

DIFFUSION OF MERCURY FROM ARTISANAL SMALL-SCALE GOLD MINING (ASGM) SITES IN MYANMAR

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ABSTRACT: In some developing countries, such as Myanmar, mercury used for gold refining in artisanal small-scale gold mining (ASGM) is emitted into the atmosphere and water, causing environmental pollution. In this study, the diffusion of mercury from ASGM in Thabeikkyin Township, Mandalay Division, Myanmar was investigated. Air samples, water samples and hair were collected from the ASGM sites. The mercury concentration in the atmosphere in the gold mining area reached 74,000 ng/m³ at the maximum concentration, which exceeded the WHO guideline of 1,000 ng/m³. The mercury concentration in the Ayeyarwady River and the groundwater pumped from the gold mining tunnel was 4.6 ng/l and 29-35 ng/l, respectively. The limit of mercury in hair is considered to be 50 µg/g, at which concentration nervous symptoms may appear, while 11 µg/g is the concentration at which adverse effects on fetuses could take place. The average mercury concentration in hair was 1.5 µg/g for ASGM workers, while it was 1.1 µg/g for nonworkers. An analysis of hair indicated that the mercury was not at a level that would adversely affect human health, so far.

Keywords: Mercury, Myanmar, Hair, Water, Atmosphere

1. INTRODUCTION

1.1 Minamata Disease

Organic mercury compounds, such as methylmercury (Me-Hg), which is more intensely toxic than inorganic compounds, could cause neurological symptoms when they are taken into the human body. Minamata disease, mercury-related diseases, occurred in 1950-1960 in Japan. Bioaccumulation took place in the fish and shellfish in Minamata Bay, where industrial effluent contaminated with Me-Hg was discharged. People who ingested such polluted fish and shellfish developed Minamata disease, resulting in loss of consciousness and even, sometimes, death [1].

1.2 The Minamata Convention

The Minamata Convention is a multilateral environmental agreement that obligates parties to reduce or control sources of mercury pollution in order to protect human health and the environment. Since mercury is easily transported across national boundaries [2], international cooperation was required for its control. The Minamata Convention on Mercury, adopted on October 10, 2013, and signed by 128 countries, is a legally binding international agreement that was designed specifically to address global mercury pollution [3]. The objective of the Convention is “to protect human health and the environment from

anthropogenic emissions and releases of mercury and mercury compounds.”

The importance of artisanal and small-scale gold mining (ASGM) on rural development has caused debate among policymakers. However, the Minamata Convention includes a mix of provisions to control and reduce the major sources of mercury, including mercury use in ASGM. For example, the development of national action plans (NAPs) for ASGM is an obligation under Article 7. The best available technology and best environmental practices (BAT/BEP) must be utilized to protect against the sources of air pollution as organized by the convention. The NAP for ASGM is required to regulate the informal sector of ASGM and intends to accomplish this through requirements for countries. Key to such a NAP is the development of mercury inventories and baselines of the ASGM sector in order to monitor improvements and to establish regulatory standards for reduction [3].

On September 24 - 29, 2017, the first Conference of the Parties (COP1) was held in Geneva, Switzerland, to initiate enforcement of the convention.

1.3 ASGM in Myanmar

The government of Myanmar had not yet signed the Minamata Convention when it was closed to signatures on October 9, 2014. However, the government of Myanmar is preparing to ratify the Convention, as stated in a letter addressed to UN Environment and the Global Environment Facility

(GEF) on June 30, 2015. During that period, Myanmar participated in the Asia and the Pacific Regional Workshop to support the ratification and effective implementation of the Minamata Convention on Mercury from March 17 to 18, 2015, in Jakarta, Indonesia [4].

The GEF and the government of Myanmar have initiated the collaboration project titled “Development of Minamata Initial Assessment and National Action Plan for Artisanal and Small Scale Gold Mining in Myanmar.” The project aims at the ratification and early implementation of the Minamata Convention by providing key national stakeholders in Myanmar with the scientific and technical knowledge and tools needed for that purpose [4].

Implementation of the Minamata Convention will require a series of international obligations on the part of the government of Myanmar to reduce the use of mercury and to control the transport and import/export of mercury. These requirements should give the ASGM sector and responsive policymakers a better understanding as to how to improve their environment.

1.4 Mercury Use in ASGM

The mercury in the atmosphere includes both natural and anthropogenic emissions. According to the United Nations Environment Program (UNEP), 1960 tons of the mercury emitted in 2010 came from anthropogenic activities such as ASGM, the burning of fossil fuels, and the production of cement. ASGM is the largest source of mercury emissions. In ASGM, mercury is used to produce a gold-mercury amalgam to extract gold from gold ore. Mercury is vaporized by burning the gold-mercury amalgam to separate gold from the amalgam. This process has been adopted in many developing countries such as Myanmar and Indonesia, since it is an easy and cheap process for purifying gold [6]. It is reported that in the watershed of the Amazon river in Brazil, inorganic mercury turns into organic mercury to bio-accumulate through the food chain after a large amount of mercury has been used for ASGM and released into the environment [5]. The number of workers engaged in ASGM is estimated to be 20 million in more than 50 developing countries. Among them are 650,000 females and 1-1.5 million children [7]. It is concerning that the workers, including children, aspirate gaseous mercury, and the residents around ASGM eat polluted fish.

1.5 Mercury Emissions from ASGM in Myanmar

ASGM is operating in the Thabeikkyin Township, Mandalay Division of Myanmar. Gold

ore is mined underground 20-30 m below the surface by digging a level after making a vertical tunnel (Fig. 1). A large amount of groundwater comes out of the tunnel and is pumped to the residential house in the village near the ASGM for daily life (Fig. 2).

The purification process in ASGM is as follows: Gold ore taken from the mine underground is first dried up and crushed by a powdering machine (Fig. 3). The powder is then put in a pan with water to separate gold particles by gravity. In the bottom of the pan, gold particles are collected with some sand. Mercury is added to the pan to extract mercury by the formation of a gold-mercury amalgam. The gold-mercury amalgam is squeezed through a cloth to remove liquid mercury, which remains without reacting to the gold (Fig. 4). Finally, an operator vaporizes the mercury in the gold-mercury amalgam using a burner to obtain purified gold. The vaporized mercury is emitted into the atmosphere without any treatment, not only polluting the environment but harming human health, especially the health of workers.

In this study, the diffusion of mercury from ASGM in the Thabeikkyin Township, Mandalay Division of Myanmar was investigated to better understand the environment as related to mercury emissions from ASGM.



Fig. 1 Vertical gold mine tunnel



Fig. 2 Groundwater leaked from the tunnel



Fig. 3 A machine that powders gold ore



Fig. 4 Squeezing the gold-mercury amalgam

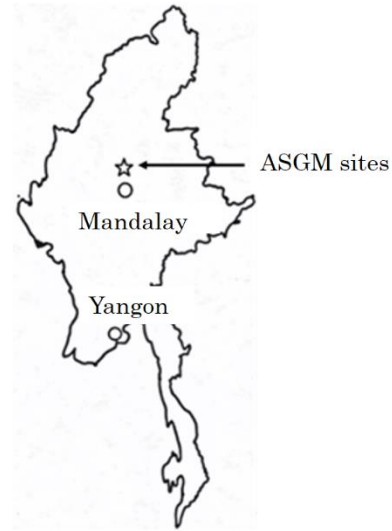


Fig. 5 ASGM sites in Mandalay Division of Myanmar

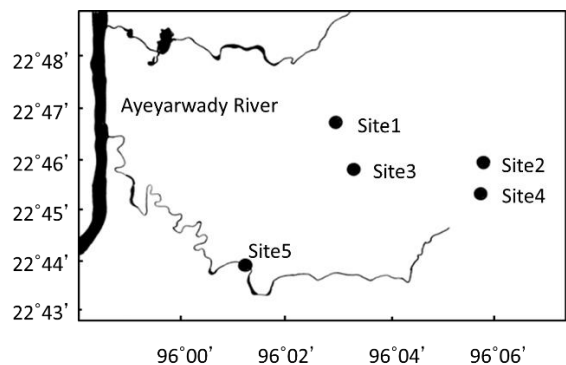


Fig. 6 Enlarged map of ASGM sites

2. MATERIALS AND METHODS

2.1 Site Descriptions

In this study, the diffusion of mercury from ASGM in the Thabeikkyin Township, Mandalay Division of Myanmar was investigated to evaluate the effect of ASGM on the environment. Figures 5 and 6 show Mandalay of Myanmar and the site where ASGM is operating heavily. At the ASGM site, five ASGMs were operating (Sites 1-5 in Fig. 6). The atmospheric mercury concentration was measured at Site 5 to elucidate the spatial distribution. At Site 5, the mercury concentration of the groundwater leaked from the gold mining tunnel, which was pumped to residents, was measured. The groundwater from Sites 1-4 was sampled. The mercury content in human hair was measured for both ASGM workers and nonworkers at Sites 1-5. In addition, the mercury concentrations of the Ayeyarwady River, which flows through Mandalay, were measured.

2.2 Measurement of the Mercury Concentration in the Atmosphere

Mercury exists in the atmosphere as gaseous mercury and particulate mercury. The total mercury is the sum of the gaseous and particulate mercury. The major forms of mercury in the atmosphere are gaseous elemental mercury (GEM, Hg(0)), reactive gaseous mercury (RGM, Hg(II)), and total particulate mercury (TPM, Hg(p)) [8]. Since Hg(0) is hard to dissolve in water, it has a long retention time in the atmosphere, and it contributes 95% of the total mercury in the atmosphere. Hg(p), which adheres to particle matter suspended in the atmosphere contributes several percentage points in general, except near the emission source [9]. Accordingly, the total mercury in the atmosphere can be estimated by measuring the gaseous mercury.

Atmospheric samples were collected by passive samplers and active samplers at the same time. An active sampler system, which collects gaseous and particulate mercury separately, is shown in Fig. 7 [10]. GEM was collected in a tube (M-160, Nippon Instruments Corp., Ltd.) with an air pump (MP-Σ30, Shibata Science). To capture Hg(p), a quartz fiber filter with a pore size of 0.3 μm was attached at the intake nozzle. The air was aspirated at a rate of 0.5 L min⁻¹. The total volume of aspirated air was recorded in the pump system, and the atmospheric mercury concentrations were then calculated from the air volume and the amount of mercury absorbed.

Passive samplers were also used to measure the spatial distribution of mercury [11]. The passive sampler had the same dimensions as the Ogawa passive sampler for sulfur dioxide, which is cylindrical with a diameter of 2 cm and a length of 3 cm. Diffuse plates with a thickness of 2mm and 22 holes were placed at both ends of the cylinder. As an absorber, a quartz fiber filter coated with gold was set inside the diffuser plate (Fig. 8). The main body and the diffuser plates were made of fluorine resin, which allows the sampler to be cleaned in acidic solution. The mercury absorbed on the quartz fiber filters was converted proportionally to the atmospheric concentrations by using the atmospheric concentrations obtained by the active sampler system.

Two and three active samplers and 13 and 17 passive samplers were placed at various locations around the ASGM for the first survey from March 2 to 3, 2017, and for the second survey from October 19 to 20, respectively. The passive sampler was set under the roof of ASGM facilities and residential houses and attached to trees. It was covered with a cup so as not to get wet from rain when it is attached to trees. Active and passive sampling continued for 24 hours. Gaseous and particulate mercury collected by the active and passive samplers was measured using a heat-vaporizing atomic absorption method (MA-2, Nippon Instruments) after taking them to Japan. The instrument has a detection limit of 0.03 ng. When a passive sampler is used, the absorbed mercury on the quartz fiber filters cannot be converted directly into the mercury concentration in the atmosphere. To obtain the ratio between the atmospheric mercury concentration and the amount of mercury adsorbed into the filter, both active and passive samplers were operated simultaneously at two or three points in the same location. Assuming that the amount of mercury measured by a passive sampler is proportional to the atmospheric mercury concentration measured by an active sampler, the

amount of mercury obtained by a passive sampler was converted into the atmospheric mercury concentration based on the proportion [11].



Fig. 7 Active sampler system operated with a dry battery

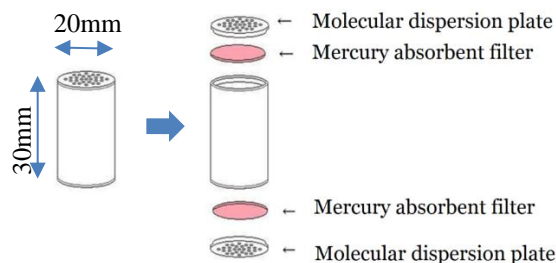


Fig. 8 Passive sampler. Quartz fiber filters coated with gold are placed inside the diffuser plates.

2.3 Measurement of Mercury in Water Samples

Bromine chloride solution, prepared by mixing 1.08 g of KBr and 1.52 g of KBrO₃ into 100 mL of hydrochloric acid, was used for cleaning the sampling bottles and the degradation of the organic matter in the sample water. Samples collected in Myanmar were kept in Teflon bottles washed by a bromine chloride solution and pure water. Ten mL of 0.1% L-cysteine solution was added to every 1 L of the sample solution to prevent the vaporization of mercury and the adherence of mercury to the walls of bottles. After adding the L-cysteine solution, samples were taken to Japan for analyses. The reduction vaporization method was applied for analysis. Five mL of bromine chloride solution was added to every 1 L of the water samples one day before analysis to degrade organic matter. On the following day, 200 mL of the samples and 2 w/v% of hydroxylammonium chloride solution were mixed in a reduction bottle to deactivate the bromine chloride. After 10 mL of 50 v/v% sulfuric acid solution and 10 mL of 10 w/v% tin(II) chloride

were added, mercury vaporized by bubbling was analyzed by a gold amalgam method using a mercury analyzer (MA-2, Nippon instruments) [12].

Two well water samples were collected at each site shown in Fig. 6: Site1 (Kapani village), Site2 (Khwin 31 Village), Site3 (Latpanpyant village), Site4 (Wattay village and Phatshae village), and Site5 (Chaungyi village). Groundwater leaked from the gold mine tunnel was collected at Site 5. Ayeyarwady River water was collected at the center flow of the river in the city of Mandalay, which is located downstream of the ASGM sites. Ayeyarwady River water upstream of the ASGM sites was also collected.

2.4 Measurement of Mercury in Human Hair

The mercury content in hair samples taken from 39 ASGM workers and 11 nonworkers (age:18-57) from Sites 1-5 was measured by the heat-vaporization method with the mercury analyzer (MA-2, Nippon instruments). Hair samples were taken in accordance with the protocol permitted by the ethics committee of Toyama Prefectural University, permission number H29-6 on the effect of the use of mercury in ASGM in Myanmar on human health.

3. RESULTS AND DISCUSSION

3.1 Atmospheric Mercury around the ASGM in Myanmar

In Fig. 9, the distribution of the gaseous mercury concentration from the first survey is shown as bars. The highest concentration of 10,900 ng/m³ was observed near a small house where the burning process took place at the ASGM site. It was more than ten times the WHO guidelines of 1,000 ng/m³ [13]. Even in the residential area outside the ASGM, the lowest concentration measured 130 ng/m³ which is a much higher level than the 0.9 -1.5 ng/m³ in non-polluted areas [14,15].

In Fig. 10, the distribution of the gaseous mercury concentration from the second survey is shown as bars. The highest concentration of 74,000 ng/m³ was observed in the same place where the highest concentration was observed in the first survey, even though there was no burning during the 24-hour sampling. ASGM workers should aspirate higher concentrations of mercury during

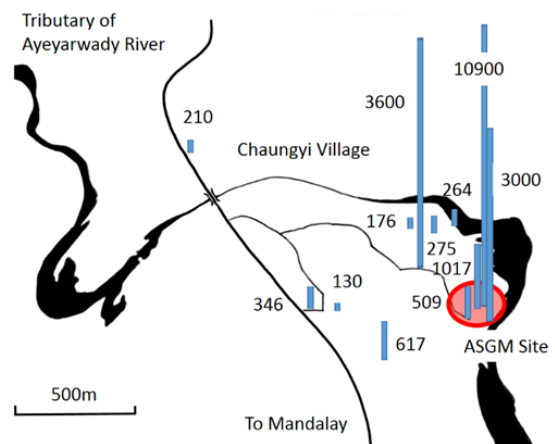


Fig. 9 Spatial distribution of Hg(0) observed in the first survey (unit: ng/m³)

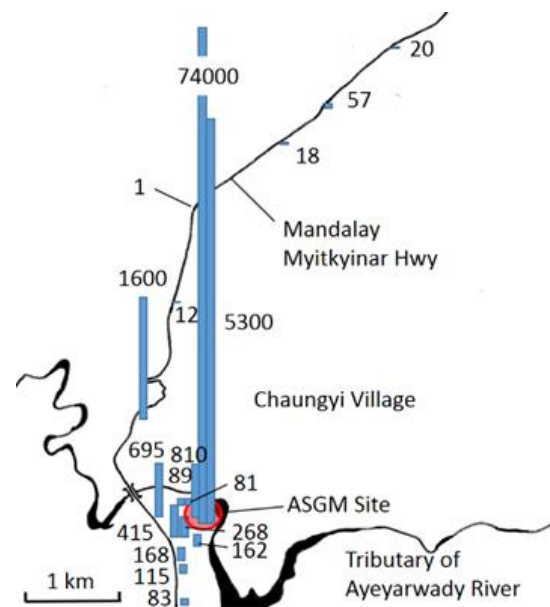


Fig. 10 Spatial distribution of Hg(0) observed in the second survey (unit: ng/m³)

the vaporization of mercury at the small house. In the main office of ASGM, 5,300 ng/m³ of mercury concentration was measured. Even in the residential area outside the ASGM, generally higher concentrations, with a maximum concentration of 1,600 ng/m³, were observed. The highest concentration was observed in front of the so-called gold shop, where the gold-mercury amalgam brought by the village people was burnt, and the gold shop bought the resultant purified gold. The gold shop sold mercury and goods needed for ASGM, such as pans. The highest concentration of mercury indicated that the burning process was also taking place in the gold shop outside the ASGM. In

fact, residents of the village dug tunnels in their backyards to obtain gold ore, and they do gold-mercury amalgamation in their house as part of their everyday activities. This is the reason for the high concentration of mercury that prevailed throughout the entire village. The high concentrations of gaseous mercury of 10-1461 ng/m³ were reported outside the ASGM area in Central Sulawesi, Indonesia which was one of the largest ASGM sites in Indonesia with 760 ASGM plants [16]. The usage of mercury outside the ASGM may be the reason why a higher level of gaseous mercury was observed in Myanmar than that in Central Sulawesi.

3.2 Mercury Concentration in Water

Table 1 shows the mercury concentration in water samples. The sample taken at the center of the Ayeyarwady River in Mandalay located downflow of the ASGM showed 4.6 ng/L. Even the sample taken from the upper flow of the Ayeyarwady River showed 3.8 ng/L. Comparing these concentrations with the typical mercury concentration in lakes and rivers, 1-3 ng/L [17], the mercury concentration in the Ayeyarwady River was slightly higher but not exceptionally so.

Groundwater leaked from the ASGM tunnel was 29.3 ng/L and 34.5 ng/L in the first and second surveys, respectively. The groundwater at Site1 and Site 4 also had concentrations higher than 20 ng/L. Although none of the samples exceeded WHO guidelines for drinking water, 500 ng/L [18], the use of mercury in ASGM could affect the mercury concentration in groundwater, since most of the mercury in groundwater is derived from atmospheric sources [19].

Table 1 Mercury concentration in water samples collected in Myanmar

Site	Type	Hg (ng/L)
Site 1	Groundwater	20.9
	Groundwater	12.1
Site 2	Groundwater	0.0
	Groundwater	2.0
Site 3	Groundwater	1.2
	Groundwater	0.0
Site 4	Groundwater	20.1
	River water	12.9
	Leaked water	29.3
	Leaked water	34.5
Site 5	Water to the village	27.1
Ayeyarwady River	Upper	3.8
	Lower	4.6

3.3 Mercury Content in Hair

Hair mercury is a biomarker for Me-Hg and is often used to characterize Me-Hg exposures [20]. The lowest limits of mercury considered to pose risks of neurosis and health concerns to unborn babies are 50 µg/g and 11 µg/g, respectively [21]. Figure 11 shows the mercury content in the hair of ASGM workers and nonworkers. The maximum levels of the ASGM workers and the nonworkers were 5.7 µg/g and 2.9 µg/g, respectively. The average levels of mercury content in the ASGM workers and the nonworkers, 1.5 µg/g and 1.1 µg/g, respectively, were within the normal level of 1-2 µg/g [18]. Nonworkers seemed to have lower levels; however, based on t-test, there were no significant differences between the two groups. The lower mercury level in hair may be due to less indexicality of hair for mercury vapor [18].

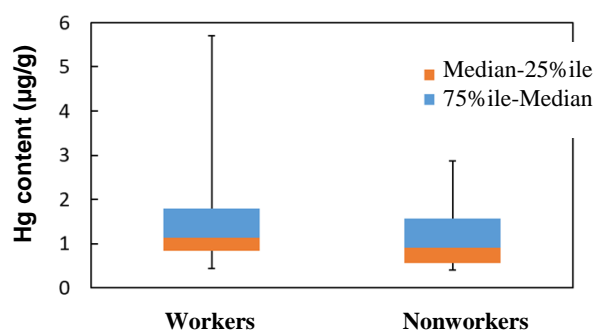


Fig. 11 Mercury content in the hair of ASGM workers and nonworkers

4. CONCLUSION

The government of Myanmar has initiated a collaborative project called “Development of Minamata Initial Assessment and National Action Plan for Artisanal and Small Scale Gold Mining in Myanmar”. The project’s goal was the ratification and early implementation of the Minamata Convention by providing key national stakeholders in Myanmar with scientific and technical knowledge and tools needed for that purpose.

In this study, mercury concentrations in the atmosphere, water, and human hair were measured in two surveys in ASGM areas in the Thabeikkyin Township, Mandalay Division of Myanmar performed in March and October 2017.

The first and second surveys revealed that the highest concentrations of mercury in the atmosphere of ASGM sites reached 10,900 ng/m³ and 74,000 ng/m³, respectively. Even in the village outside the ASGM, concentrations higher than the WHO guidelines of 1,000 ng/m³ were observed. This was caused by the use of mercury for gold

mining in village households and by the burning process taking place at the gold shop.

In the ASGM site, groundwater, especially the groundwater leaked from the gold mining tunnel, had elevated concentrations of mercury, indicating that ASGM had contaminated the groundwater with mercury. Although the mercury concentration was much lower than the WHO guidelines, the mercury concentration in the Ayeyarwady River could be affected by ASGM as well.

An analysis of hair indicated that the average levels of mercury content in the ASGM workers and the nonworkers, 1.5 µg/g and 1.1 µg/g, respectively, were within the normal level of 1-2 µg/g. Based on t-test, there were no significant differences between the two groups. To this point, the mercury is not at a level that would adversely affect human health.

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