Future perspectives on mercury waste management and role of the multilateral environmental frameworks

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[Abstract]

Mercury is a chemical element that exists on the Earth since its creation. In natural cycle, deep seabed serves as the global mercury sink. Behaviour of mercury at waste landfill facilities is being considered to enhance understanding of mercury retained in the facilities. Waste incineration facilities are potential sources of mercury emissions depending on the emission reduction devices equipped with the facility. On the other hand, a large portion of mercury is retained in the landfill sites even without proper control. Spontaneous waste combustion releases mercury into atmosphere but the degree of impact is not known as the survey method has not been established. Waste landfill could serve as an important artificial sink to reduce mercury in the society and the environment. Open burning and spontaneous combustion of waste significantly increase the mercury emission; thus, the preventive measures as well as source segregation are important for better mercury waste management. The Minamata Convention on Mercury requires the sound management of mercury wastes, while the United Nations Environment Programme and the Global Mercury Partnership often play important roles in connecting mercury science and practical solutions.

[Keywords] Mercury waste, UNEP, Global Mercury Partnership, Minamata Convention on Mercury, Global mercury sink

[Introduction]

Mercury is a chemical element that exists on the Earth since its creation. Elemental mercury is in liquid form at normal temperature, while the form can be changed by physio-chemical and biological reactions. In the biosphere, a huge amount of mercury stocks exists in the ocean and soil, and natural flow of mercury occurs at global scale (Amos *et. al.* 2013). Mercury is emitted to the air and released to water and land as a result of anthropogenic or human activities, and from natural sources and processes such as volcanic activities and rock weathering (UNEP 2019a). It circulates globally, and finally returns to the Earth's crust at the deep seabed, which serves as the global mercury sink. Unlike manmade chemical pollutants, mercury exists naturally. The global sink has thus received a certain amount of mercury throughout the Earth's lifespan.

Anthropogenic flow of mercury has been added on to the natural flow since human beings intentionally and unintentionally extract mercury and release it to the environment. The anthropogenic mercury use started as early as the Stone Age (Emslie *et. al.* 2015). Some evidence indicates that prehistoric man used mercury compound as red pigment, which is found in cave paintings and cinnabar deposits in burials. The amount of mercury emissions and releases has significantly been increased since the Industrial Revolution when a large amount of coal was used as a source of energy. Mercury uses, emissions and releases diversified as new technologies, industries and applications were invented and developed. Currently, artisanal and small-scale gold mining (ASGM) is the largest mercury user and source of emissions is accounting for approximately 40% of global mercury emission (UNEP 2019a) and is the sector demanding the largest quantity of mercury (UNEP 2017).

Industrial products such as measuring devices and lamps, and manufacturing processes such as vinyl-chloride production are also large mercury users. The estimated annual flow of mercury from mercury-added products and manufacturing process using mercury as catalysts or electrodes was more than 2500 tons in 2015 (UNEP 2017). After being consumed, these products will be eventually disposed of and enter the waste stream. The Minamata Convention on Mercury, which entered into force in August 2017, aims to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. Amongst others, the Convention provides for the phase down and phase out of a number of products, processes and activities using mercury, and requires the Parties to ensure the environmentally sound management of mercury wastes. The waste management sector has an important role to play in particular as a potential significant "mercury sink", hence avoiding mercury from being released to the environment through the environmentally sound final disposal of the mercury waste. United Nations Environment Programme (UNEP) (2019a) estimated the atmospheric mercury emissions from the waste management sector at approximately 150 tons in 2015. The amount released to water and soil has not been properly estimated but the comparison of these two figures may indicate that substantial amount of mercury is retained in the waste storage and/or landfill facilities. It is important to consider, however, that most developing countries have been facing challenges with capacities to manage mercury wastes in an environmentally sound manner.

[UNEP's actions to address mercury waste issue particularly in developing countries]

In 2005, the UNEP Governing Council called for partnerships between governments and other stakeholders as one approach to reducing risks to human health and the environment from the release of mercury and its compounds to the environment. The UNEP Global Mercury Partnership (GMP) was thus initiated in 2005 with the overall goal to protect human health and the environment from the releases of mercury. The GMP is open to stakeholders who share the Partnership's goal. Currently, with over 230 partners from governments, intergovernmental organizations, non-governmental organizations (NGOs), industry, private sector, academia, scientific community, and others, the GMP focuses on supporting the implementation of the Minamata Convention, providing knowledge and science, and raising awareness towards global action on mercury.

Eight (8) partnership areas from upstream to downstream of the mercury management cycle are operational under the GMP. Established in 2008, the Partnership area of work on waste management works under the objective to promote the environmentally sound management of mercury wastes by developing and disseminating relevant materials, enhancing capacities and awareness, and providing specific solutions at the global, regional, national, and local levels. Collaborating with over 100 partners, the Partnership area demonstrates an effective platform among public and private sectors through identification of challenges, especially in developing countries, dissemination of measures, and capacity building toward environmentally sound management (ESM) of mercury wastes. Activities of the Partnership area are undertaken by 3 Working Groups (WGs). The WG1 is led by International Solid Waste Association (ISWA) and works on resource development. As the Group's flagship activity, WG1 currently focuses on developing factsheets on certain types of mercury wastes for practical use. The WG2 undertakes capacity-building and awareness-raising activities on relevant topics of mercury wastes in collaboration with other Partnership areas. The WG3 promotes matchmaking between stakeholders in need and solution-providers on particular mercury waste management problems. A solution exchange platform will be established for consolidating problem-solving options. The three separate working groups coordinate their activities with one another in order to yield synergies for the work of the Partnership area and for the GMP areas as a whole.

The Basel Convention Conference of the Parties (COP) has adopted the revised technical guidelines on the environmentally sound management of wastes consisting of, containing, or contaminated with mercury or mercury compounds in June 2022, which also provides the basis of mercury waste management under the Minamata Convention.

The factsheets to be developed by the GMP will complement the Basel Convention's technical guidelines to provide practical and comprehensive instructions for safe management of relevant mercury waste streams. They aim to respond to concerns raised by developing countries on the fact that the technical guidelines may not necessarily be practical enough to reflect on the ground reality of developing countries. The survey conducted by the GMP waste management area in 2021 highlighted several waste streams that are of priority for developing countries. Among the 3 mercury waste categories defined by the Minamata Convention, namely waste consisting of mercury, containing mercury, and contaminated with mercury, waste containing mercury (i.e., waste mercury-added products) is the most relevant waste stream among the partners in the waste management area (Fig 1). It includes non-electronic measuring devices containing mercury, spent products containing mercury including fluorescent bulbs, high intensity discharge bulbs, and neon/argon lamps, etc.

These waste streams are commonly found in municipal solid wastes in developing countries but not properly segregated and often disposed of together with other waste. Waste consisting of mercury is mainly elemental mercury coming from activities such as ASGM as well as processes such as mercury-cell chlor-alkali production. An exhaustive list under this category is prepared by the group of technical experts established by the Minamata Convention (2019). Wastes contaminated with mercury mainly comes from industrial pollution control devices such as off-gas cleaning facilities including non-ferrous metal production. The factsheets will aim to provide good practices and examples of relevance to waste management practitioners.

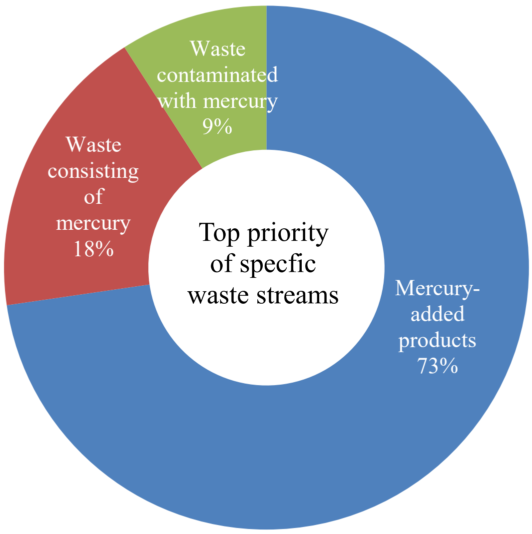

Fig 1 Top priority of specific waste streams in GMP waste management area

GMP Waste Management Area conducted an online questionnaire survey from January to February 2021 to understand the needs on mercury wastes management in developing countries, the result of which was intended to be considered for the Partnership Area's future planning. The top priority areas identified by the GMP partners are classified into the three groups of mercury waste categories defined by the Minamata Convention.

[Fate of mercury from solid waste management facilities]

Landfill of municipal solid waste is a significant mercury retention body in developing countries. With respect to mercury, an important aspect of mercury waste management in landfills will be to immobilize mercury at landfill sites, which have been operated as engineered landfill or poorly managed open dumping. In both cases, most of the mercury waste has often been disposed of together with general waste without proper segregation at source. The amount of mercury released to the environment may vary between well controlled and uncontrolled landfills. Waste combustion sometime occurs at open dumping sites which enhances mercury emissions to the atmosphere, but still certain part of mercury stays in the landfill sites (Saito *et. al.* 2022). Waste landfill is the final process of waste management scheme but very little is known about the fate of mercury in the landfill facilities in comparison with the waste incineration facilities. Incineration is often practiced for many types of wastes, but it is a potential source of mercury emission.

UNEP mercury inventory toolkit (Toolkit) was developed to understand the overall profile of mercury in a country by quantifying the sources of mercury releases. The Toolkit is based on the mass balance principle, but with some simplifications in order to make it easier to operate. One of the major simplifications was the separate calculation of the inputs to waste treatments, which is a major deviation from the principle. It was because the flows to waste of mercury-added products were generally underestimated in developing countries due to lack of data. For the outputs from engineered landfills, the default factors for releases to air and water (meaning leachate) are not mass balance derived, either. This is because no mass balance data is available for landfills. Table 1 shows the output distribution factors of the Toolkit, which is the fraction of mercury going out to particular fate in waste management sector. The factors of incineration plant without emission reduction devices are equal to the open burning of waste (1 to air), which means all mercury is emitted into atmosphere. Also, the factors of incineration plant with mercury-specific adsorbent and informal (uncontrolled) landfill are similar (0.1 to air). Instead, mercury release from well controlled landfill is very low (0.01 to air and 0.0001 to water) and most of the mercury stays in the facility. On the other hand, the fly ash from incineration plants contains certain amount of mercury, which is sometime used for the ingredient of fly ash cement. Mercury in the concrete structure may be gradually released to the environment. The output distribution factor is just an estimate based on the limited information available to date. Such knowledge, particularly the mercury behaviour in open dumping facilities is very limited.

Table 1 Mercury emission factors in mercury inventory Toolkit (UNEP 2019b)

	Incineration				Open waste burning on landfills informally	Landfill	
	No emission reduction devices	PM reduction, simple ESP or similar	Acid gas control with limestone and downstream high efficiency FF or ESP PM retention	Mercury-specific adsorbent		Controlled landfill	Informal dumping of general waste
Air	1	0.9	0.5	0.1	1	0.01	0.1
Water						0.0001	0.1
Land		0.1	0.5	0.9			0.8

PM: Particulate matter, ESP: Electrostatic precipitator, FF: Fabric filter

[Discussion]

Solid waste management is a practical industry with no 'one size fits all' solution. The composition and types of waste vary significantly depending on locations and sectors. The question of "what is good mercury waste management?" has therefore no simple answer. The technical guidelines adopted by the Basel Convention COP aims to provide some guidance towards ESM of mercury waste (Basel Convention 2021). Even with the provision of advanced emission reduction devices, waste incineration is still accelerating mercury emissions to the atmosphere. On the other hand, a large portion of mercury is retained in the landfill sites even without proper control. Spontaneous waste combustion releases mercury into the atmosphere, but the survey method to assess the impact is still lacking and actual survey data is scarce. This is a major gap to connect mercury science to solid waste management practice. The source segregation has seldom been practiced in most of developing countries. It has resulted in the solid waste in the existing landfill facilities containing certain levels of mercury. The fate of mercury particularly in uncontrolled landfills is still an unresolved question.

Fig 2 depicts the mercury concentration scale in soil and waste. As a chemical element, mercury exists in soil at trace level (estimated abundance: 0.085 mg kg^{-1}). Mercury deposition higher than 0.1% is regarded as mercury ore, i.e., resource with commercial value. Thus, mercury waste management in general terms will fall between these two levels, i.e., approx. 0.1 to 1000 mg kg^{-1}. The waste in 25 - 1000 mg kg^{-1} range should be no doubt properly managed as mercury waste although it does not mean that the level below or above is not important. Source separation is basic but the most useful measure to minimise volume of mercury waste by establishing proper recycling/recovery stream and allowing appropriate segregation, treatment, and secure final disposal of mercury. In addition to municipal waste, mine tailing waste sometimes contains mercury at this level, which must be properly managed at each mining site. The waste in 0.1 - 1 mg kg^{-1} range is commonly found in municipal waste particularly in developing countries, which is slightly higher than the background level. Although it will not fall under the category of 'mercury waste', the existing volume in landfill sites is enormous. Thus, preventing mercury emissions, i.e., avoiding open burning of waste or spontaneous waste combustion at landfill sites, is worth considering. The definition of waste contaminated with mercury (between 1 and 25 mg kg^{-1}) is currently discussed under the Minamata Convention, so current situation and fate of mercury described above should be taken into consideration when defining the threshold level.

Mercury is a ubiquitous element. Living creatures were generated in the ocean with mercury, thus it is assumed that the background-level exposure to mercury is embedded into the genetic system from the beginning. The deep seabed serves as a global sink where mercury is buried into the Earth's crust. In addition to the natural sink, mercury waste disposal also has an important role to play, including as a so-called "sink" to reduce mercury in the society and the environment. The magnitude of this anthropogenic sink has not been calculated, yet. Proper estimation of the global mercury sink, and the measures to maximize it is an important research topic for mercury waste management that connects the missing link between researchers and practitioners. For example, open burning and spontaneous combustion of waste significantly increase the atmospheric emissions of mercury from waste landfilling. The preventive measures and the evaluation of their benefits should be developed to enhance mercury waste management practices.

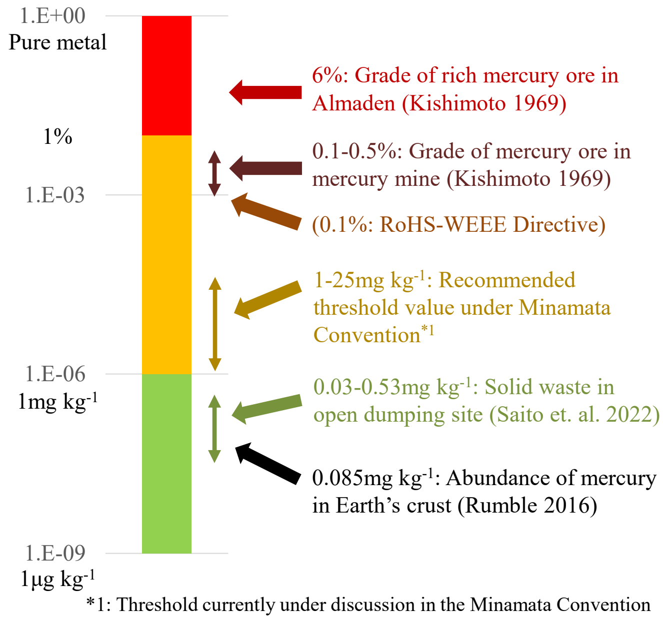

Fig 2 Mercury scale in soil and waste

Mercury levels in soil range from average background level (also known as Clarke number) to rich mercury ore. The mercury levels in solid waste and RoHS Directive are compared with them.

[Conclusion]

Mercury waste management is waste management itself. It is an integral part of environmentally sound waste management. Some aspects are unique to mercury waste, but ESM in line with proper waste management provides the basis of mercury waste management. For example, prevention of open burning and spontaneous combustion contributes to the reduction of particulate matter (PM) and unintentional persistent organic pollutants (POPs). Also, source separation and recycling (3R) will reduce the total volume of hazardous waste that needs special consideration.

UNEP and the GMP play important roles in connecting mercury science and practical solutions and in supporting the implementation of the Minamata Convention, which requires its Parties to ensure the environmentally sound management of mercury wastes. However, most developing countries have been facing challenges with capacities to do so. The GMP has been working together with Parties and relevant stakeholders such as international agencies, NGOs, private sector actors, and academia to control the anthropogenic emissions and releases of mercury throughout its lifecycle including at the stage of waste management.

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[Disclaimers]

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