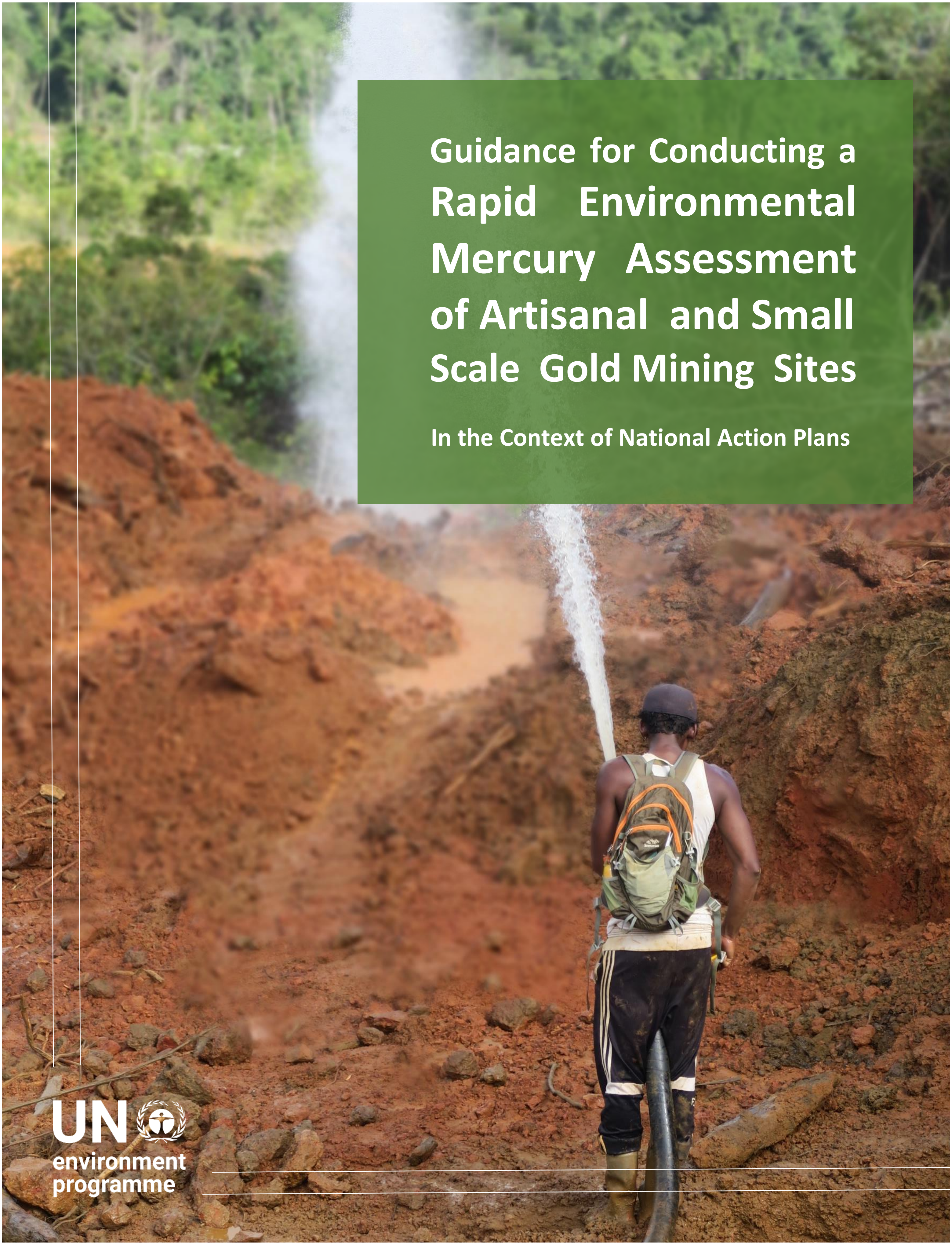
Guidance for Conducting a Rapid Environmental Mercury Assessment of Artisanal and Small Scale Gold Mining Sites

In the Context of National Action Plans



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1. Synopsis

The goal of this document is to provide guidance for stakeholders on conducting rapid assessments of mercury contamination risks to the environment and human health from artisanal and small scale gold mining (ASGM). Such assessments function to evaluate the potential risks of mercury contamination to the environment and human health and build on information gained from previously conducted baseline studies on mercury use and practices employed by ASGM.

A rapid assessment aims to evaluate these risks on a rapid timeframe and based on results from environmental mercury sampling studies that are relatively scaled down, compared to more comprehensive, longer term assessments. The motivation for providing guidance for a rapid approach is based on the need to quickly understand the extent and severity of mercury contamination risks and set priorities to manage and address those risks effectively given limited resources and capacity.

Conducting a risk assessment at any scale or timeframe is a large undertaking that requires significant planning and resources including time, financial resources, and developing partnerships to help manage mercury sample collection, analysis, and interpretation. There are many existing documents and resources that provide detailed information on how to design and conduct a sampling plan for measuring mercury contamination in the environment and dealing with ASGM-related issues and challenges. Therefore, the purpose of this document is to serve as a starting point that summarizes the approaches to conducting a mercury contamination assessment in the context of ASGMs, and references information provided elsewhere. In addition, the goal of this document is to support to countries in developing National Action Plans (NAPs), to help reduce or eliminate mercury use in fulfillment of Article 7 of the Minamata Convention on Mercury (UNEP 2017), by providing information on how assessment results may contribute to formulating a public health strategy to help prevent mercury exposures.

This guidance document provides background information on mercury in the environment and potential toxicity, mercury use in ASGM, general considerations for conducting a rapid assessment, designing and conducting a sampling plan, approaches to characterizing mercury risks based on data from the sampling plan results and other sources of information, and approaches to disseminating the knowledge gained and communicating risks to the public.

2. Introduction

2.1 Background

2.1.1 Mercury in the Environment

Mercury is a global heavy metal pollutant with known toxic health effects in humans. Mercury occurs in the environment in several different chemical forms or *species* (Morel et al. 1998), and is released into the atmosphere and water through both human-caused and natural processes. Mercury emissions to the air generally result in the deposition onto land surfaces and water bodes, including lakes, rivers, and coastal systems.

In the bottom sediments of surface waters, mercury can be converted into methylmercury, an organic chemical form which can absorbed by organisms and transferred through the food chain. Both inorganic mercury and methylmercury can *bioaccumulate* in the body of animals, or increase in concentration over time, and persist in the environment. Methylmercury can also *biomagnify* or increase in concentration as it goes through the food chain, resulting in toxic levels in animals at the top of aquatic food chains. Through these two processes, even trace amounts of mercury in the water can lead to high concentrations in high trophic level fish and mammals, including humans. (UNEP 2018a).

2.1.2 Mercury Use and Emissions from Artisanal and Small-scale Gold Mining

Mercury is used in ASGM operations in over 70 counties to capture gold particles in sediments and crushed ores. ASGM has been identified by the UNEP as a major source of anthropogenic mercury emissions to the atmosphere (UNEP 2018a), and represents the largest risk of mercury pollution to people in nearby areas. Humans and wildlife in proximity to ASGM have been found to have elevated and toxic levels of exposure to mercury (Gibb and O'Leary 2014; Basu et al. 2015; Basu et al. 2011; Pfeiffer et al. 1993). Human mercury exposure levels in ASGM regions have been associated with kidney, neurological and immunological dysfunction (Gibb and O'Leary 2014; Gardner et al. 2010). Mercury exposure may also reach elevated levels in fish and other wildlife, however the effects on wildlife populations are not well known.

The amount of mercury released from ASGM, and the fate of mercury released into different environmental components such as land or water are poorly characterized, though recent global inventories such as the UNEP Global Mercury Assessments are helping to improve understanding (UNEP 2018a). Challenges to developing accurate estimates for ASGM emissions are due to multiple technical, environmental, social and political challenges that vary among countries.

The development of effective rapid assessments for mercury in ASGM areas requires understanding why and how mercury is used in ASGM and where mercury emissions typically occur in the mining process. Mercury is used in ASGM as an aid to improve the capture efficiency of minute quantities of tiny gold particles present in gold bearing alluvial sediments or crushed ores. Mercury is introduced into the ASGM cycle during the *amalgamation* process, where liquid elemental mercury is mixed with a slurry of gold-bearing material to create an mercury-gold alloy, referred to as an *amalgam*. (UNEP 2012). The amalgam is then collected from the sediments and mixing water. The sediments and water are dumped into soils or water bodies, and the amalgam is heated to remove the mercury from the gold to create purified sponge gold. Thus, mercury used in the amalgamation process can be released into the air, water, and surrounding land.

Atmospheric mercury emissions from ASGM primarily result from the burning of gold-mercury amalgams, either in rural mining areas or in gold buying shops in urban areas. These kinds of emissions are typically in the form of elemental mercury vapor, fine aerosols (tiny droplets), or mercury attached to soot or smoke particles. After emission, most of the vapor cools rapidly and condenses into aerosols that are more likely to be deposited close to the emission source. Much of the remaining elemental mercury vapor is oxidized in the atmosphere into *gaseous oxidized mercury,* a form of mercury which is water soluble and is quickly deposited by precipitation. Particulate mercury also deposits quickly and locally by either wet deposition or dry deposition. A small fraction of atmospheric emissions vb < remains as elemental mercury vapor which can persist in the atmosphere and traveling hundreds or thousands of miles. As a result, atmospheric mercury emissions are considered both a local and a global environmental problem.

The overall goal of this document is to provide guidelines for conducting a rapid environmental assessment of mercury release, fate and transport through the environment due to ASGM activities.

The primarily audience includes countries that develop NAPs for ASGM. Specifically, this guidance aims to support countries in assessing the potential for mercury contamination and exposure as required by the Minamata Convention strategy to prevent exposure of vulnerable populations to mercury used in ASGM.

ASGM mercury emissions to water bodies are generally in the form of elemental mercury that is discarded with processed ores at the end of the amalgamation process. Most of the mercury released by ASGM to the environment occurs in this fashion. Since elemental mercury is largely insoluble in water, this waste mercury settles in the bottom sediments where it potentially can be converted by naturally occurring bacteria thru the process of *methylation* to the organic form *methylmercury*. Methylmercury is a relatively dangerous form of mercury since it more readily bioaccumulates in organisms, and biomagnifies through the food chain, increasing the risk of mercury contamination and potential toxicity.

2.1.3 Mercury Exposure Routes and Risks to Wildlife and People

Mercury can have a wide range of effects on wildlife or people. Elevated mercury exposure has been linked to numerous adverse health effects, including neuropathologies (Carta et al. 2003; Weil et al. 2005; Yokoo et al. 2003) neurodevelopmental effects (National Research Council 2000; Oken et al. 2005), and cardiovascular disease (Guallar et al. 2002; Mozaffarian and Rimm 2006; Stern 2005). Moreover, mercury has been found to have toxic health effects in wildlife, including fish and mammals (UNEP 2018a). However, the burden of disease associated with mercury exposure in wildlife from artisanal and small-scale gold mining (ASGM) are not adequately characterized.

Mercury exposure routes related to ASGM vary among mercury species and include dermal, inhalation and ingestion. Dermal exposure typically occurs as a result of human occupational exposure. For example, mine workers and gold traders touching elemental mercury without gloves can result in exposure. Elemental mercury vapor is slowly absorbed through the skin, potentially causing skin and eye irritation and contact dermatitis (Agency for Toxic Substances and Disease Registry 2014).

Inhalation of mercury vapor occurs in the form of elemental mercury and typically occurs through occupational exposure. Vapor toxicity in wildlife has been poorly studied and reference values have not been established. In humans, almost all inhaled mercury vapor is absorbed by the lungs, up to 80% (Agency for Toxic Substances and Disease Registry 2014). Children are at particular risk of elevated doses due to their higher lung surface area to body weight ratios, and lung volumes to weight ratios (Agency for Toxic Substances and Disease Registry 2014). In addition, children may be exposed to higher mercury vapor levels due to their shorter heights compared to adults, and higher levels of mercury vapor that tends to sink to the ground (Agency for Toxic Substances and Disease Registry 2014).
Ingestion of mercury from food is the primary route of exposure for methylmercury exposure for humans and wildlife and constitutes the principal risk factor for environmental mercury pollution (UNEP 2018a). Compared to other forms of mercury, methylmercury tends to persist longer in the body, allowing it to bioaccumulate in tissue and biomagnify with every link in the food chain. Therefore, long-lived predators that are high in the food chain tend to have the highest methylmercury concentrations, or body burdens. In aquatic food chains, fish at higher trophic levels have higher mercury concentrations. Therefore, wildlife and humans who consume fish are at particularly high risk for mercury exposure.

Thus, most people are exposed to mercury through diet, primarily from methylmercury exposure through fish consumption (UNEP 2018a). Children and unborn fetuses who are exposed in the womb are at high risk for mercury exposure and neurodevelopmental effects,

(National Research Council 2000; Oken et al. 2005). Therefore, in addition to adults who frequently consume fish, children and women of child-bearing age are at particularly high risk of mercury exposure and toxicity.

As mercury use from ASGM may result in release and transport to multiple environmental compartments and media (air, drinking water, food items) that may serve as potential sources of exposure, rapid assessments of mercury levels in the environment can help to identify and compare potential exposure sources to humans and wildlife.

2.2 Goals and Scope of this Guidance Document

2.2.1 Goals

These guidelines are designed for users to rapidly assess mercury levels in specific environmental components (e.g., soil, water, biota) that indicate human or wildlife health risks. These guidelines are designed to minimize the costs and time to conduct such assessments, and to be broadly applicable and useful across NAP projects globally. For example, the guidelines identify 1) specific sample media (e.g., soil, sediment, air, water, fish) that are candidates for indicators/sentinels of mercury contamination and 2) media-specific threshold mercury concentrations that indicate risk to human health and the environment.

The rapid assessment approach described here relies on analyzing mercury concentrations from samples collected from the environment. In countries where capacity for mercury analysis of environmental samples is limited or entirely lacking, a simplified, qualitative assessment that does not include sampling and analytical measurements can be conducted as an alternative. Estimating risks based on such simplified assessments can be more challenging and may be less precise compared to those based on a rapid, analytical assessment. However, this document also points out general approaches that may be taken to identify potential exposure pathways, and mitigate potential risks based on simplified assessments.

The rapid assessment sampling plans developed from these guidelines will likely vary across countries with NAPs, depending on specific needs. Ideally, a sampling plan will allow users to quantify baseline levels of mercury contamination in order to rapidly assess risk, and potentially use such baseline information to detect future changes in environmental mercury levels and risks. Larger, or more complex sampling plans may also describe approaches to examine long term trends in mercury contamination over time, or across multiple sites, develop priorities for mercury contamination and exposure management, and develop long term strategies to reduce human mercury exposure.

This document includes protocols and related guidance on sample collection, data analysis and interpretation of environmental mercury data for use in NAP related inventory and monitoring activities in implementing Articles of the Minamata Convention. This document also includes information on how to assess potential exposure pathways and risks based on the assessment data, considerations for how to interpret those risks based on potential uncertainties, and general recommendations for how to mitigate potential exposure risks, including how to inform and educate those potentially at risk of elevated mercury exposure.

This document will enable users to:

- ✓ Identify potential pathways of human exposure to mercury
- ✓ Evaluate the need for environmental sampling of ASGM sites
- ✓ Develop a mercury sampling plan to rapidly assess mercury levels in the environment, where appropriate
- ✓ Support the formulation of the strategies to prevent exposure of vulnerable populations, as required by the Minamata Convention NAP

2.2.2 Scope

The scope of this document focuses on describing approaches to rapidly assess human mercury exposure risks from ASGM through multiple potential exposure routes. However, this document does not consider the potential risks of mercury exposure to wildlife, or to the health or functioning of ecosystems. This document also does not consider the possible health risks from other factors associated with ASGM. Such additional factors, including environmental degradation, human exposure to other hazardous substances such as dust, cyanide, other heavy metals, or additional physical or occupational risks. This document was developed under the assumption that users have no prior knowledge of mercury fate and transport in the environment, or mercury toxicity. Therefore, a brief summary of such information is provided as background information. Users are also encouraged to review the additional sources of information provided. A more comprehensive description and guidance on managing these additional factors are provided in other sources (WHO and UNEP 2008). Additional sources of information on developing a NAP, mercury inventory assessment, and identifying specific populations at risk of mercury exposure from ASGM are provided below.

2.3 Additional Sources of Information

1. WHO/UNEP, 2008. Guidance for Identifying Populations at Risk for Mercury Exposure.
2. UNEP Mercury Inventory Toolkit.
3. UNEP, 2017. Guidance Document: Developing a National Action Plan to Reduce, and Where Feasible, Eliminate Mercury Use in Artisanal and Small Scale Gold Mining.
4. WHO/UNEP, 2018. Addressing health aspects in the context of developing national action plans under the Minamata Convention on Mercury.
5. O'Neill and Telmer, 2017. Estimating Mercury Use and Documenting Practices in Artisanal and Small-Scale Gold Mining (ASGM).
6. USEPA, 1992. Guidelines for Exposure Assessment.
7. Veiga and Baker, 2004. Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners.

3. General Considerations for Planning a Rapid Assessment

3.1 Rapid Assessment Approach

A rapid assessment is a limited-scope, field-based evaluation methodology meant to characterize mercury concentrations in a defined location with the goal of developing initial knowledge of mercury sources and exposure risks. As a limited-scope methodology, a rapid assessment is usually conducted during a single, or limited number of site visits, with a limited number of samples collected during a short time period. Ideally, a rapid assessment should provide initial information on the variability or range of mercury concentrations and exposures in the location of interest, and characterize the highest potential mercury levels. Assessment design should include details on sample collection procedures, data analysis methods, and plans for data interpretation and dissemination of results.

A well-designed sampling plan is crucial in obtaining meaningful data and information necessary to mitigate mercury exposure. There are several steps in developing a rapid assessment plan in order to help ensure that it can be executed within cost and time constraints. These include:

STEP 1 Information gathering on potential mercury contamination

STEP 2 Identifying specific goals and priorities

STEP 3 Identifying resources including partnerships and available budget

STEP 4 Designing a sampling plan for sample collection, data analysis, data interpretation, and dissemination of results that fits the budget and resources.

The rapid assessment sampling plan includes the following steps:

STEP 5 Sample collection

STEP 6 Data analysis

STEP 7 Data interpretation, including assessing potential exposure pathways and risks

STEP 8 Dissemination of results and information.

What can I do when analytical capacity is not available?

Some of the steps in the sampling plan take a quantitative approach to the assessment, by focusing on obtaining and analyzing data on mercury content in environmental samples. In cases where analytical capacity (i.e., the capacity to analyze environmental samples for mercury content) is unavailable, **a qualitative approach to the rapid assessment can be taken**. This qualitative approach focuses on examining how and where mercury is being used in ASGM activities in order to identify the most likely routes of exposure, and regions or populations who are most likely to be exposed. **Steps 1 through 3, 7 and 8 listed above can all be used to conduct a qualitative assessment** and include a greater reliance on information gathering, for example through interviews, focused group discussions, and observations.

3.2 Information Gathering and Potential Challenges of Rapid Assessment

There are a number of potential challenges associated with successfully conducting a rapid assessment of mercury contamination from ASGM activities. These challenges include obtaining reliable information on the location, safety and access to potential sites for assessment, the extent and type of mercury use at individual sites, and other site-related information. Other challenges include lack of, or building the capacity to collect and analyze environmental samples for mercury contamination. Gathering information is the first step toward addressing these challenges and involves a number of considerations described below.

3.2.1 Obtaining Site Information

One of the major goals in conducting a rapid mercury assessment is identifying potential mercury contamination sites as well as control sites that have no mercury contamination but are otherwise similar to contamination sites. Candidates for mercury contamination sites include locations of known ASGM and mercury use activities. In some cases, gold may be extracted from multiple locations, then brought to a separate, more centralized location for mercury amalgamation. In other cases, mercury amalgamation and gold extraction occur in the same site. Moreover, ASGM and mercury use sites can move along a transect, such as along a river, therefore can change location over time. Therefore, gathering reliable information on potential locations of ASGM activities and mercury is important for assessment, but can be difficult given the lack of consistent regulation and monitoring of ASGM activities. Therefore, efforts should be made to obtain as much information as possible on potential assessment sites, ideally from multiple sources. Sources of information include government entities, local community groups, community leaders, civil society organizations and documents including national ASGM overview documents, developed as part of the NAP project.

3.2.2 Safety Considerations

The safety of persons conducting field activities for a rapid assessment, which can include site scoping, field assessments and sample collection, should be considered explicitly in the development of a rapid assessment plan. All health and safety risks should be identified, evaluated and mitigated before any field operations are conducted. The use of a comprehensive health and safely plan is an effective tool to identify, assess and communicate potentials risks. The development of a health and safety plan is beyond the scope of this document, but references are provided in document (See Section 2.3).

Although risks in ASGM regions can vary widely due to diverse environmental, physical and social contexts, below are a number of risk factors that have been observed in several ASGM sites and regions around the world. This is not an exhaustive list but may provide examples of what to consider during the assessment planning process. If possible, *a priori* eyewitness information should be included to develop a realistic understanding of the safely context.

Potential safety concerns include:

- Remote locations with difficult ready access and egress
- Locations with limited communication access
- Locations with a limited presence of governmental authorities and law enforcement
- Locations with limited access to adequate health services
- Increased presence of illicit/criminal actors that may pose a security risk to field personnel
- Sub-standard road and trail infrastructure for accessing study areas
- Unstable or hazardous conditions in mining sites (e.g. unstable tailing piles, poorly stabilized sub-surface mining galleries)
- Sub-standard management, use and storage of chemicals using in the mining activity (e.g. elemental mercury, cyanide, acids, caustic agents)
- Hazardous mining practices that may pose direct or indirect risks to field personnel

3.2.3 Identifying Test and Control Sites

Test sites

Many countries are likely to have multiple sites of ASGM and mercury use activities. However, assessing all sites for potential mercury contamination may not be feasible or practical given time and cost constraints. Therefore, the first step is to identify a comprehensive list of potential contamination (test) and control sites, followed by the development of a sampling plan design that prioritizes the sampling of a subset of sites based on factors such as the risk of human exposure, site accessibility and safety (See Section 4.2.2).

A comprehensive list of potential test sites should include active as well as past ASGM sites. The development of this list should include information from a diverse set of sources including eyewitness accounts, remotely sensed imagery, second-hand reports, and civil society testimonials. If possible, each potential assessment site should be corroborated by at least two independent sources to reduce site identification uncertainty.

Once a comprehensive list of ASGM test sites has been developed, target sites should be evaluated and ranked according to factors related to mining characteristics, importance of impacted environmental or social ecosystems, and time, cost and resource constraints. In general, candidate test sites should be representative of the ASGM activity in that region. Additional sites may also be included to increase representation of regional ASGM variability, particularly in larger, more heterogeneous regions.

Factors to consider in identifying test sites for mercury assessment include baseline information obtained as part of the NAP, such as:

1. Where is mercury used, or released into the environment?
2. How is mercury being used in these sites, e.g., is open burning of amalgam occurring, is whole ore amalgamation practiced or are retorts used?
3. Is the burning of mercury occurring in or in proximity to food sources or residential areas?
4. How long has mercury use occurred at these sites and is it ongoing?

Control sites

Control sites are important components in a mercury assessment study, because they allow for the accounting of background mercury levels, or concentrations of mercury that occur in the study site that are not related to ASGM-related mercury emissions (e.g. mercury from geological sources, atmospheric deposition). Control sites should be locations that are as similar to test sites as possible. Ideal candidates for control sites should be:

1. Matched closely to test sites in physical and ecological characteristics (e.g. soil type, elevation, slope, land cover class)
2. Easily accessible by available transportation options
3. Have no history of mercury based ASGM
4. Not located in close proximity to mining areas that could introduce ASGM-related mercury to the control site (e.g. immediately downstream from active ASGM sites where mercury contaminated alluvial sediments can be deposited)

3.3 Identifying Goals and Priorities

A well-designed rapid assessment involves identifying specific goals at the beginning stages. Given time and cost constraints, complete assessments that include measurements of all known ASGM sites, environmental components, or for all potential exposures, are often not feasible. The design of these assessments faces a multitude of trade-offs that must be accepted. Therefore, an important step is to prioritize the assessment goals in order of importance. Goals and priorities should also be revisited and revised throughout the assessment process.

In general, the overall goal for all assessments is to measure mercury concentrations in the environment at sites that are most likely to have the highest mercury contamination levels, or with the highest potential for mercury exposure risk to communities. Specific goals and priorities define the scope of the rapid assessment and may vary among countries with NAPs. For example, the goals and priorities may focus on assessing mercury contamination at a subset of ASGM sites, or sites where children are likely to be exposed. Goals and priorities should consider the following baseline information that should be available from the NAP project:

1. The amount of mercury used at specific ASGM sites
2. The specific ways in which mercury is used at individual ASGM sites, such as whether mercury is vaporized into the open air, or released into the environment under more controlled conditions
3. The age or duration of mercury use at ASGM sites
4. The proximity of communities to ASGM sites, with highest exposures likely within ½ kilometers of ASGM sites
5. The size and potential vulnerability of communities to ASGM sites
6. The proximity of water and food resources to ASGM sites
7. The proximity to high biodiversity and/or critical wildlife areas

3.4 Identifying Resources: Building Capacity to Collect and Analyze Mercury Samples

Collecting and analyzing mercury samples requires access to relatively specialized equipment and supplies. The sampling methods and supplies needed will depend on the types of samples to be collected (See Table 1). Access to instruments needed to analyze mercury content in field samples is often a significant challenge for many countries. Establishing the access to needed equipment and supplies can often be achieved through partnerships with government agencies or university labs which have the needed analytic capacity. Alternatively, sample analysis services by a certified contract laboratory, either in-country or in a foreign country may be an option, if budgets allow.

UNEP is currently developing a databank of laboratories that conduct mercury analyses worldwide (UNEP 2016) in an effort to create a network of labs to understand the worldwide capacity to monitor mercury, including mercury analyses from ASGM areas[1]. This databank is a tool that currently includes 210 laboratories that analyze mercury samples. The registrations to the databank are voluntarily and do not indicate any endorsement or recommendations of labs from UNEP.

3.5 Costs and Time Considerations

Conducting mercury contamination assessments often requires significant investments in time and costs. Therefore, the need for environmental assessment sampling, and its scope, must be evaluated in terms of maximizing potential benefits and minimizing costs given the resources available. Once goals, partnerships, and sample analysis capacity have been identified, a detailed sampling plan and budget should be developed (See Section 4). Often, the budget can limit the sampling plan, and the sampling plan and budget need to be adjusted and revised according to time and cost considerations.

[1] https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-monitoring-project

4. Designing and Conducting a Rapid Assessment Sampling Plan

A rapid assessment should be designed to capture the highest potential mercury contamination and exposures and to estimate the range of contamination and exposure levels that occur in the country. Many of the most difficult technical challenges come when developing a plan to sample a site. Questions such as “Where should sampling be done?” and, “How many samples should be taken?” provide a range of possible answers that are ultimately constrained by budget and other considerations (ITRC (Interstate Technology & Regulatory Council) 2008).

The assessment design should include details on sample collection procedures, data analysis methods, and plans for data interpretation and dissemination of results. A well-designed sampling plan is crucial in obtaining meaningful data and information necessary to mitigate mercury exposures.

Mercury sample collection often involves multi-step procedures that must be followed in order to obtain meaningful mercury measurements, as mercury concentrations can be highly variable in all environmental components (air, water, soil, biota). Therefore, a sampling plan that identifies media and sampling sites that will best help in determining the risks of mercury pollution to humans and the environment, takes into account local factors, strives for careful sample collection, and sufficient sample replication helps minimize the chances of missing high mercury contamination where it exists, and maximize the confidence in the mercury data obtained. Detailed information on risk assessment design and analyses is also available from other sources and should be reviewed (USEPA 1992; Veiga and Baker 2004; WHO and UNEP 2008).

4.1 General Approach

A rapid assessment screens previously identified potential mercury contamination sites, and sources of human mercury exposure by collecting mercury samples from the environment and comparing mercury sample concentrations to known benchmark values that indicate human health risk, or other estimates of risk where such benchmarks are lacking. A rapid assessment should build on the activities conducted in developing the NAP (UNEP 2017), and can be conducted on a subset of relatively high priority sites, identified as likely to have higher mercury contamination or human mercury exposure, based on results of previous baseline studies conducted to estimate mercury use as part of the NAP. Field sampling protocols for specifically developed for assessing multiple environmental components of ASGM areas (Veiga and Baker 2004) should be considered in developing the rapid assessment sampling plan. The overall sampling plan should take into consideration any information regarding the likelihood and potential severity of human mercury exposure, and potential exposure routes such as dermal exposure, inhalation of mercury vapor, and dietary consumption.

4.2 Steps in Developing a Rapid Assessment Design

4.2.1 Developing a Timeline and Budget

A timeline and budget are the components of a sampling plan that help define and limit rapid assessment activities. The timeline and budget also help coordinate all partners involved in the assessment, such as field researchers, mercury laboratory staff, and government agencies, and other stakeholders (e.g., stakeholders p. 48, O'Neill and Telmer 2017).

The timeline describes the expected dates that each assessment activities should be completed, including all activities involved in sample collection, data analysis, data interpretation, and the dissemination of results. These activities should all contribute toward fulfilling the specific goals and priorities of the assessment. The timeline should also include buffers of time that allow for some flexibility due to unplanned delays in the time for specific activities to be completed. The timeline should be developed in agreement and shared with all partners as needed.

Similarly, a budget should also be developed in consultation with implementing partners. Each partner should identify the costs associated with each activity. The budget should include costs for all sampling materials, field sampling gear, travel, laboratory analysis of mercury samples, costs of shipping or transporting samples, fees or compensation for work, export and research permits, and any costs associated with data analysis and dissemination of results. Both the timeline and budget should be revisited and adjusted throughout the assessment project. A sample timeline, activities and budget can be found in Annex 4 the National Action Plan Guidance Document (UNEP 2015).

4.2.2 Identifying Field Sampling Sites

Field sampling sites should be chosen to best capture locations of suspected, or potential human exposure. Field sites for rapid assessment will likely be a subset of the study sites included in the NAP effort to establish baseline knowledge of mercury inventory and use (UNEP 2017) and will therefore build on this baseline research. Factors to consider in site identification is extensively covered elsewhere (UNEP 2015). Field sampling sites should also include control sites, as described above (See Section 3.2.3). Specific considerations in identifying potential sites should include evaluating locations with the following characteristics:

1. **Suspected mercury exposure hotspots.** Potential hotspots include locations where relatively high mercury emissions overlap with high human population densities (e.g. densely populated towns with gold amalgam buying shops). Information on identifying and sampling hotspots for mercury contamination from ASGM has been detailed elsewhere (Veiga and Baker 2004).

2. **Locations with suspected ASGM mercury use near water bodies.** Mercury contamination of aquatic environments (e.g. lakes, rivers, wetlands, estuarine, and coastal areas) can be important sources of human exposure due to the biotransformation of released elemental mercury to the more toxic form of methylmercury in water bodies. Aquatic environments should be included depending on the proximity to ASGM and mercury use, and the type and extent to

which local communities rely on wild caught fish or other aquatic food sources for consumption.

3. **Locations with relatively vulnerable human populations or subpopulations.** Vulnerability to mercury can be higher among specific subpopulations with potentially higher risk of exposure (e.g., miners who work directly with mercury on a regular basis) or higher sensitivity to mercury toxicity (e.g., women of childbearing age, and young children who may experience detrimental developmental effects).
4. **Locations with the potential for contamination of food sources.** Mercury emissions to air and water can potentially contaminate food sources, either through the direct atmospheric deposition of mercury on crops or food products, the uptake of mercury present in soils by crop plants (e.g. paddy rice), or bioaccumulation in consumable high trophic level fish or reptiles (e.g. crocodiles or turtles) .

4.3 Considerations for Mercury Sample Collection

4.3.1 Sample Replication

Mercury contamination assessments provide estimates representing mercury concentration levels in the environment. Mercury contamination in all types of media (air, water, soil, sediment, biota) can be highly localized. As a result, mercury concentrations can be highly variable among individual samples even from the same location. Therefore, it is necessary to collect multiple (or *replicate*) samples in order to increase the chances of accurately estimating mercury concentration levels from a given site. The more samples that are collected, the higher the likelihood that as a collection, those samples will more closely represent true mercury contamination levels.

> Often it is not practical or economically feasible to collect a large number of samples at a given site. Therefore, a general rule of thumb is to collect three replicate samples for each *sampling unit* for which mercury contamination will be estimated

A sampling unit can be an individual site location, a point of time, a type of environmental media, or a combination of these factors. Collecting at least three replicate samples will allow for a better estimation of the *mean* and *variability* (e.g. standard deviation) of mercury concentrations for a given sampling unit.

Estimates of means and standard deviations allow for statistical comparisons across sampling units, for example to test for differences in mercury contamination between different sites. Also, collecting at least three replicate samples allows one to more accurately quantify risk, for example by estimating the percent of samples that exceed threshold values that indicate risk to human health (See Section 5.2). Finally, collecting at least three replicate samples allow for the loss of a single sample, due to circumstances including sample contamination resulting in inaccurate mercury concentration analysis, while preserving the ability to assess mercury risk with the two remaining samples.

4.3.2 Controlling for Background Sample Contamination: Sample Blanks and other Approaches

As a naturally occurring element, mercury exists in all environmental media and is found in trace amounts even in relatively pristine, "uncontaminated" sites. Therefore, in order to accurately assess environmental mercury contamination from ASGM (or any other anthropogenic sources) mercury concentrations in collected samples must be measured relative to "background" mercury concentrations, independent of and distinct from the mercury concentrations in the sample media. For example, insect samples can contain mercury associated with the insects, and mercury associated with water used to rinse the insects during the sample collection process. In this example, the rinse water may introduce background mercury concentrations to the sample. In general, the potential for background contamination should be evaluated for each step in the sample collection process.

Sample blanks serve the purpose of accounting for potential mercury concentrations in the background introduced during the sample collection process. In general, sample blanks are collected using the same tools, sample containers, and methods used to collect replicate samples, but do not contain the environmental sample of interest. More details on sample blanks can be found for different types of environmental samples (See Section 4.4).

There are other approaches that are important for minimizing background sample contamination, including the use of clean, filtered water for rinse water of sampling equipment, and the cleaning of sample collection containers using techniques that minimize background contamination. More details on these approaches can be found for each sampling type below (See Section 4.4).

4.3.3 Record Keeping

A sampling plan should include keeping careful records of any information needed to conduct the entire plan, including 1) specific details on the sampling plan design, 2) the data to be recorded for each sample collected, and 3) plans for data analysis and interpretation. Careful record keeping can standardize collected information, and ensure quality and continuity in carrying out a sampling plan with multiple data collectors or conducted over a long period of time.

As a general rule, records for sampling plan design, methodology, and plans for data analysis and interpretation, should include sufficient detail for other users to be able to repeat the same sample plan. Plans should be made regarding how and where to record information for all samples collected. During sample collection, sample information should be written in a field notebook, or more preferably on a pre-printed standardized data collection form which ensures that data is collected in a similar manner for all samples. This information is then copied into an electronic spreadsheet that can be saved, shared, and copied. Manual data entry in the field, and digital transcription of written data into digital formats should be systematically checked for errors. Information for all samples should be recorded in a standardized format, and in standardized units.

Although data collected with a sample will vary depending on the goal of the rapid assessment and the context of the study, there are data that should always be collected and recorded with each sample. At minimum the following information should be recorded with each sample:

- a unique sample identification number or code
- the date on which the sample was collected
- a descriptive name of the location from where the sample was collected
- GPS-captured locational coordinates from where the sample was collected

Depending on the goals of the assessment, additional types of information may need to be recorded with the sample to allow for interpretation of the measured mercury concentration values. For example: for an assessment of mercury concentrations in fish in an area downstream from an ASGM site, samples of fish tissues should include information on the sampled individual fish specimen (e.g. length, weight, and species). Additional information on the sampling point were the specimen was collected (e.g. distance to nearest ASGM, turbidity of river at time of collection) may also be useful. Such ancillary information is important to aid in the interpretation of the differences in the mercury content in the samples due to these factors.

4.4 Sampling Collection and Analysis Methods

4.4.1 Mercury in Air

Assessing mercury in air in ASGM impacted areas primarily requires the measurement of elemental mercury vapor in rural and urban locations. As mentioned in Section 2.1.2 above, the dynamics of mercury in air are complex, and involve several rapidly transforming mercury species. Although the sampling and measurement of multiple mercury species is possible (referred to as *speciated measurement*), the acute and chronic inhalation of **elemental mercury vapor** is of most interest for human health, and should be the starting point for rapid assessments looking at occupational exposures (e.g. miners in the field, amalgam burners in gold shops), and exposure to the general public (commonly referred to as ambient air exposure).

There are several methods to assess mercury concentrations in air. Sampling and analysis methods are in two categories:

1. active sampling with real-time concentration measurement
2. passive sampling with off-site laboratory concentration measurement

Active air sampling and real-time measurement

Mercury vapor concentrations can be assessed in real time by using active mercury vapor analyzers such as the Jerome 431-X, J405 or J505 Mercury Vapor Analyzers (AMETEK Brookfield Inc., Chandler AZ USA), the Mercury Tracker 3000 IP (Mercury Instruments GmbH, Karlfield Germany) and the Lumex RA-915m mercury analyzer (Ohio Lumex Inc., Cleveland OH USA) (Figure 1). These instruments draw a small air sample into the analyzer body, and measure mercury vapor concentration using gold film resistance (Jerome 415-X and J405), atomic fluorescence spectroscopy (Jerome J505), or atomic absorption spectroscopy (Lumex RA-915m). Each instrument has a specific detection range that will determine its usefulness depending on the level of concentrations expected in the study area.

Figure 1.

Active real-time mercury vapor analyzers. Clockwise from the top left: Jerome J505, Jerome J405, Lumex RA-915m, Mercury Tracker 3000 IP.

The advantages of these instruments include precise real-time, instantaneous measurements of mercury vapor concentrations, and high portability which allows for easy deployment to sampling sites. Disadvantages include: high purchase costs ($10,000 – $50,000 USD), high maintenance costs (i.e. annual calibration and servicing), the need for significant training for field operators, the need for access to power to recharge analyzer batteries, a limited ability to sample air over an extended period of time, and the inability to sample several sites simultaneously.

A lower cost method for areas with high mercury air concentrations is the Dräger gas sampling tubes for *in situ* analysis (Dräger Inc., Houston TX, Figure 2). Dräger systems work by drawing a known volume of air using a small battery-powered gas pump (Dräger X-act 5000), or a hand activated pump (Dräger Acuro), through a disposable gas tube packed with a sorbent that absorbs mercury. Mercury concentrations are indicated in minutes by a simple colorimetric method. Dräger systems have the advantage of being a small, easily portable, robust and relatively low-cost method (approximately $10 USD per analysis tube), However, Dräger tubes are limited by their lower accuracy levels, lower sensitivity (they can only measure mercury concentrations at higher ranges), and they require new tubes for each sample reading.

Passive mercury air sampling with off-site laboratory concentration measurement

Passive air samplers are methods that collect mercury vapor in air without the use of an active mechanism to draw air through a sorbent or over a reactive membrane or film. They rely on passive diffusion through a membrane that separates a special sorbent from the air to be sampled. The sorbent (typically activated charcoal spiked with sulfur compound) is housed in a sealed container which is opened only during the time of measurement. Once the sampling container is sealed at the end of the measurement period, the sorbent is then transported to a laboratory and analyzed for total mercury content. Since the diffusion rate of the membrane is well known, the time of measurement combined with the measurement of the mass mercury captured by the sorbent during that time allows for the calculation of the mercury concentration for that period. Figure 3 shows the components of a mercury vapor passive air sampler (McLagan et al. 2016). Figure 4 shows the deployment of passive air samplers.

Advantages of passive air samplers include: relative low cost per sampler (< $30 per sampler), low maintenance costs, easily refurbishable by replacing mercury sorbent capsules, small and lightweight, simple construction (no moving parts), no requirement for power, high sensitivity and precision, sufficient for measuring mercury background levels, high mercury absorption capacity. Disadvantages include access to mercury laboratory analytic services with the ability to analyze mercury content of sorbent.

Because of its low cost, portability, and high sensitivity, passive air samplers are ideally suited for simultaneous deployment over a long sampling period to develop time integrated measurement of mercury concentration over wide areas.

Dräger X-act 5000 battery powered active sampler with mercury analysis tube.

Dräger Acuro hand activated active sampler with mercury analysis tube.

Figure 2.
Drager Mercury Vapor Sampling Tubes.

Figure 3.

Components of a mercury vapor passive air sampler (McLagan 2016)

Figure 4.

Deployment cycle of mercury vapor passive air samplers (HgPAS) in an ASGM region in Madre de Dios, Peru. Clockwise from the top left: Attaching a HgPAS to vertical surface in a mining town. Three HgPAS *in situ* in a tree for two weeks. Removing the sorbent from retrieved HgPAS for mercury content analysis. Mercury sorbents queued for analysis in a Milestone DMA-80 direct mercury analyzer. Photo credit: Centro de Innovaccion Cientifica Amazonica (CINCIA).

4.4.3 Mercury in Soils

ASGM activities often result in deforested landscapes with highly degraded soils that contains little or none of the original soils. Remaining soils in these areas are often low in organic matter and high sand context. In extreme cases, where soils are reprocessed repeatedly, the remaining soils may be similar to those found in deserts or alluvial beaches. The radical transformation of landscapes and soils by ASGM frequently leads to concerns regarding mercury contamination of these areas. Uncertainty about contamination of existing agricultural soils by direct mercury releases, atmospheric deposition from nearby mercury emissions, and mercury levels in degraded sites slated for reforestation or reclamation for agriculture or agroforestry often drives these concerns. As a result, soils sampling and analysis is a frequent component in rapid assessments.

Soil sampling in ASGM areas should try to capture the variation of mercury levels in a site. Estimates of this variation can be informed by knowledge of the history of the suspected ASGM or emission activity in a given site, if available. Often, limited time and resources constraint the ability to conduct extensive soil sampling, especially in large sites. Prioritization and site segmentation are useful tools that allow the assessor to limit the sampling to the key areas of interest within a site that are in line with the goals of the assessment. For example, if the goal of an assessment is to determine mercury levels in areas that may be reclaimed for agricultural plots, sample points within planned revegetation zones should be prioritized.

Once a sample site is segmented and clearly delimited, sampling points should be mapped out. The number of sampling points will be a trade-off between the need for a sample set that is representative of the site, and the number of samples that the assessment can collect and analyze. There are a number of soil sampling designs, most of which will not be covered here, and are covered elsewhere (USEPA 2002). Although opportunistic sampling is simple to execute, it may not be representative of the site. Instead there are sample designs that are useful for rapid assessments in sites of varying sizes. Linear sampling transects (a linear sampling design that span a feature in the site) is a cost-effective method to capture site variability. Transects laid down across the boundaries of disturbance classes (e.g., from mining soils to non-mined soils) can detect contaminant plume edges and characterize edge effects.

Designs for scoping assessments in large ASGM sites include a systematic grid design where one sample is collected per 100 m^2 based on a 10 m × 10 m grid. Nested grid designs, where random points are selected in a site, and a smaller grid of sampling points are collected can reflect different scales of variation in mercury concentrations. At sites where the history of mining activity suggests that contamination risk is not high, a nested grid design can be used where consolidated samples are developed by mixing samples collected at five spots per 900 m^2 (based on a 30 m × 30 m grid). The five samples are collected from a grid, including the center point of each grid and four points randomly selected in the four quadrants of the grid. The subsamples are then combined to develop the composite sample. This approach increases the representativeness of the soil samples obtained from each grid.

Sampling collection and handling methods should be informed by the analyte (e.g. total mercury, methylmercury) and the analysis method. Generally speaking, total mercury (HgT) is most frequently measured in rapid assessments due its lower analytical cost and simpler sample maintenance and transportation requirements. The sampling collection method described below is designed for total mercury analysis.

At each sampling point, soil samples should be collected between the soil surface and 50 cm below the soil. In soils with an intact organic horizon (in soil terminology: O and A horizons), individual samples should be sampled from two separate regions, one between the soil surface and 10 cm below the surface, and the other in the area from 10 cm to 50 cm below the soil surface. Soils in highly degraded ASGM areas typically lack O horizons, so sampling in a single soil region is advised. Samples should be collected with clean metal or plastic collection tools, and placed in clean, sealable plastic collection containers.

After collecting the soil samples, non-soil elements (e.g pebbles, rocks, roots, wood particles) should be removed. Sub-samples from each region of the sampling point (either 0 – 30 cm, or 0-5 cm and 5 – 30 cm) should be mixed and homogenized. After homogenization, mix an equal weight of each sample to obtain a final composite sample. If using the five-point grid sampling described above, mix an equal weight of each of the five homogenized samples to obtain one composite sample for mercury analyses. Samples should be sealed, labeled and coded to a data collection form to start the chain of custody. Samples should be stored in a in a cool, dark container for transportation to laboratory for analysis.

4.4.4 Mercury in Sediments

Measuring mercury in sediments can be an important indicator of mercury contamination of aquatic ecosystems from ASGM. The majority of mercury released to the environment by ASGM is thought to directly, or indirectly enter surface waters, such as lakes, rivers, wetlands, and estuaries, where it is converted to organic mercury (i.e. methylmercury) by anaerobic bacteria in surficial sediments. Methylmercury biomagnifies up the aquatic food chain and eventually can contaminate fish consumed by humans. Thus, mercury occurring in aquatic in sediments can be an important source of methylmercury to fish, and fish consuming populations.

In streams and rivers, sampling points should be selected that allow collection of bottom sediments located at intervals of 50 - 200 m downstream from the suspected mercury emission point(s) (e.g. mining dredges, the entry point of a tributary stream that drains a mining area, a riparian runoff point of an eroding riverbank ASGM mine). Sampling points should also include points upstream from the suspected emission points(s) as controls. Sediment samples should be collected along transect oriented perpendicularly across the river with a minimum of two points, one collected from the riverbank and one in the center of the river. The number of samples should increase with the width of the river.

In lakes, ponds and marshes, sediments samples should be collected from the pour point of the water body into the downstream river or stream, and a grid sampling survey should be conducted. If time or resources are limited, samples can be collected along a transect from the pour point towards the center of the water body.

An Ekman dredge sampler can be used to collect surface layer sediments from the bottom of rivers, lakes, and marshes. Core sediment samplers are useful for collecting columns of lake sediment that can be subsampled at difference depths, allowing for the measurement of mercury deposition rates and determination of mercury contamination history. Collected sediment samples should be cleared of large debris (e.g. wood particles, rocks, algae, and organisms and sieved through a 3-mm mesh screen. Water should be decanted from the sediments, and the sample should be well homogenized before storing it in a clean sealable plastic or glass sample container (Figure 5). Samples should be labeled clearly and uniquely coded to a sample collection data sheet where date, location, GPS coordinates and descriptive information of the sample should be recorded. Samples should be stored in a cool, dark location (ideally frozen) and transported to a laboratory for analysis.

Figure 5.

Sampling methods for collecting lake sediment for determining total mercury concentration. Top left: Collecting lakes bottom sediments using an Ekman dredge sampler. Bottom left: Homogenizing lake bottom sediment samples. Top right: Using a Universal sediment corer to collect a 100 cm lake sediment core. Bottom right: Collecting sub-samples from a sediment core. Photo credit: Centro de Innovaccion Cientifica Amazonica (CINCIA) / Jason Houston

4.4.5 Mercury in Agricultural Products

In ASGM impacted areas, there is usually considerable concern by farmers and consumers regarding the possibility of mercury contamination of agricultural products grown in former mining sites, and of possible contamination of crops by atmospheric deposition of airborne mercury.

Although there is evidence that some plants can absorb mercury deposited on their leaves (Schwesig and Krebs 2003), and others can absorb mercury from soils through their roots (Bishop et al. 1998), mercury has not been found to be readily absorbed by most crop plants. Further, mercury absorbed by plants tends to remain immobile and is not readily transported to the parts of plants that are consumed by humans (Cavallini et al. 1999). Therefore, uptake of mercury into plant tissue is not considered a significant pathway for pant contamination and the subsequent human exposure through consumption.

One notable exception to this trend is paddy grown rice (*Orza sativa*). Recent studies in China (Meng et al. 2011; Qiu et al. 2008; Zhang et al. 2010) and Northern California (Windham-Myers et al. 2014) have found that that paddy grown rice located in proximity to active or former mines can absorb mercury deposited by atmospheric deposition or waterborne sediment transport into the paddy growing ponds. The deposited mercury is converted to methylmercury by anaerobic bacteria present in the pond's submerged soils and absorbed by the rice plant roots. Absorbed mercury is transported in the rice plant and concentrated in the rice grains, which is the main food product for *Orza* (Rothenberg et al. 2014). Although researchers in China found that rice had comparability lower levels of mercury than fish, and had mercury levels well below health guidelines for dietary consumption, in some high rice eating populations, rice consumption was the primary sources of dietary mercury exposure (Meng et al. 2011).

Another possible exposure pathway is the atmospheric deposition of mercury on the fruits and vegetables of crop plants. Studies have found high levels of mercury deposited on the surfaces of fruit and vegetable plants grown in fields located close to coal fired power plants (Li et al. 2017). However, there is little evidence as well as a lack of adequate study examining whether atmospheric deposition on agricultural products such as fruits, grains or vegetables in ASGM areas serves as a significant exposure pathway. In summary, crop plants exhibit limited ability to absorb and bioaccumulate mercury, therefore are not considered important exposure pathways posing little risk for consumers. That said, local producers and decisions makers may request mercury assessment of local agricultural products to inform concerned consumers and agricultural markets.

The sampling of agricultural products to estimate mercury exposure through dietary consumption should focus on the sampling of the food product itself (the fruit, vegetable, tuber or grain), instead of components of the plant that are not consumed. A simple sampling design that randomly collects samples from plants in agricultural fields should follow the target plant cropping patterns. Ideally, samples should be collected directly from the plant, however if this is not possible, recently picked agricultural products (i.e., those products already removed from the plant) may be used, only if reliable information on the location of the growing field exists to relate mercury concentrations to possible mercury sources.

To assess if atmospheric mercury deposition and surface contamination is an important factor, duplicate samples should be collected in order to analyze washed and unwashed samples. Samples should be stored in clean, resealable plastic or glass sampling containers and labeled clearly and uniquely coded to a sample collection data sheet where date, location, GPS coordinates and descriptive information on the sample are recorded. Samples should be stored in a cool, dark location (ideally frozen) and transported to a laboratory for analysis.

4.4.6 Mercury in Aquatic Ecosystem Sampling:

Understanding mercury impacts on aquatic ecosystem is a critical aspect of assessing mercury risk to human populations and wildlife in ASGM areas. Communities often rely on fish caught in local rivers and lakes for protein, on crops planted in fertile alluvial floodplains and use the waterways for transportation. Also, aquatic food chains often have more links and are longer when they lead to humans than terrestrial food chains, therefore can serve as conduits of methylmercury exposure due to biomagnification. ASGM activities also rely on the aquatic environment to provide transportation of labor and materials, water needed for hydraulic mining, and the water body on which dredges and mining platforms float. Aquatic ecosystems also provide critical habitat for plants and wildlife, and interface with riparian and terrestrial ecosystems.

Rapid assessment of the levels and impacts of environmental mercury in aquatic ecosystems relies on monitoring key biological elements of these ecosystems. For example, key species in these ecosystems can be used as bioindicators that provide insights on ecological integrity, mercury contamination, and indicate potential exposure risks to humans. The section below discusses a sampling scheme which can be embedded within a larger bioindicator monitoring framework to provide a comprehensive rapid assessment and allow for the integration of each of the types of sampling and analysis. This approach is described in greater detail elsewhere (Evers et al. 2018) and is summarized below. More detailed information on field sample collection protocols is described elsewhere (Veiga and Baker 2004).

The approach to use bioindicators monitoring for assessing mercury impacts in ecosystems is composed of steps summarized below: 1) the selection of study sites and target species, 2) the collection of samples, 3) sample preparation and mercury analysis. The additional steps of data management and analysis, science communication, public outreach, and capacity building are described in Section 5, and Section 6.2, respectively.

1. **Selection of study sites and target species.** As discussed previously, the selection criteria to choose study sites should be closely related to the goals of the assessment. In the bioindicator monitoring approach, a critical step is the selection of the target species to use as bioindicators. Selected species should represent important ecosystem compartments which through their position in food chains, can indicate mercury

concentrations and dynamics within the ecosystem. Target species should also be relatively common across the study site, and easy to collect and sample to allow for the development of sufficient data to draw conclusions.

The selection of the specific species as bioindicators depends on the geographic location and ecosystem. However, certain types of biota are good candidates for biomonitoring including fish, marcroinvertrebrates, and birds. Fish that are abundant and relatively common across the study site are good candidates since they tend integrate methylmercury over time through bioaccumulation, therefore provide a signal of mercury loads in the ecosystem. High trophic level predatory fish species (fish that eat other fish) can indicate the higher range of potential mercury exposure to fish consuming wildlife and humans, due to biomagification. Larger, adult fish tend to have higher mercury concentrations than smaller, younger fish of the same species due to bioaccumulation. Therefore, it is important to account for these factors, such as by consistently collecting and comparing fish of similar size and age (if known) when comparing mercury levels among fish samples.

Monitoring macroinvertebrates is effective for assessing mercury levels at lower parts of the food chain. Macroinvertebrates are also effective indicators of the crossover of methylmercury from the aquatic ecosystems to terrestrial ecosystems. Macroinvertabrates (aquatic larvae of insects such as dragonflies, mayflies and stone flies) are important prey for fish in aquatic ecosystems, and once they emerge into their terrestrial adult stage, are important prey for spiders, bats and birds. Thus, the mercury in aquatic macroinvertebrates are transferred to the terrestrial ecosystems when consumed by terrestrial organisms.

Birds are also effective candidates for target species (Ackerman et al. 2016), particularly piscivorous aquatic birds in rivers and lakes, and insectivorous birds in riparian and forest ecosystems. Relatively long lived birds are well suited to provide spatially and temporally integrated information on mercury ecosystem loading.

2. **Collection of biological tissue samples.** Nonlethal sampling of biological tissues requires specialized knowledge and skill to avoid negatively impacting bioindicators species populations. Fish sampling should be done using non-lethal biopsies to collect muscle tissue plugs and avoid sacrificing sampled individuals when possible. For macroinvertebrates, non-lethal methods are not available. However, sampling multiple macroinvertebrate taxa by using different sampling methods should be done so as not to impact bioindicator populations. Sampling birds can include collecting different tissue types to obtain different types of information on mercury exposure. Blood sampling indicates short term exposures to mercury, while sampling feathers provides information about long term exposure. Similarly, in humans, the sampling of hair is a quick and easy way of measuring methylmercury exposure in the short term through the long

term, depending on the hair length of the person.

3. **Sample preparation and analysis.** Once tissue samples are collected, it is important that sample preparation and transportation protocols are followed for the transfer to a laboratory for mercury analysis. These protocols can help ensure that samples are preserved in optimal conditions for analysis and samples are not lost due to soilage or misplacement. Tissue sample analysis should be done in an analytical laboratory that has at least the following basic components: a direct mercury analyzer that can determine total mercury concentration in solid and semisolid samples using EPA method 7473 (e.g. Milestone DMA-80, Nippon Direct MA3000) or similar instruments, an analytical balance to precisely weigh samples, a freeze dryer to dehydrate and stabilize samples, and a tissue sample grinder to homogenize samples. Adequate quality assurance and quality control (QA/QC) protocols should be implemented to ensure confidence in the readings. Although such mercury laboratories may not be available in some countries, stabilized samples can be exported to academic or private-sector labs in other countries for analysis. In these cases, government custom requirements for sample export and import should be checked.

The use of this aquatic biomonitoring approach can and should integrate information generated though the collection and analysis of samples described in previous sections in this document in order to create a well integrated rapid assessment of mercury impacts in ASGM areas.

5. Data Analysis and Interpretation of Mercury Exposure Risk Assessments

A clear plan for data analysis and interpretation should be included as part of the development of the sampling plan design before field samples are collected. Understanding what types of conclusions are needed, and how the data will be analyzed in order to make such conclusions, guide the sampling plan design and help determine the type and number of samples needed. The major goals of the data analysis and interpretation steps are to try to understand the patterns of mercury contamination in the environment, and the potential for environmental and human health risk. Thus, the three main tasks to fulfill these goals are 1) data cleaning and preparation for analysis, 2) exploring and summarizing environmental mercury sample concentration patterns, and 3) comparing mercury concentration patterns to known risk benchmarks, or media-specific mercury concentration values that indicate risk when exceeded.

The primary strategy to conduct a rapid yet informative mercury assessment is to make indirect estimates of human health risk from potential mercury exposure based on environmental mercury concentrations. Indirect estimates differ from direct measurements of human exposure, such as mercury concentrations in human blood, or urine samples, that are relatively costly and difficult to obtain. In contrast, indirect estimates based on mercury concentrations in air, water, and food, for example, are less costly, easier to obtain, and are commonly used for exposure assessments. Additional information on indirect and direct assessments are available elsewhere (USEPA 2019a). The World Health Organization has developed extensive guidelines for conducting indirect estimates of mercury exposure and risk (WHO and UNEP 2008). Briefly, the general approach involves comparing mercury concentrations in environmental media to established reference levels that are known to be associated with human health risks. It is important to be aware that, in addition to environmental mercury concentrations, exposures and health risks depend on other factors including 1) the fate and transport of mercury through the environment over time (for example, mercury deposition from air to water), 2) the magnitude, frequency and duration of exposure from different sources and routes (e.g., drinking water, food, air inhalation, dermal exposure), and 3) the sensitivity of different exposed subpopulations or individuals to mercury toxicity (USEPA 2019b). These additional factors lie outside of the scope of a low cost, rapid assessment, and can be explored in greater detail during longer term, comprehensive study.

5.1 Data Cleaning and Preparation

Prior to analysis, all mercury and related data, including date and site information, should be entered into a single spreadsheet file. Methods and practices for data recording and data entry should be followed as described elsewhere for baseline studies (O'Neill and Telmer 2017). Once all data are entered and checked for errors, the following data cleaning and preparation steps must be completed before data analysis:

1. **Check for and resolve any missing data, or data gaps.** Take additional actions necessary to fill in these gaps, including revisiting field sites, if possible.

2. **Ensure that all data of the same type (for example, mercury concentrations in aquatic invertebrates) share the same commonly used, standardized units.**

3. **Check for any sample concentrations that may be erroneous**, including those that appear to be unusually high compared to other replicates. Careful judgement should be used to evaluate whether or not a sample is erroneous or has been contaminated from a source other than the sample itself. Often, high quality sample replicates can have mercury concentrations that are many times higher than other replicates collected from the same site and date. However, sample concentrations that are orders of magnitude higher than concentrations of other sample replicates, for example, should be noted to help interpret the data in later steps. In general, no data, including potential outliers, should be deleted. Rather, potentially erroneous samples should be noted.

4. **Examine and control for background contamination.** Ideally, sample blanks should have mercury concentration levels that are below detection limits (i.e., have concentrations that are lower than the mercury analyzing equipment is able to detect). Detection limits are typically available and reported by the analytical lab along with the sample data. Sample blanks with mercury concentrations below detection limits indicate no background contamination occurred during sample collection or analysis in the lab. Sample blanks with mercury concentrations above detection limits indicate mercury contamination from background. To correct for such background contamination, the average sample blank concentration should be subtracted from corresponding sample concentration values.

5. **Dealing with sample values below detection limits.** It is possible for some sample concentrations to be below detection limits. In these cases, the actual mercury concentration in these samples were too low to measure and are therefore unknown. However, the fact that these sample concentrations are less than the detection limit is useful information that allows us to include these samples in data analysis even when their precise mercury concentration is unknown. One approach is to assume the mercury concentration of these samples is equal to the detection limit reported by the lab. A second approach is to assume the mercury concentration of these samples is equal to one-half times the detection limit reported by the lab. Both approaches are commonly used in studies of mercury and other contaminant concentrations in the environment. Either approach, and the number of samples reported as below detection, should be noted in all reports that describe the data analysis methods and interpretation. Detection limits, and decisions regarding how to deal with samples below detection limits, should be discussed

in consultation with the analytical laboratory responsible for sample analysis.

5.2 General Information on Exploring and Summarizing Environmental Mercury Sample Data

Once you have prepared the data for analysis, the next step is to explore the data, and summarize the patterns. A data summary describes the shape, center, and spread of the data. Such data summaries include commonly used numerical summary statistics. Summaries can be described for the entire dataset but are particularly useful for individual sampling units of interest, such as for each field location. In general, exploratory data analysis and summaries should be conducted for all sampling units that are the focus of rapid risk assessments and other analyses.

5.2.1 Summary Statistics: Shape, Center and Spread.

Describing the shape of the data. The shape of the data distribution can be described based on inspection of a histogram plot of the data values and their frequency. Environmental mercury values typically do not exhibit a normal distribution or bell curve, in which the spread of values is symmetric relative to the center, and upon which most summary statistics are based. Rather, environmental mercury concentrations often exhibit a right-skewed distribution, in which a higher proportion of the values are low relative to the center, and a fewer number of values are very high. In cases where the data distributions are non-normal, the data can be transformed, for example by applying a logarithmic function, to normalize the data an simplify statistical analyses. Such functions are commonly built in to spreadsheet programs.

Center. The center of the data is typically described by numerical statistics. The most common measures of center are the mean, or average, and median, or midpoint (half of the observations are smaller, and half are larger). In symmetrically, or normally distributed data, the mean and median values are close together. However, in environmental mercury observations that are right-skewed, the median value is lower. Therefore, it is important to be consistent in your use of these values when assessing risk and making comparisons among sampling units.

Spread, variability and uncertainty. Spread or variability refers to the range of values of the data and is described in more detail in the context of exposure risk elsewhere (USEPA 2011). Observations of environmental mercury concentrations can be highly variable due to multiple natural factors. Accurate descriptions of variability are important in examining broad patterns in environmental mercury risk, such as when trying to detect whether mercury concentrations are changing over time or differ across sites. In rapid assessments, variability can be described using common numerical statistics including standard deviation or standard error. In more comprehensive risk assessments, variability can also be described in more detailed tables of percentiles or ranges of values. Uncertainty differs from variability and is defined as a "lack of knowledge" in the risk assessment, or one of its components (USEPA 2011). Therefore, while variability in the observed data can lead to a source of uncertainty, for example, by indicating a large range of potential exposure levels and risk, variability is different from uncertainty in that it is knowable and can be quantified. Nevertheless, accurately characterizing uncertainty is important in the later steps of assessing and communicating risk.

5.3 Rapid Risk Estimates: Comparing Mercury Data Patterns to Benchmarks of Human Health Risk

Risk estimations are the pivotal step that provides the information needed to determine whether environmental mercury levels are safe or unsafe. The goal of this document is to provide guidance on how to rapidly assess Hg levels in the environmental components (e.g., soil, water, biota) that indicate human or wildlife health risks. A rapid assessment minimizes costs and time by focusing on obtaining baseline environmental mercury data and comparing the data to known threshold concentrations that are associated with human health risk. Such comparisons reveal only whether any of the environmental mercury concentrations measured are safe or not. The calculations do not include important factors that influence overall risk, such as exposure duration, or differences in sensitivity among individuals. Therefore, the results and conclusions that are based on this rapid assessment are simplified and limited in scope and detail. However, such rapid assessment results are valuable in that they can provide baseline evidence for mercury risk and serve as a point of comparison for a more comprehensive assessment that examines the range of potential risks to humans and wildlife, or to specific subpopulations, and their attendant uncertainties.

There are multiple potential routes of exposure to mercury from the environment due to ASGM activities, including food consumption, inhalation of mercury vapor, and dermal exposure. Exposure routes vary in the dominant type of chemical mercury species present, the exposure concentration that is considered unsafe, and the health risks that can result. This assessment focuses on risk calculations for the most likely mercury exposure routes resulting from ASGM activities for which the threshold concentration values for health risks are known. However, site-specific details on mercury use from ASGM activities and potential forms of human interactions and exposures should be considered to guide the focus of risk assessment.

For rapid risk estimates, measurements from field sampling efforts can be compared to these guideline values in multiple ways. First, summary statistics of data (e.g., mean or median values) can be calculated as to whether they exceed these guideline values, or not. Second, mean or median values can also be normalized by these threshold values to quantify the extent to which exceedances occur. Third, one can calculate the percent of exceedances among individual replicate measurements, by comparing individual data points to the guidance values. In general, risk estimates that indicate exceedances of the guideline values described indicate potentially unsafe exposure levels.

5.3.1 Estimating Inhalation Exposure Risks to Elemental Mercury using WHO Guideline Values

One of the main routes of human exposure to mercury from ASGM activities is through inhalation of elemental mercury vapor from air. The World Health Organization (WHO) has derived guideline values that can be directly compared to air mercury measurements obtained through the ambient air sampling methods described in this document and elsewhere (UNEP 2018b).

The WHO estimates a tolerable air exposure concentration of 0.2 microgram per cubic meter for long-term inhalation exposure to elemental mercury vapor (IPCS 2003; WHO 2007). The WHO also defines a long-term air exposure concentration of 1 microgram per cubic meter that is considered unsafe on an annual average (WHO 2000, 2007). Governments have also established guideline values for acute and chronic exposure to mercury vapor in workplaces. In the United States, reference standards have been established for occupational exposure over a 40-hour work week: 50 ug per cubic meter (NIOSH (National Institute for Occupational Safety and Health) 1994), and ceiling levels for total maximum exposures at any given time, known as the Immediately Dangerous to Life or Health (IDLH) reference level: 10 mg per cubic meter (NIOSH (National Institute for Occupational Safety and Health) 1994).

Ambient air measurements using passive air samplers are particularly applicable for comparisons against these guideline values because their ability to produce time weighted and integrated concentration measurements.

5.3.2 Estimating Dietary Intake Risks from Mercury Exposure

Most people are primarily exposed to mercury from consuming fish. Methylmercury is the dominant chemical form of mercury in fish. Compared to other chemical forms of mercury, methylmercury has a higher toxicity, more readily accumulates in the body, and biomagnifies, reaching increasingly higher concentrations at higher levels through the food web.

In regions with potential mercury contamination from ASGM activities, methylmercury concentrations can reach high levels in fish and shellfish in aquatic ecosystems that are nearby or downstream from such activities. However, mercury release from ASGM activities can also contaminate other important food sources including grains, and sources of meat. Little is known about the types of food sources that may be contaminated with mercury from ASGM, or the chemical forms and concentrations of mercury in these other food sources. Therefore, compared to fish, estimating dietary risks from these other food sources is less straightforward. Nevertheless, total mercury concentrations in food items from contaminated and control sites can be compared to assess whether food contamination is occurring.

A number of government agencies have derived guidance values for mercury levels in fish and shellfish, that when exceeded, indicate unsafe health risks from dietary mercury exposure (WHO and UNEP 2008). A rapid assessment can indirectly estimate dietary risk by using guidance values to screen for food sources with elevated mercury content. However, in reality, exposure and risk from dietary mercury sources is more complex and depends on the consumption of multiple food sources that contain different amounts and forms of mercury. Direct estimates of dietary exposure can be obtained using approaches that include administering detailed diet questionnaires and biomonitoring (WHO and UNEP 2008) that are beyond the scope of a rapid assessment.

The US EPA established a water quality criterion wet weight concentration of 0.3 milligrams per kilogram (parts per million) for methylmercury in fish to protect consumers in the general population (USEPA 2001). Fish concentrations that exceed this concentration are considered unsafe. Other countries have established higher guidance values (WHO and UNEP 2008) that are therefore less protective. Since it can be reasonably assumed that most of the total mercury in fish is in the form of methylmercury, the USEPA criterion value can also be applied to total mercury concentrations in fish.

Alternatively, rapid assessments can compare estimates of dietary mercury intake in a population based on consumption habits and mercury concentrations in food use provisional tolerable weekly intake (PTWI) or reference dose (RfD) values. The joint FAO/WHO provisional tolerable weekly intake (PTWI) value was established as 5 micrograms per kilogram body weight for total mercury, and 1.6 micrograms per kilogram body weight for methylmercury (WHO and UNEP 2008). PTWI values indicate the amount of a substance that can be safely consumed per week over the course of a lifetime. The USEPA developed a lower, hence more protective RfD of 0.1 micrograms per kilogram body weight per day for methylmercury.

To determine mercury dietary risk, the estimated mercury intake or dose (micrograms per kilogram body weight per week or per day) is divided by the PTWI or RfD to calculate a Hazard Index (WHO and UNEP 2008). A Hazard Index >1 indicates risk of adverse health effects, whereas values <1 indicate a lack of a likely risk. It is generally assumed that the health risks increase with increasing Hazard Index values. Example calculations, as well as descriptions of the additional steps in decision making for risk managers is described in detail elsewhere (Chapters 4 and 7, WHO and UNEP 2008).

5.3.3 Estimating Drinking Water Intake Risks from Total Mercury Exposure using WHO Guideline Values

Drinking water is another possible route of mercury exposure related to ASGM activities. The primary chemical form of mercury in water is inorganic mercury. However, other mercury forms can occur in the dissolved phase. Total mercury, rather than individual chemical forms, is more commonly measured in water. However, total mercury concentrations can be too low to detect except for more contaminated systems. The WHO has derived a guidance value of 1 microgram per liter for total mercury (WHO 2007). Total mercury concentrations above this value are considered unsafe.

5.3.4 Caveats to Data Interpretation

Interpretation of the risk estimates from any rapid assessment should be done with caution and should include a characterization of sources of uncertainty. For example, one source of uncertainty may be that the chemical form of mercury (e.g., methylmercury or inorganic mercury) in a dietary item or other exposure source is unknown. More information on characterizing risk uncertainty is available in other sources (USEPA 2011). In general, risk estimates from a rapid assessment can be reasonably assumed to provide initial evidence of safe or unsafe exposure levels, and guide additional, more comprehensive monitoring and risk assessment if necessary.

6. Dissemination of Results, Human Exposure Management and Monitoring

Due to its limited scope, the information gained from a rapid assessment may not be sufficient to fully characterize, communicate and manage mercury exposure risk. Rather, the goal of a rapid assessment is to provide initial, field-based data on environmental mercury contamination to serve as baseline to inform the design of, and compare to, a more comprehensive risk assessment study. Ultimately, the rapid assessment is meant to support countries with NAPs in setting a strategy to prevent the exposure of vulnerable populations, particularly children, pregnant women, and women of child-bearing age, to mercury used in ASGM as required by the Minamata Convention.

Nevertheless, it is informative for a scaled-down rapid assessment, or qualitative assessment, to consider the latter steps of a full risk assessment study, including how to disseminate the results, manage or mitigate exposures, and communicate risks to the public. General as well as detailed information on these latter steps of risk assessment can be found in other sources. For example, WHO developed a Risk Managers Decision Tree that provides overall guidance and details on these latter steps of characterizing and managing risk. The USEPA also provides guidance for how to characterize risk, including providing sources of information for decision makers and other audiences (USEPA 2000).

6.1 Managing human exposure risks

Information on how to manage and mitigate human mercury exposures specifically from ASGM activities, including developing a public health strategy and providing information to communities have been described in NAP guidance document (UNEP 2017; WHO and UNEP 2018). In general, decisions on managing exposure risks will depend on the type of exposure routes deemed to be unsafe. However, exposure management decisions are often complex, and rely on a sufficient amount of information that may only be available from a more extensive risk assessment study. For

In a rapid assessment, environmental mercury data serve as indicators that can be used to identify exposure routes and health risks (See Section 5.3). In a simplified, qualitative assessments, information on mercury use practices, proximity to vulnerable populations, and related information serve as indicators that can help identify potential exposure routes. Thus, information from either a rapid quantitative assessment, or from a qualitative assessment can be used to develop a public health strategy as required by the Minamata Convention. Detailed descriptions of the process for developing a public health strategy specifically in the context of mercury use in ASGMs are provided in the NAP Guidance Document Sections 5.8 and 5.9 (UNEP 2017) and from WHO (WHO and UNEP 2018) and should be considered in order to manage health risks identified from the assessment.

example, decisions on managing dietary exposure risks should consider the nutritional benefits of food items, as well as the dietary habits of individuals which may be variable and difficult to quantify. Therefore, understanding the value as well as the limitations of the information gained from a rapid assessment will help guide whether management decisions are possible, or require additional information.

6.2 Dissemination of Results and Risk Communication

6.2.1 Dissemination of results to the public and various stakeholders

Public outreach, awareness raising and capacity building are critical steps in order for the information produced in the rapid assessment to inform and generate an impact on society members, stakeholders, and decision makers. The appropriateness and quality of the communication materials will serve as a basis for press conferences, informational meetings, technical workshops, public awareness building events (e.g educational events, public fairs), policy hearings and legal proceedings.

> The effective dissemination of the results stakeholders the public should be considered a vital part of the process of developing a rapid assessment. Often, concerns of key stakeholders and a lack of information are the primary reasons why a rapid assessment is initially commissioned and funded.
>
> Therefore, the information developed from the rapid assessment must be provided, promptly and effectively, to the stakeholders that commissioned the work, and to stakeholders that are invested, involved and participate in the larger system that the rapid assessment observed and studied.

Without this step, the change in knowledge achieved by a successfully executed assessment will not be realized. It is only through the act of effective communication which can increase the awareness of critical issues, inform on key findings and more subtle results, and build working knowledge of the implications of these findings, that the change in state of knowledge can be accomplished. Actors such as community groups, government agencies, NGOs, professional organizations and academia are all important components of a community of knowledge and community of practice that can be supported by the results of the rapid assessment (O'Neill and Telmer 2017). Stakeholders that participated in the development of the baseline estimates of mercury use as part of the Minamata Convention process should also be included, as these actors will have a native and invested interest in the rapid assessment results and serve as important allies in the dissemination and context setting findings and recommendations.

The public is a vital stakeholder that should always be included in the dissemination of the results of a rapid assessment. Frequently left out of consideration, the dissemination of findings to general audiences must be planned from the initial design of the assessment. The objective of communication to the public is to effectively transmit information, context and significance of findings to local residents and a wider public such that they understand this information and can accurately communicate it to another person.

Striving for this level of comprehension is a challenging goal, especially in areas where access to education and public communication is limited, but it is an important goal to strive towards if change is to be achieved. Since it cannot be expected that general audiences can effectively use technical documents produced for other audiences, dedicated resources should be planned and budgeted to create appropriate types of communication and outreach material to achieve these goals. If assessment resources are limited, it may be tempting to eliminate the communication segment of the rapid assessment process. However, resource constraints can be mitigated by using networks of allied organizations that are already in place to get the message out and reach key audiences. Effective communication to key, highly connected actors and information hubs can multiply reach significantly. The use of social networks, such a Facebook, Twitter, and Instagram can be very effective tool for low-cost and rapid dissemination of information. The use of visualization products such as images, infographics and diagrams can also help aid greatly in increasing comprehension of complex and unfamiliar technical concepts.

6.2.2 Risk Communication

Once the findings of the rapid assessment are developed, it is critical that these results are translated into narratives so that a range of non-technical audiences can quickly understand the main points and be able to communicate them to others accurately. Risk communication is frequently one of the more challenging aspects of rapid assessments focusing on mercury contamination. Partner groups participating in

mercury rapid assessments, including ASGM mining community members using mercury and non-mining community members which may be potentially impacted, often have low knowledge of mercury exposure risks but have high levels of interest and concern. Communicating assessment results within a context of relative risk to these key stakeholders requires prior knowledge about baseline interests and context on how these audiences are likely to view the results.

Although a comprehensive discussion of risk evaluation and risk communication is outside the scope of this section, resources exist that can help with the development of a well-structured risk evaluation and communication plan (USEPA 2007). Specific strategies for disseminating information and communicating risk based on assessment results are also detailed in the NAP Guidance Document, Section 5.10 (UNEP 2017). Below, some practical observations derived from field experience in several ASGM communities are offered.

A key principle in risk communication is to convey the level of risk as accurately as possible, knowing that harm may be done if health risks are overestimated or underestimated. The health effects of mercury exposure are well documented (WHO 2007; WHO and UNEP 2008; IPCS 2003), and are typically the focus of concern and for risk communication. The health effects from acute exposures are well understood and communicated relatively easily. However, the risks of negative health effects from lower level, chronic mercury exposures are less well understood, more difficult to detect, predict, hence communicate. Risk communication is particularly challenging with communities that have countervailing interests and are predisposed to skepticism. Despite these challenges, it is important to communicate risk as accurately as possible, particularly with trusted and non-partisan members of the population such as health care workers, social welfare workers, religious leaders, and traditional healers who may serve as interlocutors with other community members.

Rapid quantitative assessments and simplified qualitative assessments are somewhat limited in terms of the scope and depth of information gathered, and the characterization of risk. Therefore, effective risk communication may be more challenging compared to a full scale risk assessment study in which more information is known, and risk more thoroughly characterized and understood. In cases where larger assessments include direct measurements of human exposure through monitoring human hair samples, for example, an important principle that must be considered is the return of testing results to study participants. The rule of thumb is that test information should always be returned to the individuals, and potentially to the community, from which they were collected. In addition to the baseline requirements of national ethics boards permissions needed for any human study, there should be a clear agreement with each participant regarding if and when individual results will be returned. Returning results builds confidence and trust with participants and their communities and can significantly increase engagement and awareness with community members. Following the risk communication principles, test results should be shared in a way that participants can understand and should be placed in a context that will allow them to understand the risks these findings represent and the possible implications.

A final core principle of risk communication is the importance of communicating any major sources of uncertainty (USEPA 2011). For example, many factors that are important in determining exposure risks are not considered in a rapid assessment, such as the chemical form of mercury to which individuals are exposed, exposure duration, magnitude, and frequency, and the sensitivity of different exposed subpopulations or individuals to mercury toxicity. Although explicitly communicating these factors to non-technical audiences may not be practical or feasible, the uncertainty that results from these factors should be made clear, and should be considered in understanding the implications, and developing recommendations for behavior changes that will reduce health risks.

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