Mercury Distribution in Artisanal and Small-Scale Gold Mining Area: A Case Study of Hot Spots in Camarines Norte, Philippines

S. Murao, T. Tomiyasu, K. Ono, H. Shibata, N. Narisawa, and C. Takenaka

***Abstract*—Distribution of mercury inside/outside of rod-mill stations in artisanal and small-scale gold mining (ASGM) area was studied in Camarines Norte, Philippines. Plants, soil, sediments, tailings and artifacts were checked as well as air quality.**

Plants grown inside rod-mill station have higher values of mercury than those found outside. This suggests that rod-mill station is a source of mercury contamination.

However mercury distribution is not homogenous even inside one rod-mill station. For example the artifacts of high mercury concentration was found just above or very close to furnace. This observation implies that mercury ascends to the air quickly from furnace when amalgam is heated.

Outside of rod-mill stations, even at points far away from ASGM, mercury in sediments and soil is sometimes high in concentration. This fact implies that there are several mechanism for mercury contamination.

The primary mechanism seems to be the rapid upward diffusion from furnace through chimney to sky, but other slower ways are possible such as accumulation through water circulation and food chain.

The first countermeasure against mercury contamination should be the control of aerial dispersion of mercury but attention should also be paid to the slower dissemination of mercury on surface and underground.

***Index Terms*—Artisanal and small-scale gold mining, ASGM, gold, mercury, contamination, pollution, Camarines Norte, Philippines.**

I. Introduction

Mercury is a substance of concern due to its long-range transport, persistence, ability to bio-accumulate, and toxicity. However its control is not enough and the contamination is spreading on the globe. Already in 2002 United Nations Environment Programme (UNEP) pointed that mercury is present in various environmental media and food (especially fish) all over the globe at levels that adversely affect humans and wildlife [1].

Being concerned with such serious situation, the Governing Council of the UNEP decided in 2009 to develop a global legally binding instrument on mercury to reduce risks to human health and the environment, and the international community formulated the *Minamata Convention* which was put in force in August 2017. It must be stressed here that the artisanal and small-scale gold mining (ASGM) is the largest source of mercury emissions and releases mercury to the environment at ~1,600 tonnes per year [2].

ASGM is a type of gold recovery where those who do not belong to registered mining company use rudimentary tools without scientific and technological knowledge and skill: they dig without plan and they work without much protection gears. Some gold deposits can be worked by simple hand technologies, such as panning, but many involve digging out an ore, crushing and concentrating it, and then extracting the gold from the concentrate. Relatively simple technologies can be used to carry out these processes, although the details vary widely and the systems have typically evolved to suit the specific local circumstances.

Mercury has ability to form an amalgam with gold, which allows the workers to capture the refractory gold into a ball-shaped amalgam. The ball is heated to evaporate and drive off the mercury and the workers get so-called *sponge gold*. Sponge gold is further heated to remove residual mercury and other impurities.

Amalgam burning often takes place at or close to miners' dwelling areas, even in the kitchen to hide their practice. Consequently their families and communities inhale significant amounts of mercury vapor [3], which eventually can be absorbed by the kidneys and brain.

To prevent continuous pollution caused by amalgamation and smelting in ASGM and to stop harm to communities settled around ASGM area, it is necessary to understand the bio-/geo-chemical behavior of mercury and the compounds, and to devise strategy how to mitigate the adverse effects. This paper describes the mercury distribution in and around ASGM site to base discussion for the risk management of mercury in mining communities.

II. Study Area

The authors studied ASGM sites in the Province of Camarines Norte, Philippines (Fig. 1). The province is composed of 12 municipalities, 282 *barangays* (villages) and two congressional districts spread over a land area of 2,112.5 square kilometers. It had a population of 542,915 as of May 1, 2010 with a growth rate of 1.44 percent from 2000 to 2010

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[4].

Fig. 1. A map showing the location of the Province of Camarines Norte, Philippines (modified from [5]).

Gold potential is high and ASGM is concentrated in the Municipalities of Jose Panganiban, Labo and Paracale. Especially in Paracale some barangays heavily rely on ASGM. For example at Barangay Tugos it is estimated that 80-90 % of households are involved in this type of mining [6]. Annual production from ASGM is estimated at 2,400 kg [7] in the province.

In addition to gold mining, agriculture and fishing are the major preoccupation of the province. Livestock and poultry production is of the backyard raising types.

The main agricultural products are *abaca* (Manila hemp), banana, coconut, pineapple, and root crops. Fishing is done along the coast. In response to the request from the Municipalities of Jose Panganiban and Labo, a reconnaissance study was conducted by the National Institute of Advanced Industrial Science and Technology and the result indicated the selective accumulation of mercury in captured fishes [8].

Rice is also produced and in some barangays people make a living on rice farming. Rice samples from this province were analyzed by CVAAS (Cold Vapor Atomic Absorption Spectrometry) at the Philippine Institute of Pure and Applied Chemistry and the result showed no mercury concentration [9].

The authors' survey was conducted from 2014 to 2017 after getting permission from the Mayors at the Municipalities of Jose Panganiban and Labo because rod-mill stations in the two municipalities were selected as target. The authors also got consent from barangay captains and leaders of mining groups to disclose information on the ASGM practices.

III. Practice in ASGM

A. Mining

Although details of practice vary widely and the systems have typically evolved to suit the specific local circumstances, most gold deposits are worked by simple hand technologies [10]. In response to the two types of gold ore, i.e. placer and hard rock, three styles of operation are observed in the province: simple panning in streams (locally called *akawan*), underground mining and underwater mining.

Underground mining involves digging of shafts up to five meters deep below the surface. A lot of timbers (mainly coconut) are used to support the tunnel.

The underwater mining is a dangerous practice where miners work under muddy water breathing through a slender tube attached to a compressor on the surface. They need such operation because placer gold in this province is often found under the rice paddy and water [11]. Because of the compressor use people call this type of work *compressor mining*.

Compressor mines are simple shafts, perhaps a meter square dug straight down through mud or clay to a depth of five to six meters. At the bottom of the shaft they open horizontal tunnels which locally designate *drive*. Miners wrap air tubes about themselves in an intricate pattern of loops and knots to secure the tubes on their bodies. Then they clench their teeth around the open ends of the small tubes, breathe deeply and drop below the surface to begin scraping gold-bearing mud/sand on the bottom.

B. Gold Extraction

At panning and compressor mining sites workers get metallic concentrate by washing gold-containing mud/sand. Then they add mercury to the concentrate to separate gold from other metallic minerals which coexist with gold. This method is called *concentrate amalgamation*. Mercury can be purchased at small shops that are locally called *sari sari store*. Some people borrow mercury from such store under the condition that they sell the gold to the store.

From underground mining sites diggers bring roughly crushed ore to a rod-mill station where they use rod mills and pulverize the ore. To extract gold, they employ either sluicing, gravity concentration, amalgamation or cyanidation.

Mercury is used in two ways depending on the place and feature of ore. One is concentrate amalgamation which is similar to the placer gold treatment and the other is *whole ore amalgamation*.

Whole ore amalgamation means that mercury is poured into the gold ore as it is being crushed in a rod mill. The mills constantly spew clouds of mercury-laded dust. Precise measurement by using scale showed that miners use an average of 19.2 g mercury to process 1.0 g of gold but the amount used may range from 1.5 to 149.0 g per extraction process [12].

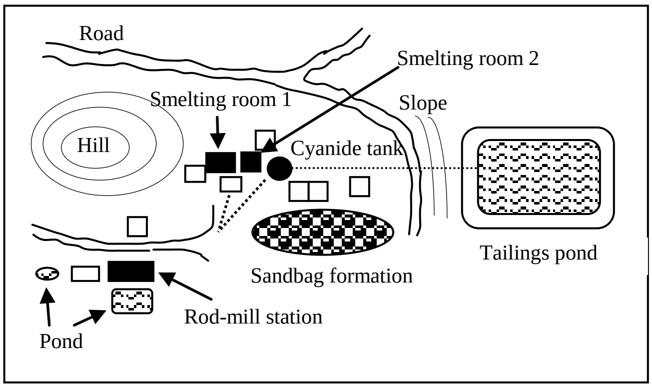

Fig. 2. Plan of a rod-mill station at Barangay Santa Rosa Sur, Jose Panganiban (not to scale).

The tailings after this process are often treated by cyanide solution to recover remaining gold. This is because of the low recovery of gold (less than 30%) by amalgamation [13].

C. Structure of Rod-Mill Station

Fig. 2 shows a typical development plan of rod-mill station in Camarines Norte. A rod-mill station in a broad sense means a facility which holds rod-mill house, smelting room/hut, cyanide tank, pond/pool for routine work, and tailings pond. A rod-mill station in a narrow sense is a building to house rod-mills (Fig. 3).

Fig. 4 and 5 are rough sketches of smelting rooms 1 and 2 in the Fig. 2. In the rooms are kept furnaces, drums, bellows, crucibles and gasoline. In addition to new crucibles a lot of old crucibles are left in the room 2. Usually mercury is hidden and is not seen by the visitors.

Fig. 3. Rod-mills at a station in Barangay Santa Rosa Sur.

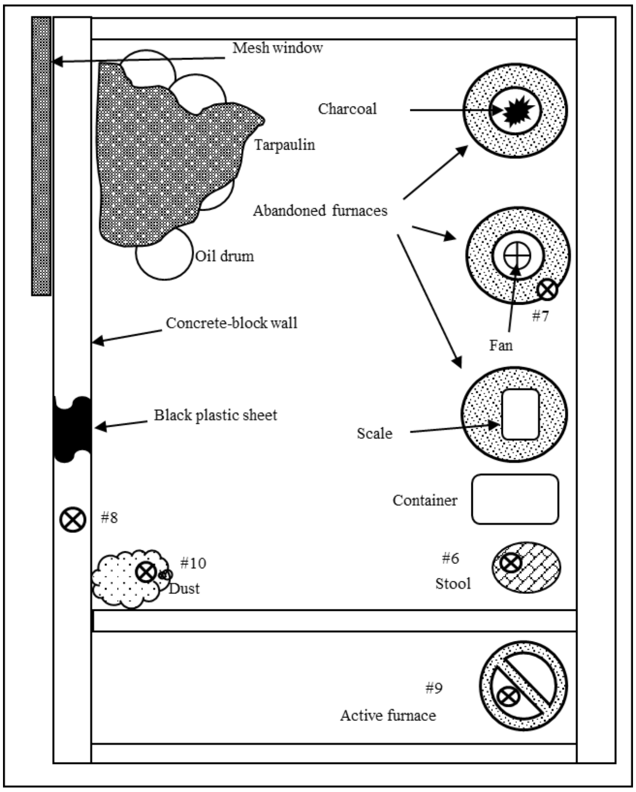

Fig. 4. A sketch of smelting room 1 at Santa Rosa Sur (not to scale). The numbers and inclined-cross-in-the-circle marks indicate measurement points.

IV. Analysis

A. Methods

For artifacts inside the rod-mill station, a handheld XRF (X-ray Fluorescence) analyzer OLYMPUS DELTA Professional was applied with the rated output 40kV and the measurement mode Soil2. The average duration of analyses was 90 sec. per sample. The limit of detection for mercury was around 5ppm except for iron products and a broken crucible.

The authors also checked the mercury level in air using two kinds of methods, conventional manual sampling of atmospheric Hg^0 and real-time measurement of atmospheric Hg^0.

With the conventional manual sampling of atmospheric Hg^0, atmospheric Hg^0 was collected by the gold amalgamation method using a mercury collector tube (NIC, Tokyo, Japan). At each sampling location, the collector tube was connected to an air pump (Sibata Scientific Technology, Saitama, Japan), and ambient air was sucked into the collector tube for 30–80 min at a flow rate of 0.5 L min^{-1}. The Hg collected in the tube was measured using double amalgamation CVAAS with a WA-4 mercury analysis system (NIC, Tokyo, Japan). The detection limit (3σ) of this system (0.02 ng Hg) was obtained from replicate determinations of blanks (n=9). The reproducibility obtained by replicated measurements of 2 ng Hg (n=5) was 2.2%.

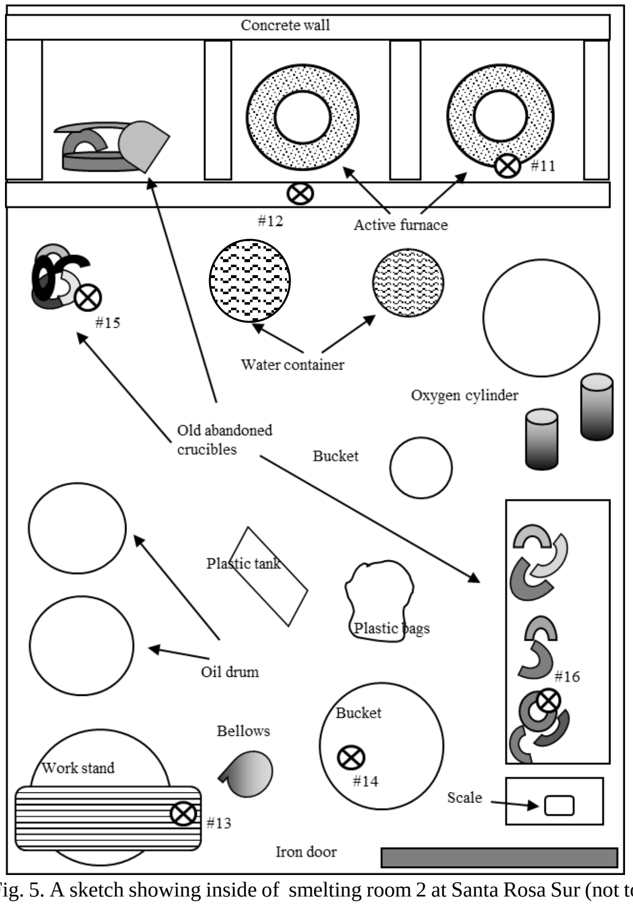

Fig. 5. A sketch showing inside of smelting room 2 at Santa Rosa Sur (not to scale). The numbers and inclined-cross-in-the-circle marks indicate measurement points.

Real-time measurements of Hg^0 in air were performed using an EMP-2 mercury analyzer (Nippon Instruments

Corporation (NIC), Tokyo, Japan). A pre-filtered sample air stream was introduced into an absorption cell without the use of any pre-concentrated unit such as a gold trap. The Hg was then determined by CVAAS, with the results shown as concentration (μg m^{-3}). The detection limit ($3\sigma = 0.1$ μg m^{-3}) was obtained from determinations of a series of laboratory injection experiments for 40 min.

Some soils were sent to the Philippine Institute of Pure and Applied Chemistry and some were sent to Kagoshima University both for CVAAS. Plants were also analyzed at Kagoshima University by CVAAS after acid digestion with 1:1 nitric acid-perchloric acid and concentrated sulfuric acid [14].

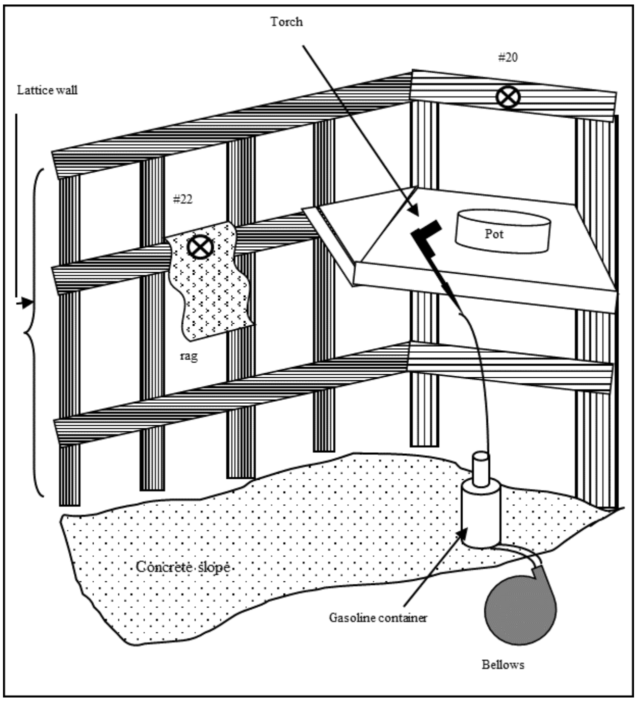

Fig. 6. A sketch of fire place at a rod-mill station in San Isidro (not to scale). Inclined-cross-in-the-circle mark means measurement points.

B. *Mercury Distribution in Rod-Mill Station*

In order to know how much mercury is left in rod-mill station after burning amalgam, mercury on the surface of artifacts was measured inside rod-mill stations in two Barangays in the Municipality of Jose Panganiban, namely Santa Rosa Sur and San Isidro. The measured points are indicated in Figs. 4 to 6.

At rod-mill stations mercury was detected only in the objects close to the furnace which miners use to heat amalgam or next to rod-mill where whole-ore amalgamation is applied (Table I). It is noteworthy that mercury does not remain much in crucibles or on the floor but sticks to objects such as wall which mercury fume passes through. The horizontal distance within which mercury is resided seems to be less than one meter from furnace. It is speculated that when amalgam is heated most of the mercury is driven off rapidly and is emitted vertically to the atmosphere.

C. *Air Quality*

Air quality was tested at Barangays Santa Milagorosa, Benit and at a suburb of the Municipality of Labo. The result is shown on Table II. At a rod-mill station in Benit, a work stand which is used for torch firing showed 314,000 ng/m^3 when the measurement was conducted a few minutes after the amalgam burning. Another furnace at Santa Milagrosa which was used four weeks before the measurement indicated 7.8 ng/m^3. A rest station built at the margin of the ASGM operation at former Buhay Top (or Bo Hai Top) Mine in Benit showed 37.6 ng/m^3.

For comparison the authors tested the air in a non-mining area, specifically at the terrace of a restaurant which faces Busig-on River in the Municipality of Labo. The result was 9.1ng/m^3.

TABLE I: REMNANT MERCURY INSIDE ROD-MILL STATION

Point	Description (distance from furnace/mill)	Hg in ppm (LOD)
	Santa Rosa Sur, Jose Panganiban	
	Smelting room 1 (Fig. 4)	
#6	A wooden stool next to a furnace (50cm)	<LOD (2.7)
#7	An empty oil drum (3m)	<LOD (22)
#8	Concrete-block wall (about 2m)	9 (2)
#9	An iron plate next to a furnace (0cm)	<LOD (64)
#10	Dust in the smelting hut (3m)	<LOD (5)
	Smelting room 2 (Fig. 5)	
#11	Wet soot deposited next to furnace (10cm)	204 (6)
#12	Concrete debris near a furnace (10cm)	87 (3)
#13	Timber above an abandoned furnace (55cm)	60 (2)
#14	Plastic lid of a bucket	<LOD (4.2)
#15	An abandoned old crucible	<LOD (15)
#16	A crucible	<LOD (45)
	San Isidro, Jose Panganiban	
#17	Wooden frame to place a torch	<LOD (3.5)
#18	A crucible	<LOD (24)
#19	Steel frame to support rod-mills (15cm*)	98 (10)
#20	Wooden lattice wall next to a furnace (20cm)	30.2 (1.6)
#22	Rag on the wooden lattice wall next to furnace (20cm)	12.1 (1.7)

LOD: limit of detection
*Distance from a rod-mill where whole-ore amalgamation is adopted

TABLE II: THE MERCURY CONCENTRATION IN AIR

Locality	Hg (ng/m^3)	Note
Santa Milagrosa, Jose Panganiban	7.8	Furnace four weeks after the amalgam burning
Benit, Labo	37.6	Rest station of ASGM in the former Buhay Top Mine
Benit, Labo	314,000	Work stand to support a furnace, just after the amalgam burning
Busig-on River, Suburb of Labo	9.1	Villa Eusevia Restaurant

Mercury was analyzed by conventional sampling method except for the work stand in Benit.

D. *Mercury in Plants*

Plants were collected widely from Barangays Benit, Motherlode, Planidel, Santa Milagrosa, Santa Rosa Norte, South Poblacion, and from urban area of the Municipalities of Labo and Jose Panganiban. They are classified into two groups: one grown closer to rod-mill station and the other which keeps distance more than a few meters away from the station.

The two groups showed a contrast in mercury concentration that the group which is closer to the station had higher values (Fig. 7). The maximum value was 34 ppm Hg for a kind of fern *Davallia sp.* (Table III).

E. Mercury in Soil

At a rod-mill station in Benit mercury was detected in two spots. The sample from a pool where miners pan the amalgam after whole-ore amalgamation indicated 71.75 ppm Hg. The sample taken from a spot next to a chimney through which mercury fume is emitted showed 34.22 ppm. To the contrary when samples were taken a few meter away from such hot spots, the mercury concentration was low. A spot one meter away from the pool mentioned above showed much lower value of mercury 2.31 ppm. Samples from rice paddy at Benit indicated a range from 0.14 to 1.83 ppm. A sample from farm land next to the smelting hut showed 19.8 ppm.

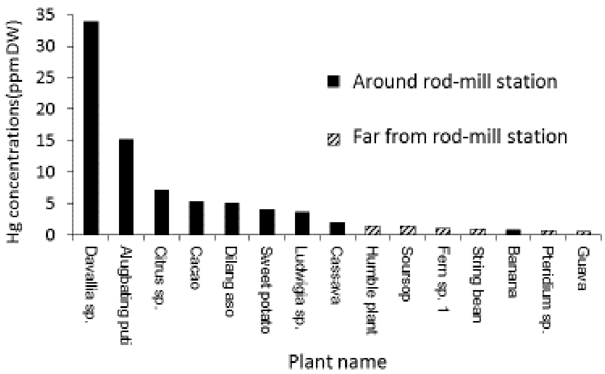

Fig. 7. Mercury concentration in two groups of plant.

In order to know the background value soil samples from non-mining area were analyzed. The background seems to be below 1 ppm (Table IV).

F. Mercury in Sediments and Tailings

Sediment samples were taken from Barangays Kalamunding, North Ponlacion, Planidel, Santa Elena, Santa Milagrosa,and Municipalities of Labo and Jose Panganiban. Tailings were collected from Barangays Dalas and Luklukan Sur.

Barangay Kalamunding is surrounded by ASGM sites. Farmers began to leave the land fallow and industrial waste is dumped in such space. Sediment was obtained from a small creek which runs through a fallow field where industrial wastes are piled up.

At Barangay Planidel where no mining and farming are seen a sediment sample was collected from the bottom of Danao River.

Barangay Santa Milagrosa faces the ocean and fish culture is a major industry. Sediment from the bottom of a fish breeding pond and from a ditch of a rod-mill station was sampled as well as clay which deposits on the sea bottom covering the gold-bearing layer below.

Sediments were also collected from a suburb of the Municipality of Labo and from the littoral zone in Mambulao Bay of Jose Panganiban where no mercury use is noticed.

All of the sediments except for the ditch of a rod-mill station are regarded from mercury-free area but the sample from the fish breeding pond and a sample from the bay indicated a higher value than the rod-mill station (Table V).

TABLE III: THE MERCURY CONCENTRATION IN PLANTS

Locality	Species/name	Hg (ppm DW)	Note
Municipality of Labo			
Benit	*Davalia sp.*	34	On the premises of a rod-mill station
“	Alugbating puti	15.1	“
“	*Citrus sp.*	7.08	“
“	Cacao	5.28	“
“	Dilang aso	5.07	“
“	Sweet potato	4	“
“	*Ludwigia sp.*	3.63	“
“	Banana	0.85	“
“	Humble plant	1.44	Between the rod-mill station and former Buhay Top Mine
“	Fern 1	1.07	“
“	Pteridium	0.64	Former Buhay Top Mine
“	Unknown 1	0.13	“
“	Unknown 2	0.11	“
Suburb	Fern 2	0.22	Busig-on River, Villa Eusevia Restaurant
“	Bamboo	0.18	“
“	Fern 3	0.14	“
Municipality of Jose Panganiban			
Santa Rosa	Gemilina	0.3	DOST-UP DMME
Norte	“	0.19	Gold Copper Processing Plant in Bicol Region
Motherlode	Soursop	1.43	Home garden
“	Guava	0.49	“
“	Cacao	0.26	“
“	Jatropha	0.08	“
“	Banana	0.05	“
Planidel	String bea	0.86	Danao River
“	Guava	0.3	“
“	Unidentified	0.28	“
“	Taro	0.25	“
South Poblacion	Indian mango	0.18	Near Apolonia Hotel
“	Banana	0.16	“
“	Sweet potato	0.08	“
“	Dishcloth gourd	0.07	“
“	Lemon grass	0.04	“
Santa Milagrosa	Jatropha	0.15	
Town	Jatropha	0.08	Back of a public building
“	Moringa	0.07	“

V. DISCUSSION

In this study data imply that mercury fume emitted at smelting spot ascends quickly to the air focusing the harm on narrow area just above or next to the furnace. Workers are advised to keep distance of their face and body from the fume and to install ventilation device such as fume hood and draft. In addition mercury-proof mask should be manufactured and distributed. Also the introduction of cheap and easy retort system using local material such as bamboo [14] or can/tin [15] is strongly recommended.

An NGO who studied ASGM in Camarines Norte also reported that the maximum reading of mercury in air was above the upper limit of their detector 30,000 ng/m^3 [16]. In this province furnaces are found not only in rod-mill stations but also in sari sari stores in residential area and such dense and wide distribution of furnace is one of the reasons why the mercury level in air is higher than non-mining areas.

In an ASGM site in Indonesia where local people are engaged in mostly the same procedures of the Philippines, the ambient air mercury level was 49,632 ng/m^3 [17]. In both cases, in the Philippines and Indonesia, the concentration is higher than the *lowest observable adverse effect level* (15,000-30,000 ng/m^3) that was established by the World Health Organization [18]. The readings are also higher than Japan's *recommended occupational exposure limit* 25,000 ng/m^3 [19]. It cannot be declined that in spite of rapid ascension to the air, mercury is partially left after burning and accumulate to a dangerous level in ASGM communities.

TABLE IV: THE MERCURY CONCENTRATION IN SOIL

Locality	Hg (ppm DW)	Analytical method	Note
Dalas, Labo	0.57	1	Red-brown soil, surface of rice paddy
"	0.62	1	Red-brown soil, 5cm deep, rice paddy
Santa Rosa Norte, Jose Panganiban	1.68	2	DOST-UP DMME Gold Copper Processing Plant in Bicol region
Motherlode, Jose Panganiban	1.96	2	Soil, surface to 1cm
"	0.71	2	Soil, 1-2cm
Benit, Labo	19.8	2	Farm land next to a smelting hut
"	1.83	2	Rice paddy near a rod-mill station
"	0.15	1	Brown soil, surface
"	0.14	1	Bluish gray soil, 5mm below the surface
"	0.22	1	Red-brown soil, surface
"	0.46	1	Gray soil, 5cm below the surface
"	0.62	1	Brown soil, 10cm Below the surface
"	71.75	2	Soil from a pool in a rod-mill station
"	34.22	2	Soil from a spot next to a chimney

1:CVAAS at Philippine Institute of Pure and Applied Chemistry;
2:CVAAS at Kagoshima University

Analyses of soil, sediments and plants in this study also imply that the mercury contamination is spreading in communities. A soil sample in the vicinity of a smelting hut indicated 19.8 ppm Hg which is much higher than non-mining area of a range between 0.15 and 1.96 ppm. Data for sediments are not suffice to discuss the detail of contamination but the mercury concentration for the fish culture pond 6.43 ppm and for Mambulao Bay 5.6 ppm are concerned when compared to a background value for sediments in the Philippines 0.042 ppm [20] and to the global background range 0.01-0.05 ppm [21].

From the viewpoint of public health special attention should be paid on children because they are more vulnerable to the harmful substances than adults. Since children are sometimes working in ASGM sites in the study area, it is recommended to post a notice *Minor Not Allowed* at rod-mill stations and sari sari stores where miners use mercury.

Attention should also be paid to the relationship between rod-mill station and land where plants, fruits or vegetables grow. At present serious damage is not observed for rice [9] and the calculated risk for fishes are low [8] in the province. However mercury contamination seems to be spreading through rapid diffusion in air and also through slower dissemination in water or food chain. Already an ASGM study in Buru Island of Indonesia raised concerns about the long term distribution and speciation of mercury [22]. The behavior of mercury should be carefully monitored.

TABLE V: THE MERCURY CONCENTRATION IN SEDIMENTS AND TAILINGS

Locality	Hg (ppm DW)	Sampling point
Tailings		
Luklukan Sur, Jose Panganiban	120	Tailings pond at an ASGM site*
Dalas, Labo	0.22	A rod-mill station*
Sediments		
Santa Elena, Jose Panganiban	0.53	Riverside near a crab culture pond (former mine waste dump site)*
"	2.4	"
Santa Milagrosa, Jose Panganiban	6.43	A fish-culture pond**
"	2.24	A ditch of a rod-mill station**
"	0.06	Clay above the gold-bearing layer which is found in the sea bottom**
Kalamunding, Labo	0.22	A creek in a fallow field**
Planidel, Jose Panganiban	1.24	Danao River**
Suburb, Labo	0.11	Busig-on River, Villa Eusevia Restaurant**
Bay area, Jose Panganiban	0.26	Mambulao Bay, littoral zone**
"	0.75	"
"	5.6	Barangay North Poblacion*

*Analyzed at Philippine Institute of Pure and Applied Chemistry by CVAAS; **Analyzed at Kagoshima University by CVAAS.

For ASGM monitoring, plants seem to be promising indicator to elucidate how much the environment is polluted with mercury. This study showed that plants have possibility to reflect the geochemical condition of land where the mercury concentration in water, soil and sediments is higher than normal land. Also the result in this study reconfirmed the well-known fact that fern accumulates heavy metals [e.g., 23 and 24]. A study on ASGM in Indonesia also pointed that fern was useful to monitor the ambient air [25]. Further investigation is necessary to understand the metabolism of fern and to find more different species which can be suitable indicators for the mercury pollution of water, soil and sediments in the ASGM areas.

VI. Conclusion

According to this study furnace in smelting room/hut is the most dangerous spot in terms of mercury intoxication. The authors detected 314,000 ng/m^3 at a furnace just after the amalgam burning.

Plants showed a range from 0.07 to 34 ppm Hg. Soil indicated a range from 0.14 to 71.75 ppm and sediments showed a range from 0.11 to 6.43 ppm. The higher values were obtained from samples closer to the hot spot, i.e., fire place in rod-mill station.

The mercury contamination seems to be spreading towards residential area. Deficiencies in the work/living environment can have serious consequences for the individual. These deficiencies give rise to increased costs of life due to illness, rehabilitation, personnel turnover and stoppages, damage to equipment, poor quality and underutilized potential. It is a pressing need for the competent agencies to take swift countermeasures against this problem.

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References

[1] *Global Mercury Assessment*, UNEP Chemicals, Geneva, 2002.

[2] *Developing Baseline Estimates of Mercury Use in Artisanal and Small-Scale Gold Mining Communities: A Practical Guide Ver.1*, Artisanal Gold Council, Victoria, BC, Canada, 2015.

[3] S. Murao, E. Daisa, K. Sera, V. B. Maglambayan, and S. Futatsugawa, "PIXE measurement of human hairs from a small-scale mining site of the Philippines," *Nuclear Instruments and Methods B189*, pp.168-173, 2002.

[4] Philippine Statistics Authority. (July 2018). Overview of the region, province of Camarines Norte. [Online]. Available: http://nap.psa.gov.ph/ru5/ overview/camnorte/default.html

[5] Your Free Templates. (July 2018). Free Philippines editable map. [Online]. Available: https://yourfreetemplates.com/free-philippines–editable-map/

[6] E. M. Rey-Saturay and S. Murao, "Artisanal gold mining and the applicability of ethical jewelry in Paracale, Camarines Norte, Philippines," *Geo-pollution Science, Medical Geology and Urban Geology*, vol. 10, pp.10-15, Jun. 2014.

[7] A. B. Galvez, "Personal communication," Ban Toxics CN Field Office, Jul. 2017.

[8] S. Murao, M. Macabuhay, N. Narisawa, T. Monroy, C. Takenaka, and S. M. Pante-Aviado, "Preliminary study on the risk of mercury exposure to the people consuming fish from Camarines Norte, Philippines," *Geo-pollution Science, Medical Geology and Urban Geology*, vol. 13, pp. 31-34, Dec. 2017.

[9] S. Murao, S. Goto, K. Ono, K. Sera, M. Macabuhay, E. Cubelo, A. B. Galvez, and S. M. Pante-Aviado, "Detection of gold and mercury in rice from artisanal and small-scale gold mining area of the Philippines," NMCC Annual Report 21, pp. 101-106, Mar. 2014.

[10] S. Murao, V. B. Maglambayan, and N. Cruz, *Small-Scale Mining in Asia, Observations towards a Solution of the Issue*, London: Mining Journal Books Ltd., 2002, p. 62.

[11] *In Search for the Pot of Gold*, ILO-IPEC, Geneva, 2003.

[12] M. D. Macabuhay, A. Galvez, J. Lucino, E. Cubelo, J. S. Lorenzo, T. Monroy, and R. C. Gutierrez, "Mercury flow analysis in artisanal and small-scale gold mining operations in the Philippines," *Geo-pollution Science, Medical Geology and Urban Geology*, vol. 14, pp. 1-8, 2018.

[13] M. M. Veiga, G. Angeloci, M. Hitch, and P. C. Velasquez-Lopez, "Processing centers in artisanal gold mining," *Journal of Cleaner Production*, vol. 64, pp. 535-544, 2014.

[14] E. Boungnaphalom, "Artisanal gold mining in Lao PDR", *Geo-pollution Science, Medical Geology and Urban Geology*.

[15] S. Leonhard, "Artisanal and small scale mining in PNG," *Geo-pollution Science, Medical Geology and Urban Geology*.

[16] *The Price of Gold: Mercury Use and Current Issues Surrounding Artisanal and Small-Scale Gold Mining in the Philippines*, Ban Toxics, Quezon City, Philippines, 2011, pp. 41-43.

[17] Pulitser Center. (2015). Indonesia: Mercury, gold and uncommon diseases. [Online]. Available: http://pulitzercenter.org/reporting/indonesia-mercury-gold-and-uncom mon -diseases

[18] *Air Quality Guidelines for Europe, Second Edition*, World Health Organization Regional Office for Europe, Copenhagen, 2000, pp. 158-161.

[19] *Recommendation of Occupational Exposure Limits (2017-2018)*, Japan Society for Occupational Health, Tokyo.

[20] T. J. Corpus, C. P. David, S. Murao, and V. Maglambayan, "Small-scale gold mining in the Ambalanga catchment, Philippines: its control on mercury methylation in stream sediments," *International Journal of Environmental Sciences*, vol. 2, pp. 1048-1059, 2011.

[21] M. S. Gustin, G. E. Taylor, and T. L. Leonard, "High levels of mercury contamination in multiple media of the Carson River Drainage Basin of Nevada: Implications for risk assessment," *Environmental Health Perspectives*, vol. 102, pp. 772-778, 1994.

[22] Y. T. Male, A. J. Reichelt-Brushett, M. Pocock, and A. Nanlohy, "Recent mercury contamination from artisanal gold mining on Buru Island, Indonesia – Potential future risks to environmental health and food safety," *Marine Pollution Bulletin*, vol. 77, pp. 428-433, 2013.

[23] F. J. Zhao, S. J. Dunham, and S. P. McGrath, "Arsenic hyperaccumulation by different fern species," *New Phytologist*, vol. 156, pp. 27-31, 2002.

[24] S. Pongthornpruek, S. Pampasit, N. Sprirang, P. Nabheerong, and K. Promtep, "Heavy metal accumulation in soil and some fern species at Phu Soi Dao National Park, Phitsanulok Province, Thailand," *NU Science Journal*, 2008, vol. 5, no. 2, pp. 151-164, 2008.

[25] Y. Kono, J.S. Rahajoe, N. Hidayati, H. Kodamatani, and T. Tomiyasu, "Using native epiphytic ferns to estimate the atmospheric mercury levels in a small-scale gold mining area of West Java, Indonesia," *Chemosphere*, vol. 89, pp. 241-248, Apr. 2012.

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He started his career as a governmental geologist at the Geological Survey of Japan and studied rare metal exploration. From 1994 to 1995 he joined CSIRO as an exchange fellow under the Japan-Australia agreement.

From 2007 to 2009 he worked for an international organization CCOP. In 2009 he served for the *Regional Implementation Meeting for Asia and the Pacific ahead of the Eighteenth Session of the Commission on Sustainable Developme*nt of the United Nations as the lead author of mining.

Dr Murao has studied ASGM nearly 20 years and served *Communities and Small Scale Mining* initiative of the World Bank as Chair for Asia and the Pacific. He edited and published two books from Mining Journal Books in London.

In 2015 for his contribution on the environmental cooperation, he was conferred *Nairamdal Medal*, the Mongolian State Award, by the Decree 75 of the President of Mongolia. At present he is the President of Japanese Society of Geo-pollution Science, Medical Geology and Urban Geology.

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He received the doctor of science at University of Tsukuba in 1998. He was promoted to an associate professor in 1999, and to a professor in 2006.

His main theme is the dynamics of mercury in the environment. The main research field are Kagoshima Bay, Japan which is affected by mercury discharged by volcanic activity; Minamata Bay, Japan that was once heavily polluted by methylmercury discharged by a chemical plant; and Idrija, Slovenia where the second largest mercury mine in the world was operating before.

From 2008, Prof Tomiyasu started the research for environmental impact of mercury discharged by ASGM. Two or three times in a year, he visited the ASGM site and does the continuous monitoring.

Kyoko Ono was born in Niigata on Aug. 8, 1973. She finished the Graduate School of Engineering, the Univeristy of Tokyo in 2001 and awarded the Ph.D for sanitary engineering.

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At present Dr Ono is senior researcher at the Research Institute of Science for Safety and Sustainability, AIST. Her previous research interests were hazardous metals' material flow analyses and soil-plant transfer. Her current research interests has expanded to developing method for risk trade-off analysis on chemicals, quantitative risk analysis on accident of a chemical plant.

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In 2013 he left JIA and founded KANCHIKEN (Laboratory of Environmental Geology) a consulting company.

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After working for Fujitsu Laboratories Ltd., she got a position of assistant professor at Department of Agriculture, Nagoya University and started research on forest environmental chemistry. She was promoted to associate professor in 1997, and to professor in 2001.

Her main theme is dynamics of various elements including nutrient and trace metals in forest ecosystems as well as radioactive cesium contamination in *Fukushima*. For ASGM she leads a project *Spatiotemporal impact of mercury released from ASGM on agricultural and marine products: evaluation and countermeasures*.

In 2012, Prof. Takenaka was given *Local Environmental Conservation Contributor Award* by the Ministry of the Environment, Japan.