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RESEARCH PAPER

A Preliminary Study on Mercury Contamination in Artisanal and Small-Scale Gold Mining Area in Mandalay Region, Myanmar by using Plant Samples

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ABSTRACT

A large anthropogenic source of mercury pollution is mercury-dependent artisanal and small-scale gold mining (ASGM). Thabeikkyin Township is a small-scale gold mining township located in Pyin Oo Lwin District in the Mandalay Region, Myanmar. The villages of Thabeikkyin Township engage in gold ore crushing, screening, refining, and other mining activities for a living. Miners in this area commonly use mercury for gold recovery by heating amalgam at their homes, gold shops, on the street, and near the riverbank. The evaporated mercury is released into the atmosphere during the heating process and then transported and deposited in the surrounding environments, resulting in the mercury pollution of air, water, soil, etc. To assess atmospheric mercury pollution, a preliminary study on the environmental mercury contamination from ASGM was conducted in Thabeikkyin Township. High mercury concentrations were observed in plant samples collected near the refining sites, ranging 0.33–6.51 ug/g, compared with 0.02 ug/g in Wet Thay Village, where no mercury use was reported. Correlation coefficients between Hg and other heavy metals showed that no heavy metal concentration significantly correlated with that of Hg. The results indicated that the atmospheric environment in the ASGM area of Thabeikkyin Township was contaminated with mercury originating from ASGM, which could very likely deteriorate the health of surrounding residents.

Keywords: Artisanal and small-scale gold mining (ASGM), mercury atmospheric pollution, plant, Mandalay Region, Myanmar

INTRODUCTION

Rapid urbanization and industrialization have led to large amounts of heavy metals contaminants being released into the air, water, and soil, resulting in global environment

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pollution (Merian, 1984; Khan et al., 2004; Vareda et al., 2019). Although some of these pollutants naturally occurring, anthropogenic sources have undoubtedly made a significant contribution to the increase in heavy metal pollution (Karbassi et al., 2016; Panagos et al., 2013). Due to their toxicity and persistence in the environment, heavy metals eventually pose a threat to human health through the food chain (Vareda et al., 2016; Karbassi et al., 2016; Hossen et al., 2021).

Mercury (Hg) is one of the World Health Organization's (WHO, 2017) top 10 chemicals of major public health concern because of its high volatility and toxicity, which can cause neurological diseases, kidney diseases, immune system diseases, heart diseases, reproductive diseases, and even genetic problems (Abu Zeid et al., 2021; Carranza-Rosales et al., 2005; Hu et al., 2021; Henriques et al., 2019; Chu et al., 2020; Ayyat et al., 2020). Minamata disease is one of the most serious disease caused by mercury pollution in the world (Igata, 1993; Harada, 1995). So far, due to no fundamental cure for Minamata disease has yet been discovered, the patients still struggled in their lives (Hachiya, 2006; Yorifuji et al., 2018). As one of the main anthropogenic sources of Hg pollution, artisanal and small-scale gold mining (ASGM) has been reported to contribute to approximately 38% of the annual global Hg emissions (The United Nations Environment Programme, 2019; Liu et al., 2020). In the process of ASGM, Hg is used to recover gold by heating amalgams with an open flame. Gold mining with Hg provides a source of income for many people living in poverty due to its low cost, easy accessibility, and simple extraction processes (Siegel and Veiga, 2009). Many studies have shown that Hg discharged directly into the environment would eventually accumulate in the human body through direct ingestion or via the food chain, resulting in irreparable effects on human health (Reichelt-Brushett et al., 2017; Mason et al., 2019; Feingold et al., 2020; Calao-Ramos et al., 2021). In order to protect human health and the environment from the emission of mercury, the United Nations Minamata Convention on Mercury (MCM) was to enter into force in August 2017. However, the estimated global number of ASGM miners still ranges from 10 to 19 million (Telmer and Veiga, 2009; Esdaile and Chalker, 2018).

To assess the level of Hg pollution in ASGM areas, air, water, sediment, and soil samples are commonly used (Black et al., 2017; Goix et al., 2019; Gafur et al., 2018; Pavilonis et al., 2017; Niane et al., 2019). However, the data are quite possibly heterogenous because of natural causes (rainfall, wind direction, etc.) or human activities (proper/improper disposal of Hg waste, the duration of refining, etc.). Most plants are passive Hg accumulators because of their innate Hg exclusion mechanism to avoid Hg uptake, their ability to convert ionic Hg into volatile Hg0, or both (Siegel et al., 1987; Tania et al., 2013; Gnamus et al., 2000). However, because of their absorptive, accumulative, and translative capacity for heavy metals, some plants provided means for obtaining a long-term overview of atmospheric Hg levels, such as mosses, lichen, and tree bark, which have been successfully used as bioindicators of Hg atmospheric pollution (Bargagli, 2016; Chiarantini et al., 2016, Prasetia et al., 2018; Birke et al., 2018; Prasetia et al., 2020). Plants accumulate Hg mainly in the forms of elemental, inorganic, and organic Hg. Plants can accumulate Hg from both air and soil (Browne and Fang, 1978; Lindberg et al., 1979). Some studies have also found that plants tend to accumulate Hg rather from the atmosphere than from soils, even in the case of severe Hg pollution (Ericksen Kiefer et al., 2003; Chiarantini et al., 2016; Rimondi et al., 2020). Amalgam burning has been reported to release up to 70% of the total Hg used in ASGM into the atmosphere (Lacerda and Salomons, 1998; Kono et al., 2012). Furthermore, the maximum Hg concentrations in air samples collected from ASGM areas in Thabeikkyin Township, Mandalay Division, Myanmar in 2017, reached 74000 ng/m^3, which 74 times higher than the WHO guideline value of 1000 ng/m^3 (Kawakami et al., 2019). However, Hg concentrations in the river and underground water from the mining tunnel were below the WHO guideline (Kawakami et al., 2019). Therefore, using plants in the ASGM area to evaluate Hg atmospheric pollution would be an appropriate method.

In this study, a preliminary study on Hg atmospheric contamination from ASGM in the environment was conducted in Chaung Gyi Village Tract, Thabeikkyin Township, Mandalay Region, Myanmar via comparison with another area (Wet Thay Village, Ohn Zone Tract, Thabeikkyin Township). To assess Hg atmospheric pollution issues, the concentrations of Hg from different tree barks, tree leaves, and blades of grass were analyzed.

MATERIALS AND METHODS

The study was mainly conducted in Chaung Gyi Village Tract, Thabeikkyin Township, Mandalay Region, Myanmar, between February and December, 2020 (Figure 1). Thabeikkyin Township is in Mandalay's Pyin Oo Lwin District, which comprises 17 villages in the district and a population of around 127000 inhabitants, of which 27.1% are involved in ASGM activities as miners. In this area, Hg and cyanide were used for extracting gold from its ore. ASGM workers in Chaung Gyi Village mainly use Hg to mine and refine gold on an individual and family-scale. Contrastingly, ASGM workers in a mining company (Eternal Group of Companies, Myanmar Golden Point Family Co. Ltd. (EGC-MGPF Co. Ltd.)) of Wet Thay Village, Ohn Zone Tract, Thabeikkyin Township, use cyanide for gold recovery (Khin Thein Oo and Hla Kyi, 2019). Therefore, Hg concentration data from Wet Thay Village were used as a control.

In Chaung Gyi Village, gold-containing ore is usually transported from the mining site to the village. ASGM workers collect this ore and perform crushing, screening, and refining at their homes, gold shops, or in open spaces on the street. They use simple equipment to crush ore in front of their houses, and then screening ore in the reservoir they dug in the yard (Figure 2). Then, Hg, sold by native gold shop or convenience stores, is mixed with the gold-containing ore separated, to make gold amalgam. During the process, when amalgam is heated in the fire, Hg is evaporated into the surrounding environment, whereas crude gold is left behind (Figure 3). The crude gold is refined again in a gold shop to obtain purified gold with a purity of approximately 90%. Most of the refining works are performed using rudimentary tools and/or poor ventilation. It can be

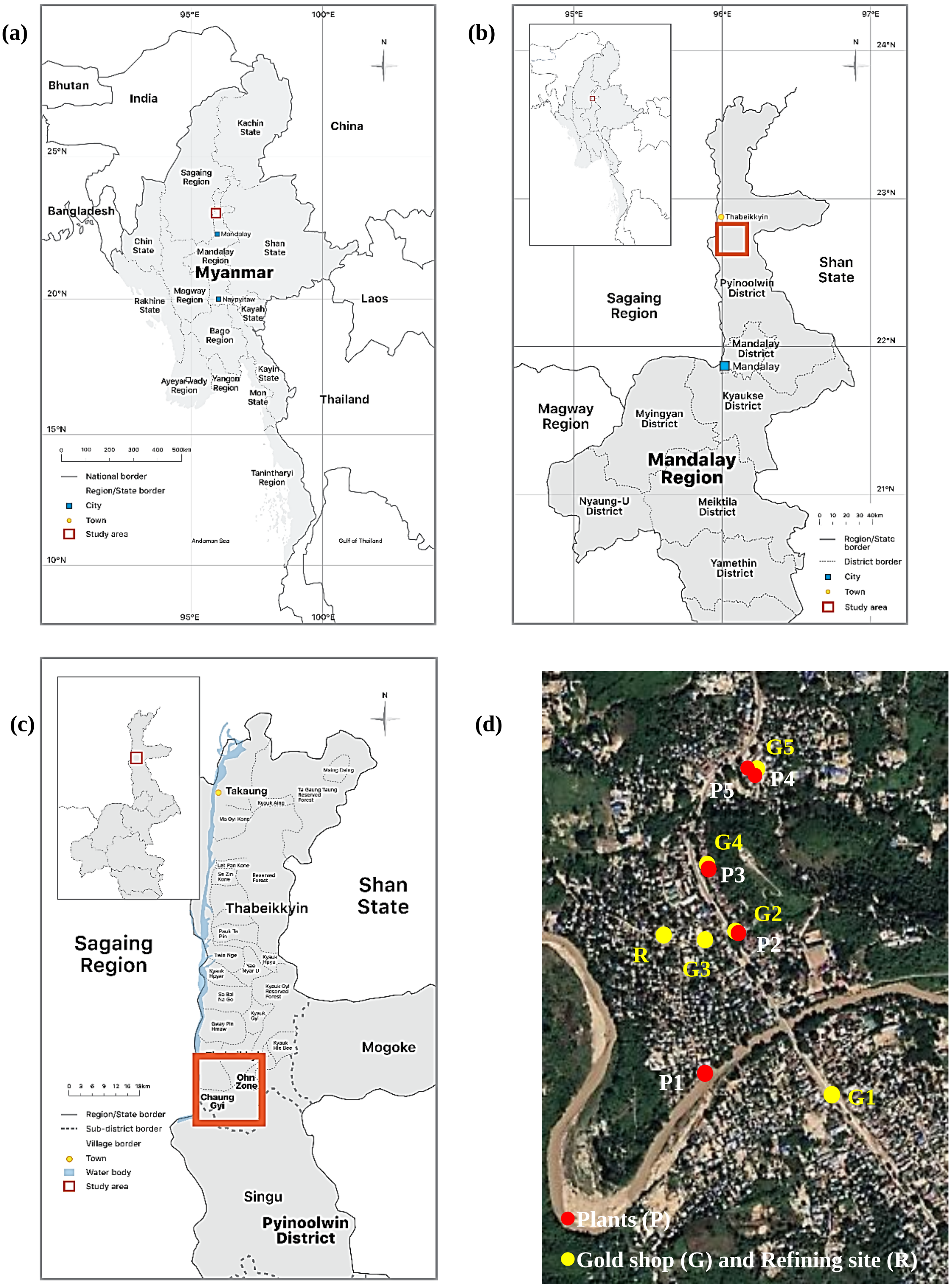

Fig 1. Study area. (a) Map of Myanmar with states and regions (Kyaw et al., 2020); (b) Map of the Mandalay Region with districts (Kyaw et al., 2020); (c) Chaung Gyi Tract and Ohn Zone Tract, Thabeikkyin Township, Pyinoolwin District, Mandalay Region, Myanmar; and (d) sampling locations in Chaung Gyi Village, Chaung Gyi Tract, Thabeikkyin Township, Pyinoolwin District, Mandalay Region, Myanmar.

performed in the kitchen, a designated open refining site, or a gold shop (Figure 4). All these processes can be completed by a single person, who has the ability to do the work, regardless of gender. During the refining process, ASGM workers directly inhale Hg vapor; furthermore, it diffuses to the surrounding environment, thereby polluting the environment and endangering public health.

Fig 2. Ore crushing (a) and screening (b) process occurred in the yard. Ore crushing equipment, which is assembled from simple agricultural equipment, and reservoirs are distributed in courtyards with limited space. Among the people we interacted with, all family members who were able to work participated in ASGM activity for a household.


Fig 3. Gold refining process. This process took place on the street outside the gold shop. No protective attire, such as gloves or masks, were used during the whole process of amalgamation making and heating.

Fig 4. Gold refining location and the equipment inside the refining site. Refining sites were a) a designated location on the street, b) in front of the gold shop with a small furnace, and c) inside the gold shop with tall chimneys. Inside the refining site: d) open space with simple tools, e) a kitchen inside the gold shop next to the counter, f) a special room near the gold shop with certain ventilation equipment. Gold refining was conducted in open spaces or in relatively closed spaces, such as a room next to the counter or a special room outside, with some simple ventilation measures. Refining time generally ranges 1–10 hours/day. Hg vapor will diffuse into the surrounding environment directly or flow far away through the chimney (Palacios-Torres et al., 2018; Brown et al., 2020; Moody et al., 2020).

Plant samples were collected from tree bark, tree leaves, and grass in five locations during February 2020 in the ASGM area of Chaung Gyi Village Tract, where Hg was used for gold refining (Figure 1). One grass sample was collected as a control from the recycled water pond of the mining company EGC-MGPF Co. Ltd. in Wet Thay Village, where cyanide was used instead of Hg for gold refining. Tree bark and leaves were collected approximately 1.3–1.5 m above ground, while grass samples were collected from the ground. All samples were collected using gloves and stainless-steel tools, immediately packed in polyethylene bags, and subsequently dried in the outside natural environment for a simple preliminary drying. The dried samples were transported and preserved in the laboratory of the Research Institute for Humanity and Nature (RIHN), Kyoto, Japan, for future processing and analysis.

Samples were cleaned using tap water, pure water, and ultrapure water, and then dried in an oven at 40°C for several days until they reached a stable weight. Dried samples were ground into homogenized particles using the Multi-beads shocker (MB601U (S), Yasui Kikai Corporation, Osaka, Japan). The total Hg in the plant was analyzed via a reducing-vaporization Hg analyzer (RA-43000, Nippon Instruments Co., Ltd., Osaka, Japan), as directed by the Hg analysis manual (Japanese Ministry of the Environment, Tokyo, Japan). Inductively-coupled-plasma mass spectrometry (ICP-MS 7500cx, Agilent Technologies, Inc., Wilmington, DE, USA) was used to analyze arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), copper (Cu), and zinc (Zn). The analysis procedure was conducted as follows. After 100-mg samples were accurately weighed, sample decomposition was conducted in a sealed Teflon container. The sample was then treated with 4 ml of HNO_3 (Ultrapure analytical reagent, Tama Chemical Co., Ltd., Kanagawa, Japan) and 2 ml of $HClO_4$ (Chemical analysis, Kanto Chemical Co., Inc., Kyoto, Japan) before being heated on a hot plate at 200°C for 48–72 h. After decomposition, the solution was diluted with ultrapure water. Separately, 4 ml of HNO_3 and 2 ml of $HClO_4$ were added to the Teflon container to obtain a blank test solution, and the same procedures as the sample test solution were followed. The same method was used for quality control with a certified reference material BCR-482 Lichen (Institute for Reference Materials and Measurements, Belgium). The measured and certified Hg and other heavy metals values in the BCR-482 Lichen are shown in Table 1. The measured concentration of Hg analyzed with Hg analyzer in the BCR-482 Lichen was 0.49 μg/g, which was within the certified value (0.48 ± 0.02 μg/g) range. The measured concentrations of As, Cd, Cr, Pb and Cu, which analyzed using ICP-MS, show high values than their certified values. As different analytical procedure based on digestion method and analysis instruments was reported to influence the measured values (Cecconi et al., 2019; Tenea et al., 2020), a suitable analysis procedure for As, Cd, Cr, Pb and Cu were needed.

Table 1. The measured and certified values of Hg, As, Cd, Cr, Pb and Cu in certified reference material BCR-482 (Lichen). (The measured value from BCR-482 Lichen is expressed on the basis of dry weight).

Elements	BCR-482 Lichen	
	Certified value (μg/g)	Measured value (μg/g)
Hg	0.48 ± 0.02	0.49
As	0.85 ±0.07	1.05
Cd	0.56 ±0.02	0.64
Cr	4.12 ±0.15	8.16
Pb	40.9 ±1.4	51.61
Cu	7.03 ±0.19	8.67
Zn	100.6 ±2.2	117.65

RESULTS & DISCUSSION

The concentrations of Hg and other heavy metals in plants were analyzed in this study (Table 2). Hg was detected in P1–P5, the grass, tree leaf, and tree bark samples collected from Chaung Gyi Village, as well as in the grass P0, which was used as a control sample

Table 2. Brief description of samples and the concentrations of Hg and other heavy metals in plants of Thabeikkyin Township, Mandalay Region, Myanmar.

No.	Plant name	Sampling site	Concentrations [ug/g]						
			Hg	As	Cd	Cr	Pb	Cu	Zn
P0	*Typha latifolia* L leaf	WTV	0.02	0.53	0.04	3.42	1.28	3.06	21.76
P1	*Typha latifolia* L leaf	CGV, Chaung Gyi Stream	0.33	0.25	0.03	3.22	0.99	6.74	23.54
P2	Azadirachta indica bark	CGV, Gold shop 2	6.51	4.70	0.36	7.45	53.43	46.52	61.09
P3	*Terminalia catappa* L. bark	CGV, Gold shop 4	0.43	0.94	0.36	3.58	19.53	14.79	29.32
P4	*Mangifera indica* L leaf	CGV, Gold shop 5	0.67	0.46	0.04	3.19	4.57	11.62	13.42
P5	Thanaka leaf	CGV, Gold shop 5	4.17	0.59	0.06	3.43	2.97	10.15	42.74

Wet Thay Village: WTV; Chaung Gyi Village: CGV

from Wet Thay Village (Table 2). The Hg concentration of P1 (Typha latifolia L; 0.33 ug/g) was higher than that in the same plant species P0 (0.02 ug/g). Typha latifolia L is wellknown as a common, perennial, and hyperaccumulator emergent because of its high element accumulation capacity (McNaughton et al., 1974; Sasmaz et al., 2008). The normal Hg level in wetland plants growing in areas with no Hg pollution has been reported to be approximately 0.04 ug/g (Moore et al., 1995; Bonanno and Cirelli, 2017). Furthermore, several studies have reported that gold shops are a source of Hg pollution in the atmosphere (Cordy et al., 2013; Moody et al., 2020; Brown et al., 2020). High Hg concentrations have been detected in the gold shop, it reached up around 200-fold than the background level even in the absence of amalgam burning (Palacios-Torres et al., 2018). There are mainly five gold shops and one refining site in Chaung Gyi Village. The gold refining process, whether in the yard, gold shops, or refining sites, was conducted for 1–10 h/day according to its scale and season. A significant amount of Hg vapor is considered to be discharged from these places to the surrounding environment, leading to a higher Hg concentration of plants in Chaung Gyi Village than in Wet Thay Village.

Hg content ranged 0.33–6.51 ug/g in all plants in Chaung Gyi Village. High concentrations of Hg were observed in P2 (Azadirachta indica bark) and P5 (Thanaka leaf) samples collected near the gold shop, with values of 6.51 and 4.17 ug/g, respectively. Total concentrations of Hg in vegetation growing on natural soils are usually below 0.1 μg/g (Xiao et al., 1998), but it can be categorized as toxic when the concentration of Hg in the plant leaves exceeds 1 ug/g (Massa et al., 2010; Kabata-Pendias, 2010). In the mining area of Almadén, Spain, the Hg concentrations of the tree bark and leaf range between 0.04–1.67 ug/g and 0.09–1.23 ug/g, respectively, whereas the Hg concentrations in the non-polluted area were 0.09 and 0.02 ug/g, respectively (Viso et al., 2021). Hg concentrations in Pinaceae tree rings at natural sites in North America are commonly within 1–4 ng/g (Clackett et al., 2021). Different plant species and different parts of the same plant have different Hg absorption and fixation capacities (Marrugo-Negrete et al., 2016; Yang et al., 2018; Kimáková et al., 2020), which could explain the difference in Hg concentrations in P4 and P5 near the same gold shop. P2 and P5 results suggested that Hg emissions from gold shops/refining sites contribute to the high content of Hg in Chaung Gyi Village, and had already influenced the surrounding environment. ASGM workers and residents are at high risk of ingesting and accumulating Hg through the air and food chain (water, vegetables, fish, etc.), which can pose risks to their health. In a previous study, the Hg concentration in hair samples from some ASGM workers of Chaung Gyi Village had already reached the warning level, and some ASGM workers even showed neurological signs and symptoms of chronic Hg intoxication (Kyaw et al., 2020). Furthermore, several studies found that residents of mining areas who were not actively involved in mining were found presenting a negative impact on human body resulting from Hg (Bose-O’Reilly et al., 2008; Steckling et al., 2011; Bose-O’Reilly et al., 2020).

Heavy metal pollutants, such as As or Cd, are often released simultaneously with ASGM activities because these hazardous elements are typically present in minerals (Pavilonis et al., 2017; Gafur et al., 2018; Dorleku et al., 2018; Tun et al., 2020; Tabelin et al., 2020). With the mining and extraction of ore and the absence of appropriate management of tailings, heavy metals stored in ore and tailings will be continuously dispersed to surrounding soils, water (river, groundwater, etc.), and the environment due to erosion, weathering, and leaching processes (Ciszewski et al., 2012). In Chaung Gyi Village, mine tailings are usually stored in the miners’ home/gold shop before being thrown into Chaung Gyi Stream, where P1 is located. To avoid the influence of the previously mentioned natural and human activities, the concentrations of heavy metals in plants were used to quantify both water and soil pollution caused by ASGM activities. In plants, the normal limits of As range 0.02–7 ug/g, Cd range 0.006–2.4 ug/g, Cr range 0.0.6–18 ug/g, Pb range 1–13 ug/g, Cu range 0.4–45.8 ug/g, and Zn range 1–160 ug/g (Hajar et al., 2014; Gjorgieva Ackova, 2018), thus showing wide ranges. According to the study of Sawidis et al. (2021), Cr concentrations in tree leaves and bark from non-polluted areas range 0.2–0.6 ug/g, Cu range 2.6–4.7 ug/g, and Pb range 2.5–3.0 ug/g. The maximum concentrations of As and Pb in the tree bark from uranium mining in the United States have been reported to be approximately between 0.02 and 0.10 ug/g, respectively (Flett et al., 2021). The maximum concentrations of Pb, Cu, and Zn in tree rings from the areas in Kabwe (Zambia) involved in Pb–Zn mining and smelting activities, which had been active for 61 years, were approximately 6.5, 10.6, and 10.2 ug/g, respectively (Baieta et al., 2021). In this study, compared with P1 and the studies abovementioned, P2 shows high concentrations of As, Cr, Pb, Cu, and Zn with values of 4.70, 7.45, 53.43, 46.52, and 61.09 ug/g, respectively; P3 shows high concentrations of Pb, Cu, and Zn with values of 19.53 and 14.79 and 29.32 ug/g, respectively; P4 shows a high concentration of Cu with value 11.62 ug/g; and P5 shows high concentrations of Cu and Zn with values of 10.15 and 14.79 ug/g, respectively. According to the results of this study, there is a high risk of pollution from other heavy metals such as As, Cr, Pb, Cu, and Zn in the study area, which would become a secondary danger caused by the ASGM activities in Myanmar.

The correlation among heavy metals was analyzed (Table 3). The correlation coefficients (Pearson's correlation) were calculated and only the values of $r \geq 0.95$ were considered significant (Ogbonna et al., 2011; Malizia et al., 2012) because of the small number of samples. It was found that no heavy metal concentration significantly correlated with that of Hg. With As concentration, that of Cr had a coefficient of 0.99, Pb had a coefficient of 0.97, and Cu had a coefficient of 0.99. With Cr concentration, that of Pb had a coefficient of 0.96 and Cu had a coefficient of 0.99. Pb had a coefficient of 0.98 with Cu. In summary, Hg did not correlate well with other metals; instead, high correlations among As, Cr, Pb, and Cu were observed in the plants. The difference in correlation coefficients could be because the main source of Hg is from the atmosphere (Lacerda and Salomons, 1998; Kono et al., 2012; Kawakami et al., 2019; Moody et al., 2020), whereas the main sources of other heavy metals are from the soil (Pavilonis et al., 2017; Dorleku et al., 2018; Tabelin et al., 2020).

Table 3. Correlation analysis among heavy metals in the plant from Chaung Gyi Village (n = 5)

	Hg	As	Cd	Cr	Pb	Cu	Zn
Hg	1						
As	0.8175	1					
Cd	0.3657	0.6939	1				
Cr	0.8283	0.9978	0.6577	1			
Pb	0.7105	0.9752	0.8307	0.9621	1		
Cu	0.7951	0.9971	0.7094	0.9908	0.9802	1	
Zn	0.9368	0.8394	0.5688	0.8482	0.7842	0.8076	1

Although the data obtained in this study were sparse, the results indicated that the atmospheric environment of Thabeikkyin Township may be contaminated with Hg originating from the ASGM area, which could harm the health of surrounding residents.

CONCLUSION

A large amount of Hg vapor was discharged from the refining site to the surrounding environment in Chaung Gyi Village, Thabeikkyin Township, Mandalay Region, Myanmar. High Hg concentrations in plants indicated that the study area's atmospheric environment was contaminated with Hg and may pose a threat to the surrounding environment. The hair sample data in our previous study demonstrated that the residents of this village were already negatively affected by Hg. Although the data obtained in this study were sparse, the results serve as a data reference for future research on Hg pollution in Myanmar. More investigation into Hg pollution and other heavy metal pollution due to ASGM activities in this study area is required. Furthermore, plant samples can be used to evaluate long-term atmospheric Hg pollution in the ASGM area. In another hand， some protective measures, such as wear masks and gloves when refining, don't drink under group water and eat local food and so on, are needed in study area. However, mining without mercury is the fundamental way to reduce mercury emission problem. Mercury-free gold mining technologies would be a good way to solve this problem.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely avoided by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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