemically resistant liners in the tailings containment ponds to stabilize the small volume of mercury-contaminated tailings and prevent mercury leaks.
- Promote the use of impermeable lining systems or concrete to avoid leaching into groundwater. Cover tailings structures with impermeable material to prevent rainwater infiltration.
- Ensure that inert materials are used for the construction of physical barriers for tailings storage, not the mercury-contaminated tailings themselves.
- Ensure that tailings structures are constructed well away from rivers and or other waterbodies and outside of flood plains.
- Choose a location away from community settlements, grazing and farming areas.
- Ensure tailings structures are clearly marked and fenced so that local people know to stay away (and keep animals away).
- Inclusion of tailings structures (data on location, land deed, size, type of tailings, land and contaminants) in a national database is recommended as it can help monitoring and land use planning.
- If possible, select a centralized site for disposal in collaboration with local and national authorities, who can provide the relevant environmental and geotechnical information to ensure safe and secure disposal.
- If transport of tailings is necessary, care must be taken to avoid spilling mercury-contaminated materials (e.g. using lining and covers on trucks).
- In alluvial mining, tailings are commonly generated directly adjacent to waterbodies. Special care must be taken not to dump the tailings back into streams or in flood-prone areas. Tailings should be transported to a secure area way from riverbanks for treatment and disposal.

## 5.2. Ecological restoration

ASGM practices, especially with mercury use, might have damaging impacts on the surrounding community and its environment (Tomiyasu et al., 2019a; Tomiyasu et al., 2019b; Tomiyasu et al., 2020). Improper handling, storage, and transport of mercury contaminated tailings, and unintentional mercury spills around ASGM communities often result in soil and water contamination (Espinoza et al., 2019). Moreover, ASGM operations might alter the landscape and impact the ecosystem resulting in deforestation, morphology changes (especially in the open pits or alluvial mining) and biodiversity decline.

Full restoration and remediation (if mercury or other contaminants are present) of the ASGM sites might require securing a significant technical and financial capital. The option might also require coordination with local or national governments and other affected parties. While the full restoration and remediation might be prioritised for some sites, ASGM miners can also employ simple and relatively cheap practices to restore the landscape when the mining operation ceases, including, for example: backfilling of the pits to restore the original morphology of the landscape, and revegetating the land to reduce erosion and liberating water streams. Governments can consider including simple restoration activities as a requirement for the mining permits and environmental license for ASGM miners. Nevertheless, the requirement should not be unrealistically burdensome and should reflect the local circumstances and capacity of the ASGM community.

Although ecological restoration approaches might be conducted with local leaders and decision-makers' participation, all actors, including other land users' involvement are critical in the restoration of mercury-contaminated sites. Furthermore, it is essential to apply local experience and knowledge (e.g. information about historical composition, structure and function of the mercury-contaminated tailings and ecosystem, etc.) to succeed in the remediation approach (Espinoza et al., 2019).

### ***Restoration ASGM community in Colombia***

*In 2017 the miners at Gualconda mine in Colombia fully transitioned to mercury free gold extraction. The mining association, La Fortaleza, has also launched a reclamation project to deal with the mercury contaminated tailings - legacy of four decades of mercury use at the site. The clean-up plan includes the complete remediation of the original processing site. Contaminated soil is to be removed from original tailings ponds and stored in a secure holding area. Finally, the area will be overlaid with several feet of soil, seeded with native plants and will become a destination site for visitors. ( campaign "Better without mercury" <sup>28</sup>).*

### ***Reforestation of alluvial ASGM sites in Peru***

<sup>28</sup> <https://ethicalmetalsmiths.org/better-without-mercury>

*Due to the nature of alluvial mining in Peru, miners tend to abandon the ASGM sites after they have completed the gold extraction process. These activities are degrading the Amazon basin at an unprecedented rate, with the worst damage occurring in Madre de Dios, one of the most biodiverse and pristine areas in the world.*

*Within the context of “Community-driven Artisanal and Small-Scale Gold Mining Remediation Planning in Peru” project financed by US DoS the objective of the Environmental Remediation Plan was to improve environmental quality of the soil by decreasing the concentration of mercury. The project team considered and compared a variety of onsite and offsite strategies to accomplish this objective, including immobilization, phytostabilization, phytoextraction, containment, excavation, thermal desorption and soil washing. The following measures were determined most suited to the contamination context in Ollachea region:*

- *Closure of the tailing ponds and quimbaletes in proximity to the Oscocachi River;*
- *Excavation and safe disposal of contaminated topsoil (10-30 cm) in an offsite facility;*
- *Adding a layer of waterproof gravel and drainage ditches to roads where soil excavation took place;*
- *Improvement of tailing ponds using bricks and roof repair to prevent rainwater entrance.*

*In terms of revegetation, the team selected and planted the local tree species, based on miner input and longstanding research in the area. Frequent visits were made to monitor growth and replant any seedlings that have died since the original planation. Gradually, fast-growing pioneer species will be replaced by intermediate and late successional species, developing a vital undergrowth and stratified canopy. Within about thirty years, the eco-system should be self-sufficient and can be considered on the path to complete restoration. Read more about restoration and remediation efforts undertaken in Peru in “Community-driven Artisanal and Small-Scale Gold Mining Remediation Planning in Peru” Pure Earth, US DoS, 2019, Espinoza et al., 2019).*

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In alluvial mining, the ASGM miners often discharge high volumes of mercury-contaminated tailings around river banks. In such cases, a restoration of riverine sediments and soil has to be considered. The need for an ecosystem rehabilitation plan is adequately linked to each ASGM site's requirement, demanding an understanding of the past, present and future conditions of the target site.

Potential options for restoration and remediation of the ASGM sites, in the context of tailings management, are presented below. For more details and further options please refer to the Global report “*Remediation of mercury contaminated soil, water, and air: A review of emerging materials and innovative technologies*”<sup>29</sup>.

### **Phytoremediation**

Through phytoremediation, different types of plants are used to extract and immobilize the contamination. Mercury is up taken by the root systems and incorporated into plant body. Subsequently the plants need to be treated to extract the mercury which in turn needs to be disposed of safely. For example, in Indonesia, tobacco plants were used to recover metals from ASGM tailings (Krisnayanti et al., 2016). Although the studied ASGM tailings showed 85 mg/kg of mercury content, the researchers successfully recovered gold but did not track mercury. In Colombia (r3 Environmental Technology Ltd), plants were used for in-situ reduction and removal of mercury from contaminated lands. The phytoremediation techniques were chosen due to its low cost and the feasibility to amend biological soil productivity. In Philippines, analysis of the sediment samples that were collected from tailings dams and contaminated riverbanks (Hidayati

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<sup>29</sup> <https://www.sciencedirect.com/science/article/pii/S0160412019324754?via%3Dihub>

et al., 2009) indicated that plants growing in mercury and cyanide contaminated sites accumulate the mercury and uptake cyanide. Mercury immobilization and fate of the mercury-containing plants (i.e. the need for monitoring, storage or final disposal of the contaminated material) has to be carefully assessed while considering the use of plants for ecological restoration in ASGM tailing.

### **Adsorption**

Another remediation method involves the use of adsorbents. Adsorption can be applied using local absorbents such as zeolites, nanoparticles and some chitosan derivatives. Adsorption, oxidation and reduction can occur by presence of minerals such as pyrite ( $\text{FeS}_2$ ) in some tailings. The materials used for adsorption can be also produced by irradiating fibers with an electron beam that leads to formation of large amounts of active radicals on/in fibers. The generated radicals react with the active monomers and the graft reaction proceeds on/in the fiber to produce metal ion absorbable “seats” (e.g., Hori, 2013). An effective adsorption seat for adsorbing mercury is a thiol group (Miyazaki et al., 1999). The materials with thiol groups were shown to be effective with removal of oxidized mercury ( $\text{Hg(II)}$ ) from the liquid phase (e.g. wastewaters).

### **Bioremediation**

The use of either the naturally existing or intentionally added microorganisms to transform toxic environmental pollutants like heavy metals to the non-toxic form is defined as bioremediation. These microbes (bacteria) use the toxic pollutants as an energy source in metabolic processes resulting in non or less-toxic by-products. In case of bioremediation of ASGM sites, mercury resistant bacteria are capable of actively converting inorganic  $\text{Hg}^{2+}$  into the metallic form of  $\text{Hg}^0$  which is insoluble in water (Kumari et al., 2020). Because  $\text{Hg}^{2+}$  in soil could be converted to the most toxic form methylmercury, reducing  $\text{Hg}^{2+}$  to elemental mercury  $\text{Hg}^0$  is considered to be detoxification and immobilization mechanism .

To stimulate the miners to be part of an ecological restoration program it is recommended to engage them actively from the onset in the restoration activities (define roles and responsibilities) and organize educational sessions focused on the benefits of restoration and future restored land use possibilities. An example of community involvement is provided by Espinoza et al. (2019) in the project in Madre de Dios in Peru. Many miners were involved in an integrated plan, including trainings on mercury free techniques, tailings management and land remediation. The success of the project in Peruvian ASGM relies upon three main steps: developing restoration plans; demonstration of mercury-free technologies; demonstration of remediation approaches; and involvement of government to continue restoration plans by community participation.

## **Recommendations**

### **Options for ecological restoration**

- After tailings structures and other ASGM process are no longer in use, restore the surface and revegetate the land to reduce erosion. Ideally revegetation would also restore lost habitat or productive use to the site.
- Consult with the ASGM community and apply knowledge and local experiences to succeed in the restoration approach. The most sustainable approach will be the one that best serves the needs of the local community.

- Stimulate ASGM community commitment to restoration plans by engaging them actively in the restoration activities (ideally community engagement should be already taking place during operation of the ASGM site) and organizing educational sessions focused on the benefits of restoration and future restored land use possibilities.
- While designing a restoration strategy for the specific site and tailings material, include the information obtained through site and tailings characterization, if it was conducted.
- In line with Article 12 of the Minamata Convention, Parties/countries should develop appropriate strategies for identifying and assessing sites contaminated by mercury-contaminated tailings for future risk reduction and remedial actions.

### 5.3. Monitoring and tracking of mercury-contaminated tailings

Due to health and environmental hazards, mercury-containing tailings, even if soundly managed in a designated tailings facility, and disposed of in a controlled and safe manner, must be adequately monitored to track any potential impacts on the surrounding environment and local communities.

Firstly, it is crucial to keep a record of the locations of the tailings ponds and other types of tailings storage facilities. New or previously unknown tailings can be identified using remote sensing (e.g. through analysis of the satellite and drone images). Secondly, each of the identified tailing locations should be monitored in order to track physical and chemical changes and impacts on the environment. Geospatial tools, such as GIS, can be used to support the monitoring and data management in a localized manner.

While deciding on a monitoring strategy, it is essential to apply information obtained through tailings analysis and characterization (see Chapter 3), including data on mercury and any other contaminant presence and levels in the tailings. To allow the tracking of mercury-contaminated tailings, ASGM governments might use for example remote sensing and other geospatial tools. Geographic information systems and remote sensing can help to create a geospatial database of tailings and potential mercury hotspots as the basis for defining locations or zones for restoration and monitoring of contaminated land.

Using satellite images, ASGM tailings, especially but not limited to alluvial settings, could be detected and monitored over time. For example, ASMSpotter<sup>30</sup> is a tool that automatically identifies artisanal and small-scale gold mining sites on satellite imagery based on a large training data set and machine learning algorithms, that could potentially be used as well to identify and monitor tailings progression. Other solutions, for example, Landsat, SPOT, and CBERS-2, could be also used to identify or monitor ASGM operations producing tailings on a regional scale.

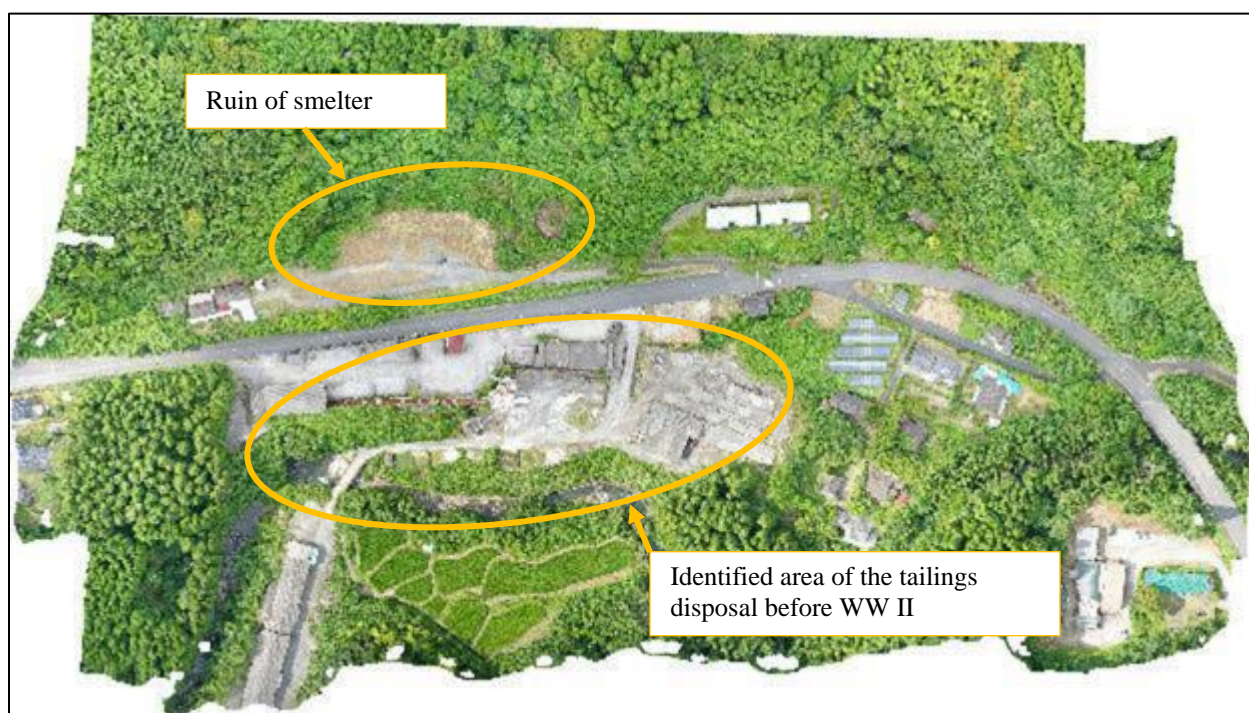
Maps of the biophysical environment help describe terrestrial and aquatic units impacted by mercury-contaminated tailings. Managing ASGM tailings requires looking at numerous sites and deal with details at multiple scales that can be shared with various users. Geographic information systems are essential for data management, working large data sets and making their interpretations in a geographic area. MapX is an online platform for managing geospatial data on natural resources,

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<sup>30</sup> <https://www.artisanalminingchallenge.com/semi-finalists/asmspotter>

developed by UNEP and GRID-Geneva. The Minamata NAP specific interface has been developed to support countries with management of geospatial data that has been obtained through NAP project<sup>31</sup>. The platform could be used for tracking the location of ASGM tailings and analysing its potential impacts on other land uses (water resources, community locations, protected area etc.). Geospatial databases of tailings locations and characteristics would be as well beneficial for providing concrete information to the affected communities. In addition, The Toxic Sites Identification Program (TSIP)<sup>32</sup> could be used to track the locations and characteristics of the ASGM tailings. The TSIP aims to locate and assess contaminated sites in low- and middle-income countries and identify those that pose the greatest threat to human health.

Drones are useful instruments for monitoring, especially it is navigated under the “Real-time kinematic (RTK)” environment. RTK positioning is a satellite navigation technique used to enhance the precision of positioning obtained (Figure 26).



**Figure 26.** A drone-sourced orthomosaic of a gold smelter ruin where ASGM workers treated their ore (Photo courtesy of Prof Ryoji Tanaka, Daiichi Institute of Technology)

Moreover, as part of the monitoring system, a periodic sampling and characterization of the tailings could be envisioned, to track of any potential physical or chemical changes to the tailings material, including level and speciation of mercury. Chapter 3.3. provides an overview of possible methods to characterize tailings material and mercury levels.

Sustainable monitoring systems are classically portrayed as the interface between environment, economic and social sustainability. In this regard, sustainable monitoring for the objective of managing

<sup>31</sup> <https://www.mapx.org/minamata-convention/>

<sup>32</sup> <https://www.contaminatedsites.org/>

mercury-contaminated tailings and ecological rehabilitation of sites will be enhanced by raising awareness about the ASGM community's environmental problems, social inclusion, and feasibility analysis of the proposed approach. Expectations and interests of different stakeholders should focus on sustainability, especially for ASGM communities' long-term subsistence.

## Recommendations

### Considerations for monitoring and tracking of mercury contaminated tailings

- While deciding on the monitoring strategy, it is essential to apply baseline information obtained through tailings analysis and characterization, including data on mercury and any other contaminant presence and levels in the tailings.
- Remote sensing methods, using satellite imagery, might be used to identify and track progress of the existing tailings, especially in the alluvial ASGM settings.
- Geospatial tools, e.g. GIS or MapX, might be used to keep track of the locations and characteristics of mercury contaminated tailings.
- Periodic sampling and characterization of the tailings could be envisioned, to track of any potential physical or chemical changes to the tailings material, including level and speciation of mercury.

## 6. LEGAL ASPECTS AND GOVERNANCE

Existing laws and institutional frameworks have a great impact on the sound management of tailings and mitigation of environmental pollution. As such, an assessment and understanding of the legal framework, along with detailed review of governance dynamics in the sector is important to for the sound management of mercury-contaminated tailings.

One of the critical elements to be considered is the level and status of formalization. Even though formalization is not within the scope of this document, it is crucial to analyze its links and impact on mercury use, and tailings management and governance. Often the ASGM sector is informal, which does not necessarily mean it is unorganized or unstructured, but that it takes place largely outside the scope of government regulations. The informal status of many mining communities makes it difficult to organize and educate miners and consequently has implications when choosing and applying strategies for the tailings management. Formalization may include reforming the legal status of ASGM as well as formulating policies, building capacity, and increasing provision of services among a variety of agencies and institutions (such as mining, education, environmental, labor, and health) that address different dimensions of ASGM, including the sound management of tailings.

In the Minamata Convention NAP context, each country must develop a strategy to formalize or regulate the sector that will enable better governance necessary for mercury reduction, its elimination, and actions to manage contaminated tailings. While designing and implementing formalization strategies under the NAP, it is recommended to review legal gaps and propose improvements to the current regulatory framework directly related to tailings management. Enforcement interventions and roles must be clearly defined to ensure the compliance with the proposed regulations. Moreover, it is crucial to designate ASGM miners' and local and national government's responsibilities for the final disposal, management and eventual reclamation of tailings and mining landscape restoration. UNEP's guide<sup>33</sup> *"Handbook: Developing National ASGM Formalization Strategies within National Action Plans"* provides targeted guidance on setting formalization strategy under the NAP project.

Tailings ownership in ASGM was identified (Lanzano and Arnaldi di Balme, 2021) as one of the main aspects that should be understood and addressed when setting sound regulatory framework for ASGM tailings management. A regulatory reform focusing on the gold processing flow chain, analyzing economic transactions for tailings trade and the environmental implications of waste management needs to be addressed to define tailings management's ownership and responsibilities among the different actors. In some countries, the regulatory framework states that all environmental management responsibility, including tailings management, is designated to the mine permit owner. For example, in Ecuador according to the law, mining concessionaires or mining title holders are responsible for their area and its environmental restoration. ASGM tailings governance reveals the importance of understanding all aspects of the ASGM labour division and responsibilities. It is thus crucial to involve all stakeholders, including mine permit owners, in any program to manage mercury-contaminated tailings, for example by including them in an educational program.

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<sup>33</sup> <https://web.unep.org/globalmercurypartnership/handbook-developing-national-asgm-formalization-strategies-within-national-action-plans>

Piloting various local tailings regulatory models may help test out different approaches that will support the creation of a regional or national regulatory framework to further guide key needs such as mercury recovery from tailings, and techniques for safe tailings disposal. The below cases, respectively in Ecuador and Guyana, describe possible approaches depending on the national context.

#### **Ecuador**

*In the transition to mercury-free ASGM in Ecuador, the Government was concerned about the contamination of a watershed and decided to put in place a treatment system for tailings produced in around 85 ASGM processing centers (Velásquez-López et al., 2019). The Government decided to construct the tailings facility for disposing of the mining waste and mitigating environmental pollution in its central mining district. Due to the nature of the processing centers, for a better communal management of tailings, the Government' decided to create a communal tailings facility for ASGM mining waste and organize the miners as appropriate (Tarras-Wahlberg 2002). The objective was established as a priority for the Ecuadorian Government, aligned to sustain miners' work. Once the Government constructed the tailings facility and implemented the tailings disposal system, several discussions about who will be responsible for managing the tailings were held, including ownership of the tailings. The issue became challenging when ASGM miners and processing centers' owners felt that they were excluded from the conversations. The provincial government became the manager of the tailing facility which created a further dispute regarding the tailings ownership between processing plant owners (who provided the tailings material) and the government (the owner of the tailings facility). The example demonstrates the importance of involving and clearly designating roles and responsibilities among all ASGM stakeholders, including government and the miners.*

#### **Guyana's Code of Practice for ASGM**

*The ASGM sector in Guyana is robust, accounting for 70% of its gold production, and it is almost entirely legalized. Extraction takes place predominantly in alluvial deposits along the river basins. It is also the primary source of employment and revenue for more than 15,000 people in Guyana's hinterland, including members of local indigenous communities.<sup>34</sup> Guyana Geology and Mines Commission is set to prepare a Code of Practice that will provide further guidance on practices involving mercury use, cyanide use and the disposal of effluents, including management of the amalgamation tailings. Standards of practice are supposed to, among others, develop criteria for site selection and design of tailings facility and disposal, promote the setting up of regional processing centers equipped with appropriate tailings containment facilities, and develop guidelines for handling and transport of amalgamation tailings from mining sites to regional processing/storage centers. A legal and regulatory review undertaken under the NAP project (in 2020) revealed the need to strengthen the proposed Code of Practice by addressing potential issue of cyanidation of tailings that contain mercury.*

The regulatory documents should provide guidelines to execute technical control of the mercury-contaminated tailings, their monitoring process and related aspects regarding the sale of gold recovered from the tailings. For example, in Colombia, the ASGM tailings are considered a hazardous

<sup>34</sup> <https://www.planetgold.org/guyana>

waste and the environmental authorities often do not allow to reprocess them due to its status (Alfonso Rodrigues, personal communication). Depending on each country's regulatory structure, the national or local government should include ASGM community members in the decision-making process. The governments should facilitate the management of tailings without being directly involved or trying to be part of the mining chain, taking advantage of ASGM miners' inefficiencies. Instead, governments should encourage ASGM miners to be more efficient and socially responsible within the ASGM chain, including in the management of tailings. The knowledge assimilation and the experiences acquired by ASGM miners will build efficiency while mitigating environmental contamination.

Complying with regulatory and legal frameworks is sometimes hindered by the lack of economic resources to undertake sound management of tailings by ASGM actors. Mine tailings are chemically complex materials, and treatment, storage, disposal, and management require a high degree of technical knowledge and responsibility (Edraki et al., 2014). Incentives for improving environmental performance are necessary. The current mechanism of ASGM management in many sites generates the transfer of responsibilities from one miner to another, which requires control. By providing access to financial mechanisms and training ASGM miners can be empowered and equipped with the necessary means and knowledge to comply with the regulations.

The sustainability and effectiveness of the planned tailings management activities requires the allocation of specific financial mechanisms and responsibilities. For example, when it comes to landscape restoration or possible remediation of the tailings, governments could consider incorporating this as a requirement under the permits or environmental licences that miners must obtain to operate in the formal economy. The requirements should be adjusted to the scale and reality of the ASGM miners, and not being unrealistically burdensome if compliance is to be achieved. Accompanying financial mechanisms, for example access to credits, local or national incentives programmes, might be considered to support the restoration activities. When it comes to monitoring and tracking of the ASGM tailings, government might consider investing in local capacity and secure necessary expertise and tools that will allow for long term monitoring and evaluation mechanisms at the national level. The financial mechanism and responsibilities should be also identified for the secure interim storage of recovered mercury, including storage costs.

## Recommendations

### Considerations for legal and governance aspects surrounding tailings management in ASGM

- Involve and consult ASGM miners in all steps of tailings management planning.
- Formalization or regulation of the sector are key to ensure good governance of tailings management. Especially in small-scale hard-rock mining contexts, where responsibility of tailings management is passed from one actor to another (from miner to processing plant owner) it is essential to agree on common approach while designing tailings management solutions.
- Ensure that financial mechanisms and responsibilities are allocated to ensure the sound management of tailings along the value chain, through mine closure, restoration, and monitoring.
- Review legal and regulatory frameworks, identify gaps and propose improvements directly related to the governance of tailings management in ASGM, such as:
  - Define the responsibility of mining permit owners to dispose of mine tailings and in an environmentally sound manner.

- Facilitate collaborative approaches among miners and investors to create financial mechanisms to support environmentally-sound gold recovery from ASGM tailings and effective application of regulations.

## 7. PROVIDING INFORMATION AND ENGAGING COMMUNITIES

ASGM communities involve title owners, mine operators, processing plant owners, and other members that participate in the mine life cycle. The community can also include landowners and people affected by backward and forward linkages along mining production and supply chains, such as populations living downstream from any mining operation (Kemp, 2010).

Since it is challenging to manage mercury-contaminated tailings as a separate step, clear communication among, and engagement of all relevant stakeholders along the entire ASGM gold processing cycle, is essential to enhance their participation and support for further steps. Most ASGM communities suffer from a lack of trust between them and authorities. Therefore, building trust is the key to effective and sustainable cooperation. The diverse interest among the stakeholders and the nature of gold as a commodity make the relationship challenging. As such, it is crucial to create collaborative conditions while working together to tailor management strategy by promoting good communication, equitable participation, and transparent support.

Providing information about tailings management in ASGM that include current and historical status of mine lands and affected areas, and the community's interests in the surrounding ecosystem, to a wide range of community members will help select approaches fully adapted to the local community's needs and interests.

Sometimes, lack of will and actions to manage ASGM tailings areas is due to limited knowledge and information among community members. The community may not be well informed about the tailings' management process, its impacts on the environmental and remediation plans. In this case, promoting community engagement and efficient communication to manage mercury-rich tailings from the beginning is essential.

While designing and implementing communication strategies on tailings management one should consider the following:

- Include local knowledge of the sector, and the community's interests in the sector and impacted ecosystems.
- Select communication approaches fully adapted to the local community's needs and concerns.
- Provide information about current ASGM practices and associated life cycle of tailings to the community members.
- Inform communities about the presence of mercury and associated risks for human health and the environment, including best practices to prevent exposure to mercury contaminated tailings.
- Discuss criteria for the selection of the sites for tailings disposal.
- Include overview of the potential benefits of restoration approaches for the environment and human health.

For example, the experience of the TransMAPE project with community engagement in Ecuador provides three operational steps: (i) orientation and exploration; (ii) raising self-awareness, and (iii) applying and experimenting. Under these three steps, miners, processing plant owners and governmental officials engaged in mutually respectful manner, increasing their awareness, reflecting on their values and beliefs, reconsidering their current process, and promoting a new way of thinking among their community.

Involving ASGM miners and community members in the decision-making process will motivate their commitment and enhance their confidence in the proposed approach to manage mercury-containing tailings. Once the trust and relationship are established, it is critical to maintain communication and accountability to strengthen and continue improving the tailings management. Building trust is difficult due to ASGM nature but not impossible when all parties have a voluntary attitude to collaborate towards finding the most suitable solution to tailings management.

The construction of a communal tailings facility in the Zaruma-Portovelo region in Ecuador, presented in the box below, provides an example of communication and community engagement for a sound management of tailings in ASGM.

*Communal tailings' facility in the Zaruma-Portovelo (Ecuador)*

*Reaching a decision to build a tailings facility was a long-term process mainly due to the lack of understanding among stakeholders. Initially, the communication was weak and lack of common knowledge led to frustration for the project's development. After several years, the communication re-started within a new process integrating community members, policymakers, and academics that allowed for a learning process to empower the local community in decision making. The essential point was to review previous information and know what the local ASGM community considers as alternatives to selecting the site for tailings disposal. The lesson learned was that ASGM tailings management is a long process that can take many years without completing the action to remediate the problem. The second lesson learned was that ASGM miners need to be part of the communicative process and engaged continuously in the whole tailing's management, including closing operations.*

Community engagement in managing ASGM tailings should be considered along entire process of tailings management, including among others:

- Selection of the location for tailings disposal.
- Attribution of roles and responsibilities distribution among title owners, mine operators, and owners of processing centers.
- Preparation for emergencies and risk management.
- Monitoring of the tailing facilities.

In some cases, when indigenous territories are involved or affected by the tailings management, it is essential to consider indigenous community sensitive areas, traditional land use and beliefs, and ensure their participation throughout the entire process of ASGM tailings management.

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*Guyana: Patamona Indigenous Miners (Vallejos et al., 2018)*

*In some regions of Guyana, ASGM activity occurs in the indigenous land where it has failed to contribute to local development. Therefore, some of the indigenous people in Amazon region decided to mine their land for economic purposes. Indigenous mining operations in Guyana are conducted with the approval of traditional leaders, meet the interests of the community, and allow for indigenous people to capture important mining benefits. While mining in Guyana is the main driver of deforestation, indigenous miners have shown willingness to practice mining in a way that has minimum impact on the environment and is safe for people. For example, the Patamona indigenous miners<sup>35</sup> have been encouraged by their leaders to find innovative ways to reduce the impact of mining (e.g., by learning from the planetGOLD programme<sup>36</sup> on responsible mining), while also increasing production and profits. In doing so, they could ensure sound management of tailings produced during predominately alluvial gold extraction process and minimize environmental and health risk, while maximizing social and economic benefits.*

## Recommendations

### Considerations for providing information and engaging communities

- Inform the public about the presence of mercury-contaminates tailings and the associated risk through signs, meetings, or other means of communication.
- Engage all relevant actors and affected communities in the planning and execution of mercury-contaminated tailings management (ensuring participatory process).
- Disseminate information about mercury pollution and restoration programs in affected communities.
- Design and conduct educational programs, facilitating ASGM miners' opportunities to present ideas and models for their organization to implement acceptable practices for tailings management.
- Ensure the engagement of indigenous populations, including from territories in conflict, in the decision-making process for a sound management of tailings aiming at the protection of human health and the environment.

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<sup>35</sup> [https://wriorg.s3.amazonaws.com/s3fs-public/Report\\_Indigenous\\_Lands\\_and\\_Mining\\_in\\_the\\_Amazon\\_web\\_1.pdf](https://wriorg.s3.amazonaws.com/s3fs-public/Report_Indigenous_Lands_and_Mining_in_the_Amazon_web_1.pdf)

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## Annex I. ASGM tailings management and NAP strategies

The table presents the key recommendations and best practices in ASGM tailings management to be considered while designing required strategies under the NAP. As demonstrated in the table, tailing management in the ASGM sector crosscuts all the required dimensions of the NAP, from environmental, technical, health, socio-economic to legal aspects. While designing the NAP, countries may choose to reflect actions towards sound management of tailings in each of the required strategies or design a standalone additional strategy for tailings management.

NAP strategy (as required by Annex C of the Minamata Convention)	Tailings management considerations/best practices
Actions to eliminate worst practices	<ul style="list-style-type: none"> <li>✓ Avoid generating large volumes of mercury-containing tailings by eliminating the worst practice of whole ore amalgamation.</li> <li>✓ To avoid worst practice of cyanide leaching of tailings with mercury, remove the mercury from the tailings prior to reprocessing with cyanide, e.g.               <ul style="list-style-type: none"> <li>○ by using metal plates coated with metal mercury amalgam,</li> <li>○ applying thermal treatment,</li> <li>○ applying gravimetric methods to separate mercury.</li> </ul> </li> <li>✓ Due to the variable nature of ASGM tailings, there is no single procedure to recover mercury from tailings which fits all circumstances. Instead, it is necessary to examine the most economically, technically, and socially acceptable method for the conditions at each ASGM site.</li> </ul>
Steps to facilitate the formalization or regulation of the artisanal and small-scale gold mining sector	<p>While designing formalization or regulation strategy ensure that the tailings management process is understood and considered, and actors involved are consulted.</p> <ul style="list-style-type: none"> <li>✓ Review legal and regulatory frameworks, identify gaps and propose improvements directly related to the governance of tailings management in ASGM</li> <li>✓ Define the responsibility of mining permit owners to dispose of mine tailings and in an environmentally sound manner.</li> <li>✓ Facilitate collaborative approaches among miners and investors to create financial mechanisms to support environmentally-sound gold recovery from ASGM tailings and effective application of regulations</li> <li>✓ Allocate financial mechanisms and responsibilities to ensure the sound management of tailings along the value chain, through mine closure, restoration, and monitoring.</li> </ul>

Baseline estimates of the quantities of mercury used and the practices employed in artisanal and small-scale gold mining and processing within its territory	<ul style="list-style-type: none"> <li>✓ Ensure that key characteristics of the ASGM tailings are being measured and collected. This information will form a basis to update plans for treatment, disposal or reprocessing of tailings.</li> <li>✓ Include key ASGM tailings characteristics in the baseline studies e.g.: <ul style="list-style-type: none"> <li>○ mercury presence and content,</li> <li>○ other parameters, such as grain size, minerology, presence of cyanide or other hazardous substances (such as arsenic), and residual gold content.</li> </ul> </li> </ul>
Strategies for promoting the reduction of emissions and releases of, and exposure to, mercury in artisanal and small-scale gold mining and processing, including mercury-free methods	<ul style="list-style-type: none"> <li>✓ Apply best practices to minimize generation of mercury-containing tailings: <ul style="list-style-type: none"> <li>○ Avoid the generation of mercury rich tailings by switching to mercury-free technologies.</li> <li>○ In the transition to mercury free techniques, apply concentrate amalgamation that produces smaller amount of contaminated material.</li> <li>○ Avoid mixing mercury-contaminated tailings with other tailings throughout the entire process, including during generation, storage, transport and reprocessing of tailings.</li> </ul> </li> <li>✓ Ensure that design, construction, storage and disposal of final ASGM tailings follow best practices, e.g. <ul style="list-style-type: none"> <li>○ Promote the use of impermeable lining systems or concrete to avoid leaching into groundwater.</li> <li>○ Cover tailings structures with impermeable material to prevent rainwater infiltration and dust emission.</li> <li>○ Choose a location away from water bodies and from community settlements, grazing and farming areas.</li> </ul> </li> </ul>
Strategies for managing trade and preventing the diversion of mercury and mercury compounds from both foreign and domestic sources to use in artisanal and small scale gold mining and processing	<ul style="list-style-type: none"> <li>✓ Ensure that ASGM miners, local and national authorities collaborate on the collection, storage and safe disposal of mercury recovered during the tailings treatment in order to avoid diversion of recovered mercury. Create incentives for disposal of recovered mercury.</li> </ul>
Strategies for involving stakeholders in the implementation and continuing development of the national action plan	<ul style="list-style-type: none"> <li>✓ Inform and engage all relevant actors (including miners) and affected communities in the planning and execution of mercury-contaminated tailings management (ensuring participatory process).</li> </ul>
A public health strategy on the exposure of artisanal and small-scale gold miners and their communities to mercury AND Strategies to prevent the exposure of vulnerable populations, particularly children and women of child-bearing	<ul style="list-style-type: none"> <li>✓ Inform the community about the presence of mercury-contaminated tailings and the associated risk through signs, meetings, or other means of communication</li> <li>✓ Ensure the engagement of vulnerable populations, including from territories in conflict, in the decision-making process for sound management of tailings aiming at the protection of human health and the environment.</li> </ul>

age, especially pregnant women, to mercury used in artisanal and small-scale gold mining	
Strategies for providing information to artisanal and small-scale gold miners and affected communities	<ul style="list-style-type: none"> <li>✓ Inform the community about the presence of mercury-contaminated tailings and the associated risk through signs, meetings, or other means of communication</li> <li>✓ Disseminate information about mercury pollution from tailings and restoration programs in the affected communities.</li> <li>✓ Design and conduct educational programs, facilitating ASGM miners' opportunities to present ideas and solutions for acceptable practices for tailings management.</li> <li>✓ Ensure the engagement of indigenous populations, in the decision-making process for a sound management of tailings aiming at the protection of human health and the environment.</li> </ul>
Additional strategies to achieve NAP objectives	<p>Options for ecological restoration (e.g. reforestation, revegetation):</p> <ul style="list-style-type: none"> <li>✓ After tailings structures and other ASGM works are no longer in use, restore the surface grading and revegetate the land to reduce erosion. Ideally revegetation would also restore lost habitat or productive use to the site.</li> <li>✓ While designing a restoration strategy for the specific site and tailings material, elaborate plans based on the information obtained through site and tailings characterization, if it was conducted.</li> <li>✓ Consult with ASGM community and apply knowledge and local experiences to succeed in the restoration approach. The most sustainable approach will be the one that best serves the needs of the local community.</li> </ul> <p>Monitoring and tracking of mercury contaminated tailings</p> <ul style="list-style-type: none"> <li>✓ While deciding on the monitoring strategy, it is essential to apply baseline information obtained through tailings analysis and characterization, including data on mercury and any other contaminant presence and levels in the tailings.</li> <li>✓ Remote sensing methods, using satellite imagery, might be used to identify and track progress of the existing tailings, especially in the alluvial ASGM settings.</li> <li>✓ Geospatial tools may be used to keep track of the locations and characteristics of mercury contaminated tailings.</li> <li>✓ Periodic sampling and characterization of the tailings could be envisioned, to track of any potential physical</li> </ul>

	<p>or chemical changes to the tailings material, including level and speciation of mercury.</p> <ul style="list-style-type: none"> <li>✓ In line with Article 12 of the Minamata Convention, Parties/countries should develop appropriate strategies for identifying and assessing sites contaminated by mercury-contaminated tailings for future risk reduction and remedial actions.</li> </ul>
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## Annex II. Overview of the industrial techniques to remove mercury from soil, water and wastewater.

- Source: US EPA, 2007, Treatment Technologies for Mercury in Soil, Waste, and Water U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation

Technology	Characteristic of the method
<b>Solid phase</b>	
<b>Stabilization</b>	Physically confines mercury within a stabilized mass and chemically reduces the tailings' hazard potential by converting the contaminants into less soluble, mobile, or toxic forms.
<b>Soil washing</b>	It uses the principle that mercury preferentially adsorbs onto the fines fraction of solid matrix. The solid tailings are suspended in a wash solution, and the fines are separated from the suspension, thereby reducing the contaminant concentrations in the remaining tailings. Acid extraction uses an extracting chemical, such as hydrochloric acid or sulfuric acid.
<b>Thermal treatment</b>	It flows into two steps of desorption and retorting. It covers an application of heat and reduced pressure to volatilize mercury from the contaminated tailings, followed by converting the mercury vapours into liquid elemental mercury by condensation. Off-gases may require further treatment through additional air pollution control devices such as carbon units.
<b>Liquid phase</b>	
<b>Precipitation</b>	The chemical additives transform dissolved contaminants into an insoluble solid or form insoluble solids onto which dissolved contaminants are adsorbed. The insoluble solids are then removed from the liquid phase by clarification or filtration.
<b>Adsorption</b>	Concentrates solutes at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The adsorption media is usually packed into a column. Mercury absorption occurs as contaminated water passes through the column. Applicable in liquids.
<b>Membrane filtration</b>	Separates mercury from water by passing the water through a semi-permeable barrier or membrane. The membrane allows some constituents to flow while it blocks others.
<b>Biological treatment</b>	Involves using microorganisms that act directly on mercury species or create ambient conditions facilitating the leaching of mercury from soil or precipitate/coprecipitate from water.