Artisanal and small-scale gold mining in Myanmar: Preliminary research for environmental mercury contamination

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Abstract

This study investigates artisanal and small-scale gold mining in Myanmar and presents analytical data on mercury pollution for the first time. The way of gold mining in Myanmar is detailed. The sampling and investigation areas were Kyaikhto in Mon State, Shwekyin in Bago Region, the middle reaches of the Ayeyarwaddy River in Mandalay and Sagaing regions, and north of Kalewa in Sagaing Region. The total mercury concentrations of river sediments and human hair samples were determined by cold vapor atomic absorption spectrometry. Some river sediments were contaminated and the highest mercury concentration of 81 μg/g was found in a sample from Ayeyarwaddy River. The total mercury concentrations in the hair of mineworkers ranged from 0.6 to 6.9 μg/g and the average value was 2.9 μg/g, which is 2.4 times higher than the value of non-mineworkers. Although the data obtained in this study was not sufficient, the results indicated that the environment of Myanmar may be contaminated with mercury that originated from artisanal and small-scale gold mining. Large-scale environmental investigation is required in the near future to determine the detailed situation for water quality and human health.

1. Introduction

Since the occurrence of Minamata and Niigata Minamata diseases, mercury pollution has been a serious environmental pollution problem for the human race. The ruinous disaster of Minamata disease taught us the importance of mercury management, and such catastrophic disasters have been practically eliminated from developed countries. However, mercury pollution has become increasingly serious worldwide because of artisanal and small-scale gold mining in developing nations. On January 19, 2013, a new convention, the Minamata Convention on Mercury, was universally approved at the fifth session of the Intergovernmental Negotiating Committee (held in Geneva, Switzerland) to prepare a global legally binding instrument on mercury (INC5). The purpose of the global treaty is to prevent global environmental pollution and health hazards due to anthropogenic emissions and release of mercury; the Minamata Convention on Mercury includes international regulations for the informal sector of artisanal and small-scale gold mining.

Small-scale gold mining, which is widely conducted in developing nations, extracts gold using simple tools and methods. Most miners adopt the amalgamation method to obtain gold because of its simplicity. This primitive mining process has been used since ancient times. The amalgamation method and the toxicity of mercury are described in Naturalis Historia, published by Gaius Plinius Secundus in AD 77–79. In the gold mining process, wet gold ore is mixed with metallic mercury, which is easily alloyed with the gold. The mud is removed and remnant gold amalgam is then recovered and heated to release the mercury.

Artisanal and small-scale gold mining is a major source of income in many countries. An estimated 100 million people live by mining gold [1], meaning that massive amounts of mercury are used and most mercury is exhausted to the atmosphere from gold

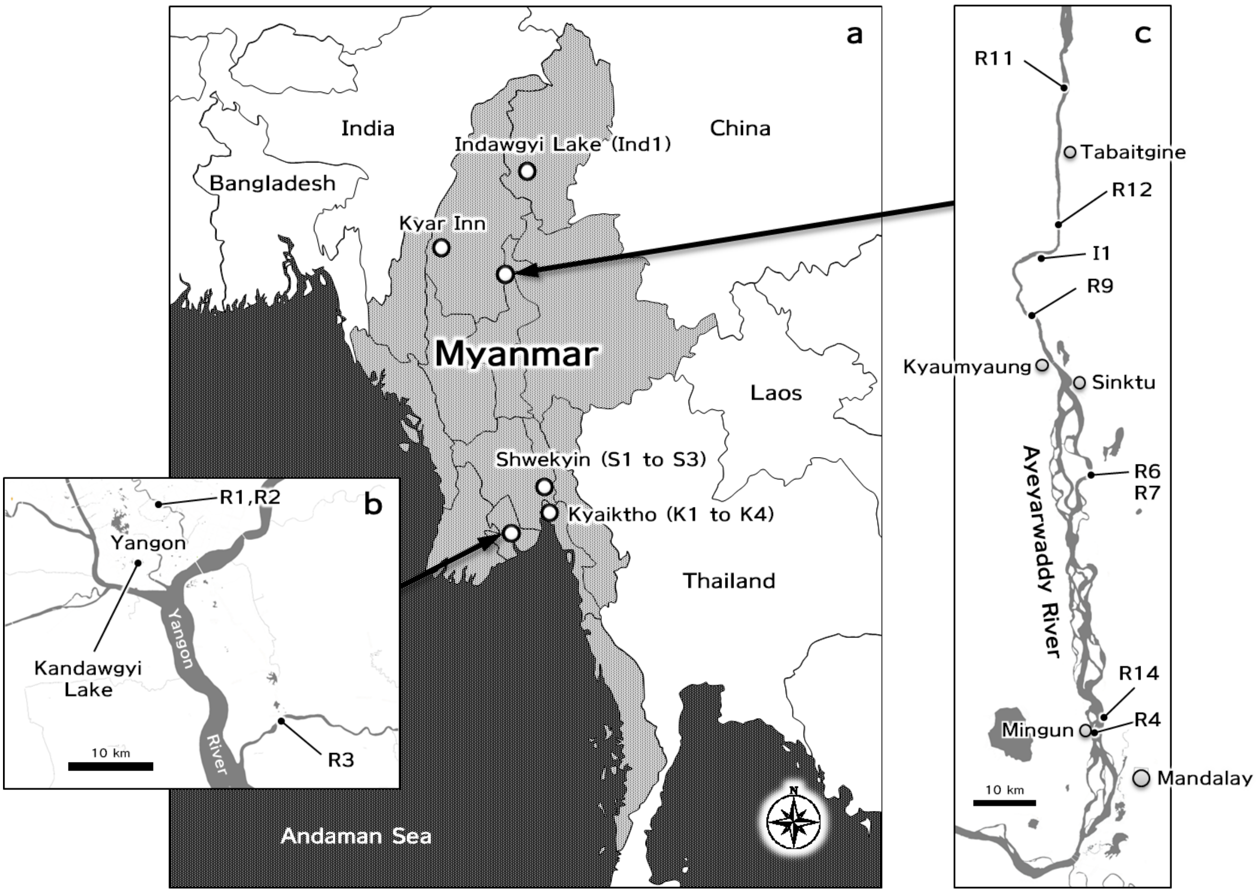

Fig. 1 Sampling and investigation sites in Myanmar. The numbers shown in (b) and (c) are the numbers of sediment samples.

amalgam by heating. Mercury concentrations in air as high as 60 mg/m^3 have been associated with amalgam burning at a mining site [2]. Therefore, the use of enormous amounts of mercury in small-scale gold mining has become a major environmental problem in recent years because such local environmental pollution due to mercury significantly increases the risk of health hazards around the mining area. In cases of small-scale gold mining in developing countries, proper control techniques to prevent diffusion of mercury are not used.

Although some reports on the effects of mercury pollution from gold mining have been published in Tanzania, Brazil, Philippines and Mongolia [3-10], information on mercury pollution in Myanmar is lacking. In particular, information on environmental pollution in Myanmar is extremely limited and there are no data on mercury pollution, although Moody (2000) [11] and Kyi Htun (2014) [12] provide valuable information on the state of mining in Myanmar. Images Asia & Pan Kachin Development Society (PKDS) (2004) [13] and Images Asia & Kachin Development Networking Group (2007) [14] provide important information on small-scale gold mining in Kachin State, but these papers contain no scientific data and the reports focus only on Kachin State. Earth Right International and Karen Environmental and Social Action Network (2003) [15] also provide valuable information on gold mining in Shwekyin, but it is not scientifically interesting.

The lack of information on environmental analysis in this nation is not unrelated to the political situation. As Myanmar has been ruled by a military regime for many years and the government had closed the country to foreigners, mercury pollution resulting from artisanal and small-scale mining in this nation has not been discussed. Although Myanmar has now been working on various measures for democratization and

Fig. 2　Placer mining in the middle reaches of the Ayeyarwaddy River. (a) Gold panning in a river (*ta-naing-ta-paing ye-myaw*). (b) A wooden sluice with a water pipe (*si-phwa-phyit kone-myaw*). (c) A placer mining pit with a depth of over 10 m. (d) Gold mining boat (*si-phwa-phyit ye-myaw*).

national reconciliation, the entry of foreigners to many parts of several states in this nation is still prohibited, indicating that it is difficult for foreigners to investigate the environments of mining areas in Myanmar.

This paper is the first scientific report on small-scale gold mining in Myanmar. The results of mercury measurements of river sediments, tailings, small fish and human hair samples from mineworkers and non-mineworkers in mining areas are presented.

2. Small-scale mining in Myanmar

Gold mines are widely distributed in Myanmar from Kachin State in the north to Tanintharyi Region in the south. The main mining areas are Kachin State, Sagaing Region, Mandalay Region, and Bago Region.

Various small-scale gold mining styles are used in Myanmar, which can be classified into two groups based on the scale, i.e., *si-phwa-phyit* and *ta-naing-ta-paing* in Burmese. *Si-phwa-phyit* is relatively large-scale mining, in which some machines are usually used to improve the efficiency of gold gathering. Conversely, *ta-naing-ta-paing* is small-scale mining, in which machines are never used (Fig. 2a). Using another criterion, gold mining can be classified into *kone-myaw* and *ye-myaw*. *Kone-myaw* means "washing on land," and ye-myaw means "washing in the river." Therefore, gold mining in Myanmar can be classified into four styles, i.e., *ta-naing-ta-paing ye-myaw*, *ta-naing-ta-paing kone-myaw*, *si-phwa-phyit ye-myaw*, and *si-phwa-phyit kone-myaw*. These classifications not only describe a mining method but also determine the associated lifestyle and economic activity. In addition, the health risks from mercury may be different for each style.

There are four main methods used for placer gold mining in Kachin State, i.e., panning, river mining with bucket dredges, suction dredging, and hydraulic mining [13]. Although the mining methods can be classified using various criteria, only three tools are universally used, i.e., pan, carpet, and wooden sluice. The carpet is usually an artificial turf. The wooden sluice (called *Myaw-sin* (Fig. 2b) in Burmese) is assembled by hand and miners never use a ruler, even an anthropomorphic unit. They use neither nail nor hammer and bind the wood with string. The carpets are laid on the wooden sluice. Gold-bearing material is mixed with water and is washed on the sluice. In the case of *si-phwa-phyit*, the muddy water, called *Byone* in Burmese, is drawn up with a diesel engine, which is usually made in China. Note that a 100 horsepower cheap engine appeared in this country in recent years, and the gold rush was revived. Although the inferior Chinese-made turbines are frequently destroyed, many people are enthusiastic about gold mining. As another diesel engine is required to draw up the river water to blast the riverbank and make muddy water, two engines are necessary for gold mining. Such mechanized mining is called *Set-myaw* in Burmese. The diesel engine that is used to draw up the muddy water is set at the bottom of a pit such as a sand pit trap of an ant-lion (Fig. 2c). The engine, which is carried by human strength, is hung from a wire to prevent it being soaked in muddy water. In general, an owner owns a pit, and the size of the hole at the riverbank is from ten to a few hundred meters in diameter. It is necessary to remove stones from the hole because the turbine will be destroyed if it sucks in stones. Women usually remove the stones; they form a line and throw stones to each other. The men blast the riverbank using water pressed through a hose, and make muddy water.

In the case of *ta-naing-ta-paing*, miners draw up muddy water to a small sluice with a bucket. The sluice is shorter than 2 m in length. Some miners do not use a wooden sluice and use only a gold pan made of wood that is called *Kyin-Kwet* (*Inn-kwet*) in Burmese. They collect gold dust from the muddy water that flows from the large wooden sluice used by another miner.

The simple sluice is widely used in Myanmar regardless of the mining scale, but its size varies from 1 to 15 m. A typical gold mining boat is also equipped with a sluice, and all the processes of gold mining can be performed on the boat (Fig. 2d). The special boat has a long hose with a length of about 10 m and a diesel engine to draw up river water and river sand. The boat, therefore, has two engines; the engine for gold mining is much bigger than the other engine that is used for cruising. As gravity concentration using wooden sluices on boats has recently been prohibited by the government, the sluices are used at the riverbank. Gold mining by boat is licensed by the government.

The carpets are removed from the wooden sluice and are washed in the water tank in the evening. Gold nuggets are collected by gold panning. Almost all gold miners in Myanmar use mercury to extract gold, using the same amalgam method. A piece of mercury as big as the size of the tip of a little finger is put into a pan and mixed with the river mud. The mixture is squeezed through a fine cloth to obtain gold amalgam. Miners can choose whether to burn the obtained amalgam themselves or to sell it. If the miners do not burn the amalgam themselves, they sell it to a goldsmith, who heats the amalgam and obtains gold. In the case of *ta-naing-ta-paing*, they often sell the amalgam. For *si-phwa-phyit*, the miners usually heat the gold amalgam themselves. They use a metallic spoon or a crucible as a container to burn the amalgam. The amalgam is heated by burning charcoal; they usually use neither fossil fuel nor burner. In many cases, the women do this dangerous work in the kitchen. Mercury is not recovered at all, and the mercury vapor fills the kitchen. Their houses are simple and the permeability is good but tableware and food are stored in the kitchen. Moreover, children are near the kitchen. Thus, mercury vapor is generated in the most dangerous place.

3. Sampling sites and samples

The sampling and investigation areas in this study are Kyaikhto in Mon State, Shwekyin in Bago Region, the middle reaches of the Ayeyarwaddy River in Mandalay and Sagaing regions, Indawgyi Lake in Kachin State, and the north of Kalewa in Sagaing Region (Fig. 1). The area between Tabaitgine and Sintku in the north of Mandalay Region was mainly investigated because this region is one of the major artisanal and small-scale gold mining areas in this country. Sampling sites and sample names are shown in Fig.1. River sediments in the riverbank (R1 to R14) were collected using a shovel and all of the sampling sites were bottom of the river in the rainy season. The samples were dug out from the ground and stored in Teflon bottles. Human hair samples were collected from back of the head

Table 1 Total mercury concentrations of river sediments and tailings samples.

Site	Sample name	Sampling date	Hg (μg/g)	Remarks
Ngamoeyeik Creek	R1	Nov. 25 2013	0.86	Fine sand from downstream
	R2	Nov. 25 2013	15	Muddy sediment
Maw-wun River	R3	Nov. 25 2013	23	Muddy sediment
Ayeyarwaddy River	R4	Nov. 26 2013	81	Muddy sediment
	R6	Nov. 27 2013	0.39	Fine sand
	R7	Nov. 27 2013	5.3	Tailings
	R9	Nov. 27 2013	0.32	Fine sand
	R11	Nov. 28 2013	0.64	Fine sand
	R12	Nov. 29 2013	0.54	Fine sand. Confluence with Kyowlay river
	R14	Nov. 29 2013	0.21	Fine sand
	I1	Nov. 28 2013	51	Tailings collected from a water tank
Kyaiktho	K1	Nov. 23 2013	526	Tailings collected from a drain
	K2	Nov. 23 2013	4.9	Tailings before using cyanide
	K3	Nov. 23 2013	0.71	Tailings after using cyanide
	K4	Nov. 23 2013	1.5	Fine sand
Shwekyin	S1	Sep. 7 2012	0.014	Fine sand
	S2	Sep. 7 2012	0.004	Fine sand
	S3	Sep. 7 2012	0.006	Fine sand
Indawgyi Lake	Ind1	June 18 2014	0.016	Fine sand
Tokai-mura, Japan	Tokai JAEA	July 3 2014	0.029	Fine sand (Beach)

using a scissor and put them in the plastic bags. All samples were transported by aircraft and were preserved in the cool dark place.

Each sample and sampling situation is detailed below. R1 and R2 were gathered from the riverside of Ngamoeyeik Creek and the place is not gold mining area. R1 is from an artificial sand hill transferred from downstream of the river. R2, R3, and R4 are muddy sediments of Ngamoeyeik Creek, Maw-wun River, and Ayeyarwaddy River, respectively and sampling place of R3 is not gold mining area. All samples of Ayeyarwaddy River, Kyaiktho and Shwekyin are from gold mining area. R7, I1, K1, K2, K3 are Tailings after using mercury. Other sediment samples other than a Tokai sample are fine sand of riverbank.

Both *si-phwa-phyit* and *ta-naing-ta-paing* are actively conducted around the sampling area of Ayeyarwaddy River. R7 is tailings of *ta-naing-ta-paing*; miners mixed sands with mercury in the river and recovered gold amalgam and mercury. On the other hand, I1 is tailings of *si-phwa-phyit* collected from a water tank in which many carpets are washed and the amalgamation is performed in the water tank. The sampling place of Kyaiktho is a mine of big-scale *si-phwa-phyit*; there are big mining pits over 100 m in diameter and several big wooden sluices. K1 is tailings deposited in a drain connected with a sink that is used in amalgamation. Sampling sites of Shwekyin is vast sands and may be gold mining area but mining was not conducted during a field investigation.

A small dried fish sample was provided by a Burmese. The fish was caught in Indawgyi Lake and gold mining was actively conducted in the shore of a lake and banks rivers that flows into the lake.

4. Analytical Methods

Human hair samples were washed with soapless soap and rinsed in pure water and acetone. River sediment and solid samples were dried in a desiccator before analysis. A small fish sample was dried and crushed by a food processor. Mercury concentrations were measured by cold vapor atomic absorption spectrometry using a HIRANUMA HG-2500 mercury analyzer. Sediments and human hairs were measured on May 2015. Mercury concentrations are determined using a mercury standard solution. The mercury levels in sediment samples, solid samples, and hair samples were measured by the heat vaporization method. For hair samples, 1.6 to 1.9 mg of finely chopped hair was used. The weight of sediment and solid samples was from 0.4 to 266.2 mg. The uncertainties for mercury concentrations are lower than 15%. In this study, only total mercury concentrations were obtained. The mercury measurement method using prompt gamma-ray analysis developed in the previous work [16] was not used because the operation of the Japan Research Reactor No. 3 Modified (JRR-3M) has not been restarted.

5. Results and discussion

5.1 Total mercury levels in river sediments and solid samples

The total concentrations of mercury in river sediments and solid samples are summarized in Table 1. Extremely high mercury concentrations were observed in some river sediments; the highest concentration (i.e., 81 μg/g) was found in sediment collected from Ayeyarwaddy River (R4). Mercury concentrations higher than 10 μg/g were also found in the samples from the Ngamoeyeik Creek and the Maw-wun River. As gold mining using mercury does not occur in the area of Ngamoeyeik Creek, it can be concluded that mercury derived from upstream has accumulated in this area. These three samples consist of clayey materials; a large amount of mercury may be adsorbed to them because their surface area is large. Although the chemical form of mercury is unknown, clayey material may concentrate mercury carried from upstream.

Other sandy river sediment samples contained detectable amounts of mercury, with mercury concentration from 0.21 to 0.64 μg/g. These high mercury concentrations may be attributed to the presence of anthropogenic mercury, because these values are much higher than the Clarke number of 0.05 μg/g [17]. A high level of contamination (51 μg/g) was also found in sample I1, which was collected from a water tank in which artificial turf is washed. The water tank is polluted not only with amalgam but also with mercury that was stored underground for a quarter of a century. Small-scale gold mining using mercury was conducted before 1988 in this mining area, but gold mining had been discontinued for a long time. Metallic mercury droplets, representing unfavorable legacies of past deeds, are occasionally excavated and discovered in the water tank (Fig. 3). It is clear that a vast amount of mercury is still preserved underground. Such relict mercury is also reported in the case of Kachin State [13].

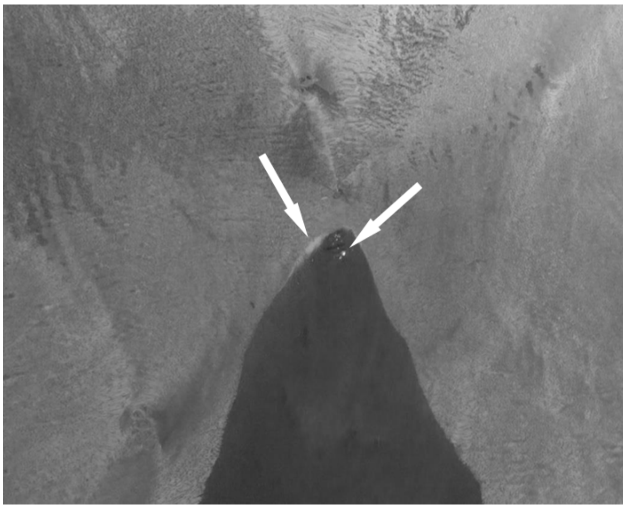

Fig. 3 Metallic mercury droplets recovered by placer mining on a wooden pan. Arrows indicate the droplets. The mercury was used in 1988 and stored under the ground for a quarter of a century. The river beach has become an artificial mercury mine.

Sediment samples collected from a pond in Shwekyin showed normal mercury concentrations, i.e., 0.014, 0.004, and 0.006 μg/g. These values are lower than that of a reference sample collected at Tokai-mura, Japan (0.029 μg/g). The concentration of the reference sample is relatively low for the mean value of Japanese sediment, 0.040 μg/g [18]. As the pond at Shwekyin is isolated from a large river and the concentration of mercury does not occur, it is assumed that comparatively low concentrations are maintained. A sediment sample collected from Indawgyi Lake showed a low mercury concentration, 0.016 μg/g, which is corresponding with the lowest value of Ayeyarwaddy River. However, a small fish sample from the Indawgyi Lake has very high Hg concentration of 1.5 μg/g, which is comparable with the mercury level of whales and is much higher than the fish consumption advisory level by EPA, 0.22 ppm. It cannot be denied that the lake is polluted with mercury because many mineworkers collect gold using mercury around the lake.

A solid sample collected from a drainage trench in Kyaiktho had an extremely high concentration of total mercury, 526 μg/g. Water contaminated by mercury during amalgamation flows to the drain, and a large amount of mercury might naturally accumulate in mud in the drainage trench.

5.2 Total mercury in human hair

Total mercury concentrations in hair collected in Myanmar are summarized in Table 2. Eleven samples are from mineworkers (H1-H4, #1-#7) and 10 samples are from non-mineworkers (N1-N10). The mercury concentration of 11 samples taken from mineworkers was from 0.6 to 6.9 μg/g, with an average value of 2.9 μg/g. The level of mercury is clearly lower than the range obtained in investigations in the other gold mining regions, for example Brazilian Amazon [6, 10] but is 2.4 times higher than the value of non-mineworkers (1.2 μg/g). The highest mercury concentration of 6.9 μg/g was found in a 50-year-old man, who has made a living from gold mining since the age of 13. The second and fourth highest values were observed in 40- and 43-year-old female, with concentrations of 4.7 and 3.9 μg/g, respectively.

As in previous studies, hair mercury levels are highly variable, but some important information on the relationship between lifestyle and mercury pollution is reflected in these data. In daily life, the most dangerous act is presumably the burning of gold amalgam, because the worker is directly exposed to mercury vapor. As described above, women often carry out this risky operation in kitchens without protection against the harmful gas. Cooking and gold extraction are

Table 2. Total mercury concentrations of human hair

Sample	Sex	Age	Sampling Place	Sampling date	Diet	Previous work site	Starts working date	Hg (μg/g)
H1	Female	39	Mandalay Region, Thone Gy Village	Nov. 27 2013			17 years old	2.5
H2	Male	42	Mandalay Region, Myaung River	Nov. 27 2013				0.7
H3	Male	13	Sagaing Region, Yone Pine Village	Nov. 28 2013				2.3
H4	Male	50	Mon Region, Kyaiktho Township, Sein Kale Village	Nov. 23 2013			13 years old	6.9
#1	Male	26	Sagaing Region, Kyar Inn village	Feb. 22 2014	Chicken, Pork, Fish, vegetables	U Ru river	16 years old	2.3
#2	Female	43	Sagaing Region, Kyar Inn village	Feb. 22 2014	Beef, Pork, Fish, vegetables	KoeTan Creek	20 years old	3.9
#3	Male	4	Sagaing Region, Kyar Inn village	Feb. 22 2014	Chicken, Pork, Fish, Beef, vegetables	-	-	4.0
#4	Male	4	Sagaing Region, Kyar Inn village	Feb. 22 2014	Chicken, Pork, Fish, Beef, vegetables	-	-	2.1
#5	Female	40	Sagaing Region, Kyar Inn village	Feb. 22 2014	Chicken, Pork, Fish, Beef, vegetables	U Ru river	37 years old	4.7
#6	Male	20	Sagaing Region, Kyar Inn village	Feb. 22 2014	All kind of food	KoeTan Creek	2 months ago	0.6
#7	Male	23	Sagaing Region, Kyar Inn village	Feb. 22 2014	All kind of food	U Ru river	20 years old	1.9
N1*	Male	40	Naypyidaw	Dec. 16 2014				1.9
N2*	Female	24	Naypyidaw	Dec. 16 2014				0.7
N3*			Naypyidaw	Dec. 16 2014				0.6
N4*	Female	60	Naypyidaw	Dec. 16 2014				1.0
N5*	Female	43	Naypyidaw	Dec. 16 2014				2.8
N6*	Male	53	Naypyidaw	Dec. 16 2014				1.7
N7*	Male	35	Naypyidaw	Dec. 16 2014				1.2
N8*	Female	26	Naypyidaw	Dec. 16 2014				0.5
N9*	Female	24	Naypyidaw	Dec. 16 2014				0.9
N10*	Male	28	Naypyidaw	Dec. 16 2014				0.9

*All testees of Naypyidaw are not mineworker.

performed in the same space. Therefore, the mercury concentrations of female miners may be naturally higher than those of male miners. The slightly high mercury concentrations of two women living in Kyar Inn Village are consistent with this hypothesis. The mercury concentration of another woman, who is a goldsmith in Thone Gy village, was 2.5 μg/g. She burns amalgam in a workshop.

The mercury concentrations in hair samples from a 4-year-old child was relatively high, i.e., 4.0 μg/g. The value is higher than adult male miners in the same area. This fact may be explained by their relationship to their mothers' work. As infants are usually near their mothers, they may have more opportunities for exposure to mercury vapor than male miners. Here we assume that the mercury concentration inside the human body is determined only by the opportunity to be exposed to mercury vapor. Needless to say, the intake of fish and water contaminated with mercury is problematic, but in a village only river water is drunk, and the diversity of eating habits is small. The gross weight of mercury in orally ingested material must be lower than the mercury concentration in hair. The hair of a 42-year-old male engaged in gold mining (sample H2) does not show a high mercury contamination, i.e., only 0.7 μg/g. This man uses mercury to make amalgam and drinks river water, but usually does not burn amalgam. This observation provides support for our idea, but further investigations will be necessary in future because samples are very limited in the present stage.

5.3 Importance of health hazard education on mercury pollution

It is difficult to recover metallic mercury that was exhausted and remains in the environment because the amounts involved are enormous. Images Asia & PKDS (2004) [13] reported that Kachin children dig up and reuse mercury from former mining processes as droplets from the ground. There is a similar situation in the middle reaches of the Ayeyarwaddy River investigated in this study. Miners sometimes find metallic mercury under the ground; this mercury was used and left behind in the past. Although metallic mercury left under the ground continuously contributes to environmental pollution, it might be almost impossible to collect the mercury completely because the tailings are widely diffused over a vast area. If the polluted tailings are settled in a limited area, for example tailing ponds, they can be recovered by a simple method, for example State Battery. In a previous study, we developed a mercury cleaning method using State Battery in the Philippines [19] but the method may not be adapted for Myanmar. It is, therefore, important to educate people about the easiest methods of protection from the health hazards due to mercury.

6. Conclusions

Our investigation of artisanal and small-scale gold mining in Myanmar shows that river sediments in this nation are polluted with mercury, and many gold miners and their families may be contaminated, although the data obtained in this work is limited. The mercury concentrations of river sediments are very high; in particular, mercury is extremely concentrated in muddy sediments, which have mercury concentrations higher than 10 μg/g. The total mercury level in miners' hair is from 0.6 to 6.9 μg/g. Although it is difficult to determine the background level of mercury in the area and we cannot prove that the mercury concentrations are affected by gold mining completely.

Further detailed investigations of mercury pollution in Myanmar are necessary in the near future because the analytical data obtained in this study are limited. Economic development will bring substantial changes to the local economy of this country, and mercury pollution might become more serious.

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