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Mercury Contamination from Artisanal Small-scale Gold Mining Activities in Simpenan District, Sukabumi Regency, West Java, Indonesia

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Abstract: Mercury is still used in the amalgamation process in small-scale gold processing. This study aims to evaluate the mercury contamination of various environmental media in the artisanal small-scale gold mining (ASGM) area in the Simpenan District, Sukabumi Regency. The ecological media examined in this study included groundwater, river water, soil, sediment, biota, and plants. The threshold number was determined using APHA 3125 and Indonesian National Standard (SNI) 7387:2009. Meanwhile, the mercury concentration in the ambient air was measured directly using a mercury analyser. Mercury concentrations in the water, soil, sediment, biota, and plant matrices were calculated using a calibration curve. The study found that the levels of mercury in groundwater, river water, and sediment were all below the applicable quality standards of <0.0001, <0.0001 and 0.001 mg/L, respectively. However, the levels of mercury in soil and plants were 27.28 and 0.52 mg/kg, respectively. Additionally, the levels of mercury in four types of fish found in a river adjacent to the ASGM location, namely beunteur (0.33 mg/kg), snakehead (0.05 mg/kg), catfish (0.26 mg/kg) and eel (0.20 mg/kg), exceeded the specified quality standards. In conclusion, mercury contamination is present in the soil, plants, and aquatic biota (fish) in the ASGM area in the Simpenan District, Sukabumi Regency.

Key words: Artisanal and small-scale gold mining mercury, bioaccumulation, bioconcentration factor, soil contamination.

Introduction

The Minamata Convention (in Article 2-Definitions) defines "artisanal and small-scale gold mining (ASGM)" as illegal gold mining carried out by individual miners or small companies with limited capital investment and production. In practice, ASGM refers to miners using manual or simple extraction processes, many of which have been in use for centuries. Mercury (Hg) is a commonly used material in community and small-scale gold mining operations, including those in Indonesia. The increasing number of ASGM hotspots particularly in developing countries, raises concern about the use of mercury in gold production (Prescott et al., 2022). The Indonesian government has committed to eliminating the use of mercury in the

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ASGM sector entirely by 2025. However, as of 2020, only 1.7% of this goal has been achieved. Eliminating mercury from ASGM is a challenging task due to the ease of access to mercury and the lack of knowledge regarding gold ore extraction methods. According to Esdaile and Chalker (2018), the two main obstacles to its elimination are the aforementioned factors. ASGM miners use up to 650–1,000 kgs of mercury per year to extract gold ore, which is illegally supplied to their locations throughout Indonesia via ports. It is estimated that 2000 kg of mercury is used in Indonesian ASGM activities, although the actual amount may be higher. Approximately 200 kg of Hg is discharged into the environment each year from nearly 900 ASGM sites in the country (Kocman et al., 2013).

Mercury contamination resulting from ASGM activities is widespread throughout Indonesia, affecting 29 provinces and producing 53.8 tonnes of gold. The gold extraction process involves the use of 1,725 tonnes of mercury which results in the release of 345 tonnes of mercury into the surrounding environment. According to Krisnayanti and Probiyantono (2020), Central Sulawesi, Banten and West Nusa Tenggara are the three provinces with the highest mercury emissions producing, 48.4, 36, and 33.4 tonnes per year, respectively.

Mercury contamination arises from the mercury cycle, which includes anthropogenic emissions from the burning of fossil fuel coal in the atmospheric system, as well as emissions from the atmosphere and soil in the land system, and through anthropogenic emissions in the aquatic food chain in the ocean system (Selin, 2009; Zhang and Wong, 2007). Mercury is widely used in the ASGM sector worldwide, estimated to affect negatively the environment and around 5 million people (Dewi and Ismawati, 2012; Ovadje et al., 2021).

Studies conducted in Indonesia have found mercury contamination in soil media and crops near ASGM areas, such as in West Lombok Regency (Johari et al., 2020), Tasikmalaya Regency, KulonProgo Regency, Bogor Regency (Tomiyasu et al., 2013), Sukabumi Regency (Saragih et al., 2021), and Palu City (Nakazawa et al., 2021). Mercury contamination has been found in various river and aquatic species such as the Cikaniki River (Tomiyasu et al., 2013), the Kuantan River (Johari et al., 2020) in paddy fields (Tomiyasu et al., 2017) and green mussels in the Gulf, Jakarta (Riani et al., 2018). Additionally, mercury contamination has been found in river sediments in the Saba Padang irrigation (1.63 mg/kg) and soil from the HutaBargot planting area (1.62 mg/kg) in the Mandailing Natal District (Astika et al., 2021).

Mercury contamination in humans and the environment is caused by the toxicity, persistence, and bioaccumulation of mercury. It can move over long distances in the atmosphere. For instance, the ASGM activities have led to mercury accumulation in the Amazon region resulting in soil, biomass, and birds, which hinders forest conservation efforts (Gerson et al., 2022). In Ghana, mercury contamination occurs in plants due to ASGM activities, which increases the mercury content in the food chain around the area to 2-3 times that of sediment (Amoakwah et al., 2020). Furthermore, ASGM activities can lead to the destruction of eco-terrestrial systems, resulting in the loss of vegetation and pollution of rivers and protected areas (Barenblitt et al., 2021). Mercury contamination is also found in various human bodily fluids, including hair, blood, breast milk, and urine (Calao-Ramos et al., 2021).

Mercury contamination is hazardous to both the environment and human health. Nonetheless, mercury is still used in the amalgamation process in ASGM activities, including those in Sukabumi Regency. The objective of this study was to evaluate mercury contamination in various environmental media within the artisanal small-scale gold mining (ASGM) area in the Simpenan District, Sukabumi Regency. The study results are expected to aid in monitoring the environmental impact of ASGM activities and developing long term solutions to prevent the harmful effects of mercury contamination on both humans and the ecosystem.

Method

Research Design

This study is based on original data collected by sampling at an ASGM hotspot in West Java, Indonesia, that still uses mercury. Six media samples were taken, namely groundwater, river water, soil, sediment, plants, and fish, and each location was repeated three times. The quality standard values and references used in this research are listed in Table 1.

Research Site

The research site is described in detail in the following section:

The study was conducted in the ASGM area located in Kertajaya Village, Simpenan Subdistrict, Sukabumi District as shown in Figure 1.

Table 1: Threshold reference for mercury contaminated media

Media	*References*	*Quality standards*
Groundwater	Ministry of Health Regulation No. 02:2023	0.001 mg/L
River water	Government Regulation No.22:2021	0.002 mg/L
Sediment	Canadian Sediment Quality Guideline	0.13 mg/kg
Soil	Canadian Soil Quality Guidelines	6.6 mg/kg
Plant	SNI 7387:2009	0.03 mg/kg
Biota (fish)	SNI 7387:2009	0.03 mg/kg
Ambient air	WHO	1,000 ng/m^3

The ASGM activity in Simpenan involves small-scale mining with an underground system using simple/manual equipment. Gold ore is traditionally processed, using the amalgamation method with the addition of mercury as a gold solvent.

Sampling Method

Groundwater and river water sampling followed the guidelines of SNI 8995:2021. The soil was sampled using the 2008 Soil Research Institute procedure outlined by Agus (2005). Sediments sampling followed the SNI 3414:2008 and SNI 8910:2021 standard. Biota (fish) samples including beunteur, cork, and eel were collected from the nearest river to the ASGM location, specifically the Cihaur River. Additionally, samples were taken from rice plants in fields near the ASGM location. The ambient air monitoring was conducted at the workplace of the workers responsible for amalgam burning (mercury evaporation).

Time and Frequency of Data Collection

Data collection was conducted over a period of 12 months, from October 2021 to September 2022.

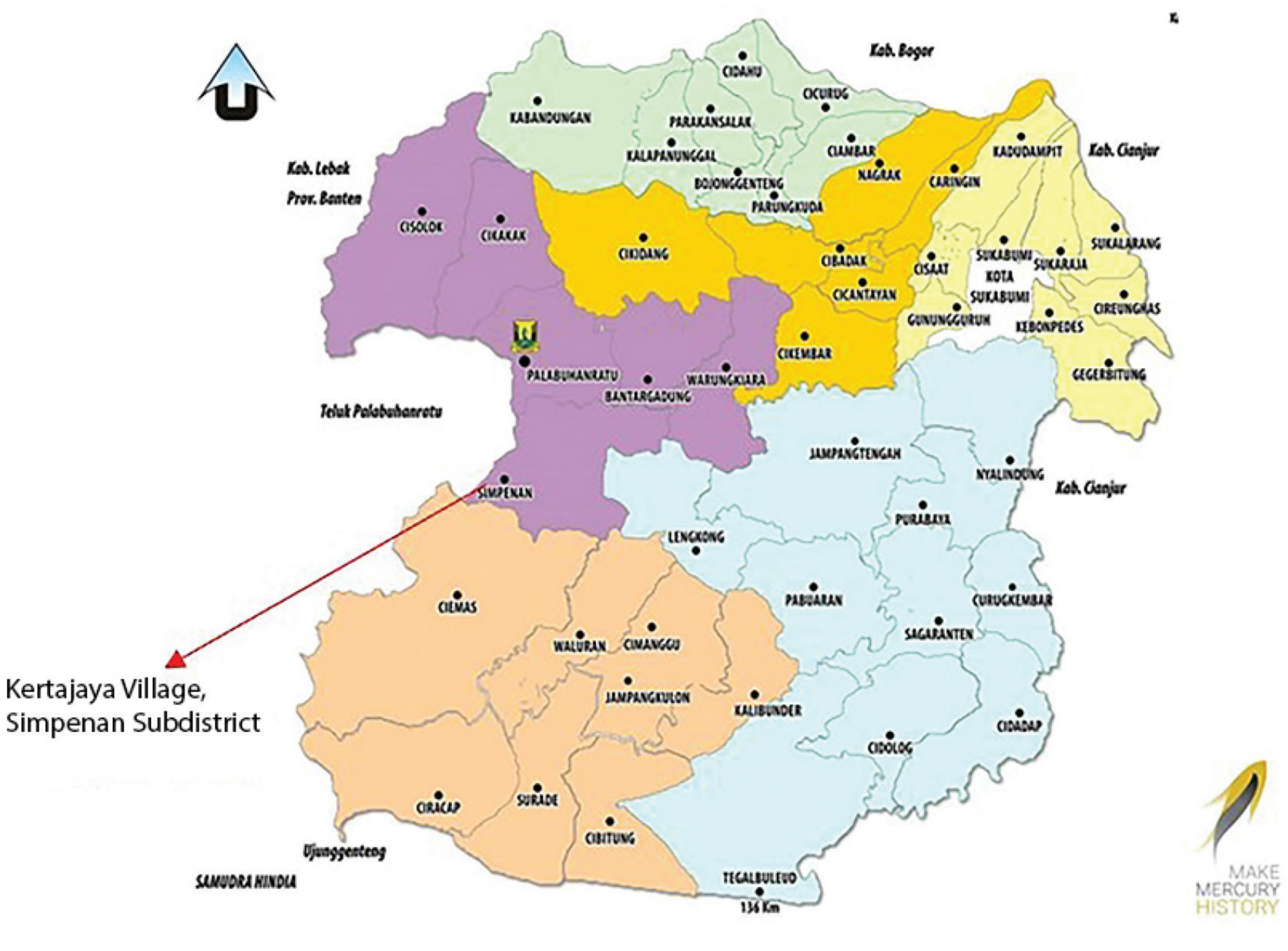

Figure 1: Location of the research, ASGM area in Kertajaya Village, Simpenan Subdistrict, Sukabumi District.

Data Analysis Procedure

The APHA 3112 B method was used for water samples, while the SNI 7387:2009 method was used for soil, sediment, plant, and biota samples. Both methods employed The Cold-Vapor Atomic Absorption Spectrophotometer instrument. Mercury in the ambient air was analysed using a portable mercury analyser (EMP-2) NIC-600-2170-06, manufactured by Nippon Instruments Corporation. The analysis of the sample was repeated 7 times to get the RSD (%RSD < 10%).

Description of Location and Process of ASGM Activities

ASGM activities using traditional methods in the Simpenan Subdistrict, Sukabumi, have been ongoing for a long time. The mining process starts with vertical digging of a mine pit using a hammer and chisel. The rock/gold ore obtained is then transported to the earth's surface using jerry cans pulled by a pulley. The stages in this ASGM activity begin with the crushing of large rocks into smaller pieces, either manually or using machines. The ore is crushed into smaller, uniform grain sizes using a tool called *glundungan* (or *tromol*) to extract gold. Mercury is then added to the ore to separate the gold from other minerals forming amalgams (soft mixtures of about 50% mercury and 50% gold) with the gold particles in the crushed ore. The process involves heating the amalgams to vapourise the mercury, allowing for the separation of gold. The resulting "*Sponge gold*" is then melted to remove impurities of gold doré, with a small amount of ore dregs remaining. The final step involves refining the dore to obtain 24K gold which is typically done in a gold shop.

Results

Table 2 shows that the concentration of mercury in groundwater near the ASGM location 500-700 m and Cihaur River water, is below the applicable quality standard of 0.001 mg/L, with a value of <0.0001 mg/L. The sediment sample from the Cihaur River has a mercury content of 0.0001 mg/kg, which is also lower than the applicable quality standard of 0.13 mg/kg.

Table 3 shows that there are high concentrations of mercury in the air in the ASGM area of Simpenan District, Sukabumi Regency. This indicates the use of mercury in gold processing activities which evaporates during the gold refining process due to the amalgamation process. Mercury pollution can be transferred from the air into water and soil, which increases the concentration of mercury in biota around the oceans.

Table 3: Mercury content of ambient air at ASGM location in Simpenan District, Sukabumi Regency

Sampling location	*Mercury content (ng/m^3)*	
	Point 1	*Point 2*
Simpenan District	998	956

Table 4 shows the bioconcentration factor (BCF) used to determine the ability of fish to accumulate mercury from sediments. The elevated BCF values observed for beunteur, cork, catfish and eel are likely attributed to the disposal of the remaining gold processing waste directly into the Cihaur River, where the fish samples were collected. Beunteur exhibits the highest BCF value; suggesting that it can accumulate mercury from sediments more efficiently than plants, snakehead fish,

Table 2: Mercury contents of groundwater, river water, sediment, soil, plants, and fish media at the ASGM location in Simpenan District, Sukabumi Regency

Sampling location	*Mercury content (mg/L)*		*Mercury content (mg/kg)*						
	Groundwater	*River water*	*Sediment*	*Soil*	*Plant*	*Beunteur*	*Cork*	*Catfish*	*Eel*
Simpenan District	<0.0001	<0.0001	0.0001	27.28	0.52	0.33	0.05	0.26	0.20

Table 4: Bioconcentration factor (BCF)

Sampling location	*BCF*				
	Plants/Soil	*Beunteur/Sediment*	*Cork/Sediment*	*Catfish/Sediment*	*Eel/Sediment*
Simpenan District	0.02	3300	500	2600	2000

catfish, and eels. This is likely due to the predatory nature of beunteur fish, which allows them to absorb pollutants in their habitat.

Discussion

In ASGM activities, mercury that enters the environment during amalgamation combustion can settle in the top soil layer, therefore soil is an important indicator for monitoring environmental mercury concentrations. Additionally, mercury absorption from the air can increase mercury accumulation in the top soil horizon through litter accumulation and decomposition. The mercury content of the soil at the ASGM location is relatively high (27.28 mg/kg) which exceeds the standard of 6.6 mg/kg (Table 2). The mercury content of the sampled rice plants is also high (0.52 mg/kg) which is above the existing quality standard of 0.03 mg/kg. The high mercury concentration in the soil around Simpenan District is due to the metallic content in the ASGM location, which is consistent with previous studies by Basri et al. (2020) which stated that mercury contamination was detected in soil media in the Bombana area (South Sulawesi) and Poboya, Grand Forest Park, and Ngatabaru (North Gorontalo), and was found to accumulate in plant tissues and food chains. Moreover, studies conducted in Myanmar and several Asian countries showed that individuals living near ASGM locations could be harmed by mercury exposure during the amalgamation process (Soe et al., 2022). Furthermore, mercury from contaminated soil can leach into rivers, streams, and underground water systems, specifically in locations where these waters are used for drinking purposes (Addai-Arhin et al., 2022).

Table 3 illustrates the significance of the mercury level in the sediment, and more importantly, the soil in the Tobongan, Lanut, and Tateluregions.

In summary, soil affects the mercury content of plant tissues. It is caused by mercury that may accumulate from groundwater, sedimentation, and river water at an ASGM location. High concentrations of mercury in plants indicate that the atmospheric environment, such as the soil, has been contaminated by mercury, which can endanger the surrounding environment (Kuang et al., 2022). Heavy metal content can be hazardous to plants due to oxidative stress, inhibition of cytoplasmic enzymes, and cell death. Furthermore, plant development is also influenced by soil microbes. Basri et al. (2020) found that soil microbes affect plant development, biochemical structure, and physiology. Mercury contamination, on the other hand, hinders tiller and panicle formation in rice (*Oryza sativa*), resulting in shorter stem height and lower yields.

The mercury contents from the Cihaur River (Table 2), (beunteur, snakehead, catfish, and eel), are 0.33, 0.05, 0.26, and 0.20 mg/kg, respectively, which are all above the threshold value of 0.03 mg/kg, indicating bioaccumulation and biomagnification have been occurring due to the impact of mercury pollution on aquatic biota around ASGM. Mercury bioaccumulation in the environment is highly likely to occur in ASGM areas due to the accumulation of the total amount of mercury. According to Hananingtyas et al. (2022), mercury accumulation in the environment can be observed not only in biota but also in crops grown on mercury-contaminated land.

This study identified several indications that the environment in the ASGM location in the Simpenan Subdistrict is contaminated with several ecological media. Mercury pollution affects various ecological media, including soil, resulting in high concentrations of mercury in plants. The study findings demonstrate that mercury pollution in the soil can encourage mercury pollution in plants due to the nature of mercury, which continually accumulates (bioaccumulates) and can harm the ecosystem above it. Soil provides a habitat for various living organisms, including plants, and it also stores and filters water while maintaining the environment. Mercury pollution in paddy fields is suspected of accumulating in plants. If the plant portion is swallowed by animals or humans, it will progressively create health issues for individuals who consume it (Suhadi et al., 2021).

Conclusion

Mercury pollution has been found in soil media, plants, and aquatic biota (fish) in the ASGM region of Simpenan District. The food crop evaluated was rice, as it is the major source of carbohydrates for those living near ASGM sites. Plants acquire mercury pollution from different media due to mercury bioaccumulation. Pollution levels in groundwater, river water, sediment, and ambient air were all below the stipulated quality criteria at the sample site. However, the analytical results indicate that the concentration of mercury in food crops near ASGM sites exceeds the stated threshold. Plants absorb contaminants from other media, which can cause serious problems in the human and environmental food chains. This study highlights the importance of monitoring environmental quality in regions near ASGM, that still use mercury.

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