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Artisanal gold mining related mercury pollution in Ratatotok area of North Sulawesi, Indonesia

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Abstract—Gold mining in the Ratatotok area has a long history going back to the activity of a Dutch company, Nederland Mynbouw Maschapai in the years 1887 to 1922. After about 60 years latter, artisanal or small groups of local community started to seek their fortune in the gold mining using techniques learned from the Dutch company, consisting of gold vein tunnels and mercury amalgamation processing. In the 1990s an American company, PT. Newmont Minahasa Raya obtained a gold mining concession in a part of this area. This company uses advanced technologies such as open pit mining, cyanidation processing, detoxification of sludge, and a sub-marine tailing system. While the problems of mercury emissions from artisanal gold mining have been well studied in much of the world, little has been written about the state of mercury pollution in this area. It is vital to understand how the situation has affected the surrounding aquatic environment, because fish is the main protein source and income for the local community. This study has been carried out with aims of determing the influence of mercury emissions from artisanal gold mining activity upon the surrounding aquatic environment. Research included total mercury determination in water, sediment, and fish samples taken along the impacted Totok River. Total mercury determinations were accomplished using an atomic absorption spectrophotometer employing cold vapor generation. As a result, high concentrations of mercury in sediment and fish meat has been noted. The water samples showed only small amounts of mercury. In sediment, mercury contents were seen to increase at deeper layers, reaching up 40 mg/kg dry weight. The analysis of fish meat samples showed that the mercury the range from 0.08 mg/kg in pelagic fish to 0.89 mg/kg in bivalve. The present findings demonstrate that a more comprehensive monitoring of the presence of mercury in fish taken in the area of Totok Bay in order to better mitigate this problem.

Key words: mercury, artisanal gold mine, bioaccumulation, Indonesia

Introduction

Mercury has been used in the process of extracting gold in artisanal gold mining in North Sulawesi. The locations of artisanal mining are widely distributed in the North Sulawesi region. As indicated in Limbong et al. (2003), artisanal mining has been the main source of mercury pollution in this region. The Ratatotok area is the one area that has a long history going back to the gold mining activity of a Dutch company, Nederland Mynbouw Maschapai in the years 1887 to 1922. In 1982, artisanal or small groups of local community started gold mining using the techniques they learned from the Dutch company, consisting of gold vein tunnels and mercury amalgamation processing. In the 1990s, an American company, PT. Newmont Minahasa Raya, obtained a gold mining concession in a part of this area. This company uses advanced technologies such as open pit mining, cyanidation processing, detoxification of sludge, and a sub-marine tailing system. While the problems of inorganic mercury emissions from artisanal gold mining are well studied in much of the world, little has been written about the state of mercury pollution in the Ratatotok area.

Mercury pollution may originate from several sources ranging from natural to anthropogenic origin. The over all types of pollution will generate a general pathway that consist of water system such as river, lake, coastal water, and ocean as the ultimate depository area. In the environment, inorganic mercury may become methylated particularly in soil and sediment. Under normal conditions, only a maximum of 5% of inorganic mercury is methylated. This rate may increase under certain conditions depending on organic material content and pH of the soil or sediment. In water systems, methyl mercury is the most important form, which is readily accumulated by biota and magnified through the food chain. Most of the mercury that accumulates in fish tissue is methyl mercury, and fish are probably the most common indirect exposure route by which mercury affects humans. In humans, methyl mercury can cause damage to the neurological, excretory, and reproductive systems. Accordingly, methyl mercury is the mercury form of greatest toxicological concern (Samoiloff 1989, Akagi and Nishimura 1991, Ikingura and Akagi 1996, Clark 1997, Lodenius and Malm 1998).

In order to prevent mercury contamination in early stages, periodic monitoring of the environmental mercury level is necessary. This study has been carried out to provide baseline information regarding mercury contamination of the aquatic environment surrounding the artisanal gold mining in the Ratatotok area located on the southeast coast of North Sulawesi peninsula, Indonesia. The study was carried out in late 2000 and involved observations of the artisanal mining operations, demonstration of the retort used in amalgam burning, and total mercury determination of soil from location of gold processing unit, water and sediment samples taken along the impacted Totok River, and fish and bivalve samples collected from Totok Bay.

Materials and Methods

The present study was conducted in the Ratatotok area located on the southeast coast of the North Sulawesi peninsula of Indonesia facing the Maluku Sea (Fig. 1). Its topography consists of plains at the coastal area and becomes hilly several hundreds meters from the shoreline. Mangrove forests and coral reefs are spread along the shoreline. The gold mining area is located at about 500 m from sea level on hill sites. The artisanal mining takes place at the upper stream of the Totok River which runs into Totok Bay, and the mining area of Newmont Minahasa Raya Company located at upper stream of Buyat River that running into Buyat Bay (Fig. 2).

There are two coastal villages, Ratatotok and Basaan in Totok Bay. The total population of those two villages was about 5678 according to the 2000 census, of which about 465 are fishermen. The fishermen catching fish within and outside of Totok Bay use lift nets, hand lines, drift gill nets, small purse seines, and traps. The fish caught consist mainly of skipjack, tuna, scads, barracuda, mackerel, snapper, grouper, and anchovy. The total fish production of the two coastal villages was about 150000 kg/year.

Field survey had been implemented in artisanal gold mining area. Most of the time had been spend at the gold processing units, and only a brief observation on mining activities at mountains area. In order to elucidate the degree of mercury emission from amalgam burning activities, the use of a closed system or retort was introduced and demonstrated. A number of trials were carried out, and the weights of amalgam, produced bullion, and recaptured mercury was recorded. In addition, soil samples were taken at the location of two selected gold processing units for total mercury determination. The soil samples were taken at three different distances 5 m, 15 m, and 30 m, from the processing units with three replication sites, and three vertical soil layers 0–5 cm, 5–10 cm and 10–15 cm. Then, one composite sample from the three replication sites was prepared for each distance and soil layer.

In order to investigate mercury contamination of the water system, water and sediment samples were collected from four sampling sites along the Totok River and one additional site at the estuary of the Buyat River (Fig. 2). Due to the difficulties in access to the up-stream sides of the gold processing units, all of the sampling sites in Totok River were located down-stream of the processing units. Fish and bivalve samples were caught within Totok Bay by selected local fishermen. Water samples were taken using pre-labeled and clean 250 ml Nalgene polyethylene bottles. Sediment samples were taken by a sediment core sampler down to 30 cm from the sediment surface, and packed in three different layers 0–10 cm, 10–20 cm, 20–30 cm in pre-labeled 250 ml plastic bottles. Total mercury content of the samples was determined using cold vapor technique as described in Limbong et al. (2003).

Result and Discussion

Artisanal gold mining in the Ratatotok area is performed mainly by informal, illegal, and small less-organized groups. Fairly primitive processing technology was observed at 20 of the approximately 40 artisanal gold processing units in this area. Such methods range from manually crushing the ore by using hammers, grinding the ore to finer particles using a ball mill and introducing mercury to form amalgam, and open-air roasting of amalgam. Gold processing causes mercury pollution in various ways. One way is when mercury is unintentionally spilled onto the ground because of careless handling. Another is when mercury is discharged together with other wastes into inadequate tailings ponds, or worse, thrown away directly into waterways and rivers. Still another way is when

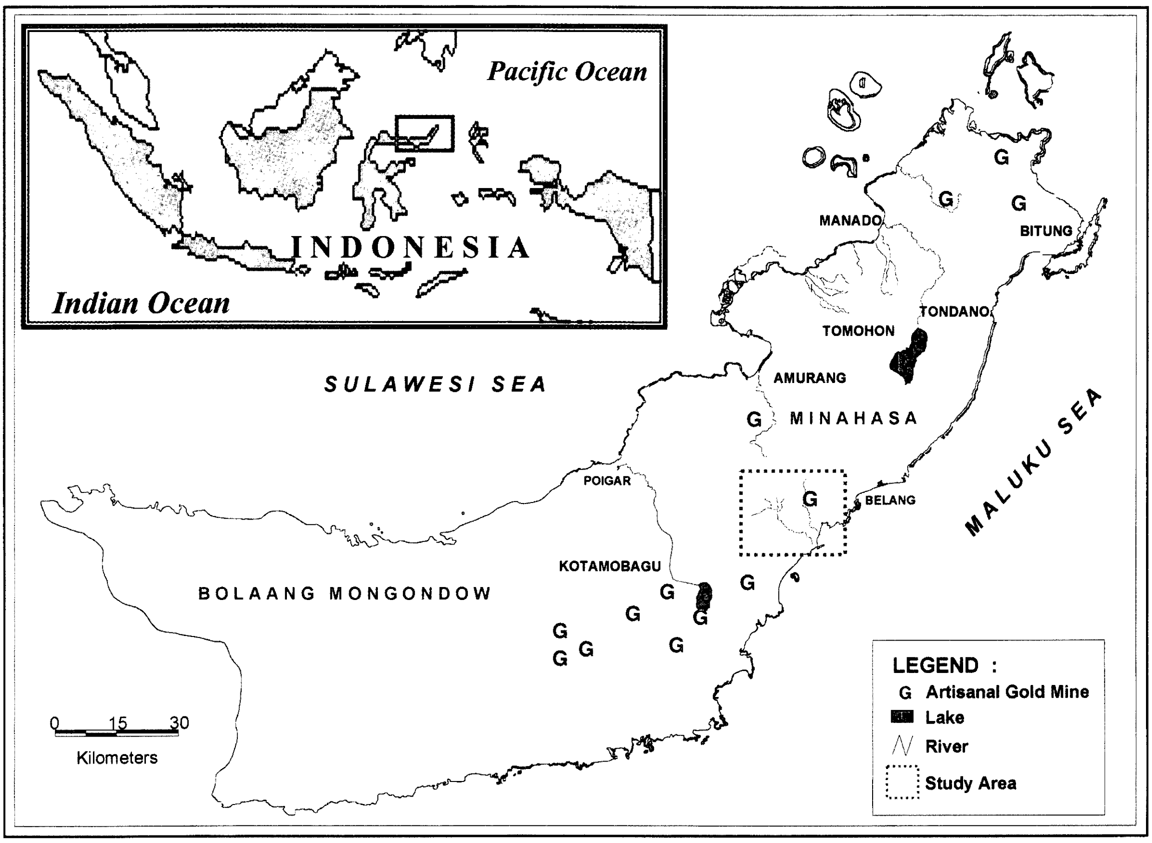

Fig. 1. Study area in the North Sulawesi Peninsula, Indonesia.

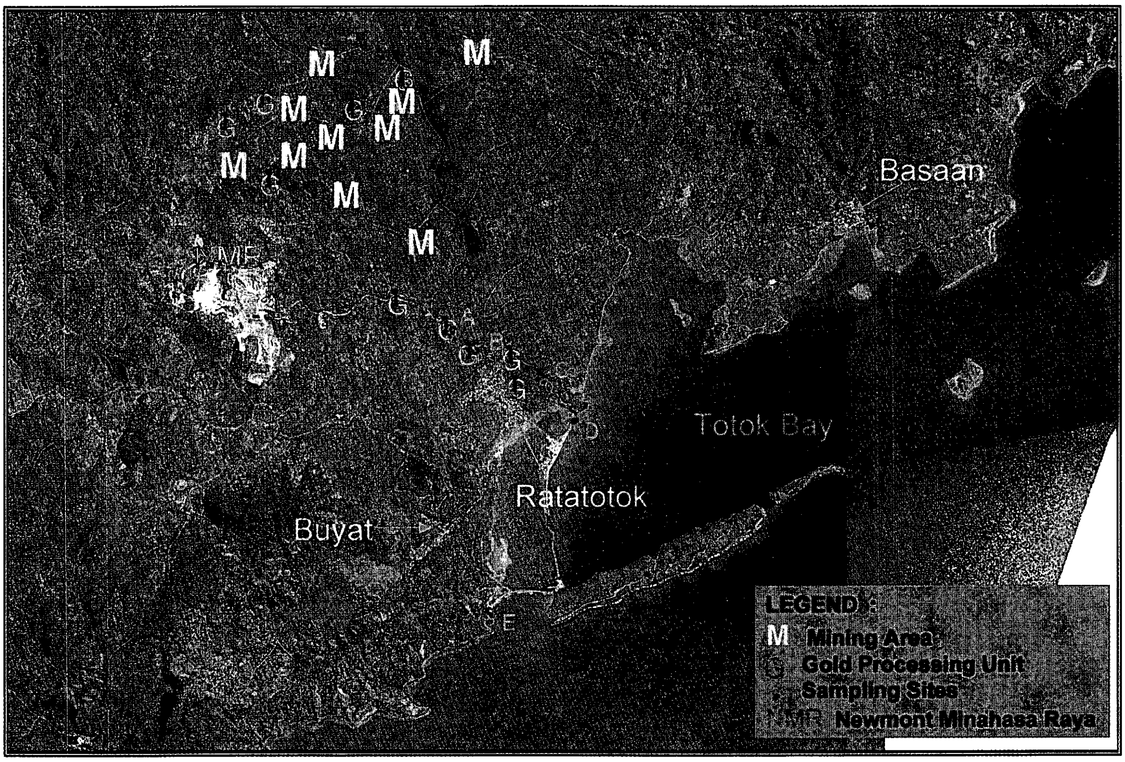

Fig. 2. Sampling sites in the Ratatotok area.

vaporized mercury is released into atmosphere when the amalgam is burned.

On average, every processing unit operated 10 ball mills, and the ore process is set out in the range of 1–3 times per day, depending on the availability and quality of the ore. One kilogram of mercury is inserted into every ball mill for the amalgamation process. Considering that the total amount of processing unit in the area is 40 units, then the amount of mercury should be maintained for amalgamation process in all processing unit is about 400 kg. Adding a 75% stock supply, then the estimate of the continuous total amount of mercury available at the artisanal mining area is about 700 kg.

The results from soil sample analysis and the regarding the retort used for the amalgam burn, provide strong evidence that a significant amount of mercury used in the processing unit is released into the environment by the current processing practices. As depicted in Fig. 3, the soil surrounding the gold processing units is contaminated by mercury. The concentration of mercury in soil is high at sites close to the processing units, and gradually decreases towards beyond them. The vertical gradient of mercury level in soil also confirmed that the processing unit is the main source of the emission of mercury.

Trails of amalgam burn using retort were successfully conducted 33 times at 15 processing units. Data recorded from those trails provide a clear explanation about the amount of mercury vapor lost to the environment during amalgam burning. Some of the owners of the gold processing units were convinced by the results of the retort trails. They were encouraged to use retort for amalgam burn process because it is not only improves work safety but also provides an economic advantage. The regression line between weights of recaptured mercury and amalgam (Fig. 4) with a high regression coefficient revealed that the amalgam practices maintain a constant proportion of the amount of mercury vapor released to surrounding atmosphere which is approximately 70% of amalgam the weight.

Based on field observations and retort trial results, the artisanal gold mining in this area shows the following values. On average, 58 g of amalgam was produced in one cycle of the amalgam process. If every processing unit makes two cycles every day, then the amount of amalgam produced by all processing units within one day would be 4640 g (40×2×58 g). Using the amalgam-recaptured mercury regression equation (Fig. 4), an estimate of 3222 g or approximately 3 kg of mercury is lost to the atmosphere by burning the 4640 g of amalgam every day. Taking into account that every processing unit will operate 20 days in a month and be able to work 10 months in a year, and then the estimated amount of mercury vapor released to the surrounding environment is about 600 kg per year. If a gold processing unit adopts retort technology

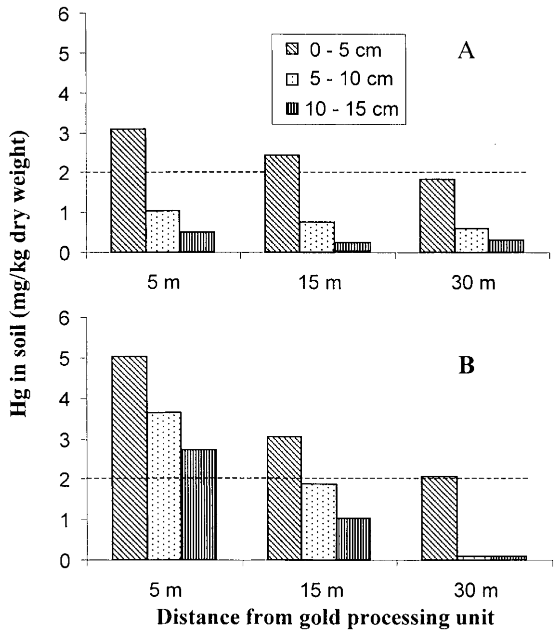

Fig. 3. Mercury content in soil from the Ratatotok artisanal gold mining area.

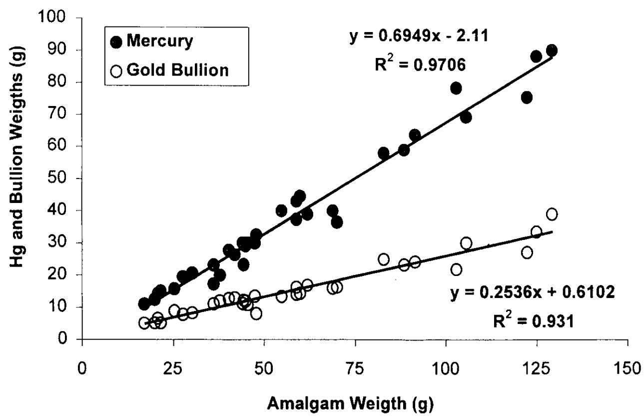

Fig. 4. Relation between recapture mercury (●); gold bullion (○) and amalgam weight.

for amalgam burning then its will reduces or save 15 kg per year or 1.25 kg per month of mercury that lost to environment by open air burn method. According to Harada et al. (1999), mercury lost from the amalgam burning process contributes 60% of the total mercury lost from the artisanal gold mining activities in Tanzania. Assuming that the artisanal gold mining in Ratatotok has the same tendency, then the estimate of total mercury emission from all the processing units would be about 1000 kg (600 kg/0.6) per year. The corresponding estimation of gold bullion production is about 235 kg per year.

As indicated from several studies, the transportation of mercury-enriched sediment into the watershed will dependent on topography, climate, and ore deposit type:carbonate or sulfate. Mercury released into the environment can either remain close to its source for long period, or widely disperse (Glass et al. 1990, Watts 1998). In the case of the Ratatotok artisanal mining area, the concentrations of mercury found in the soil surrounding the processing units (Fig. 3) appear relatively low when considering the estimated amount of mercury lost from the processing units that had already operated for nearly two years. This suggested that the mercury-enriched sediment from gold processing units apparently remains nearby for a while, and then is released into the watershed during rainy periods. The steep hill topography and wet climate of the Ratatotok area (JICA 2002) are expected to generate a strong flow even during a light rain. This in turn will concentrate the mercury-enriched sediment at the river mouth. As revealed in Fig. 6, the mercury levels in sediment from the mouth of the Totok River are approximately 20-fold greater than the safety level of 2 mg/kg for sediment (WHO/ICPS 1990).

The mercury level in water at all sampling sites of the Totok River were quite far below the recommended safety level of 1 μg/l (Fig. 5). A comparison to the high levels in sediment (Fig. 6) suggested that the mercury-enriched sediment is dominantly present as elemental and amalgam phases then particle transport to watershed is dominant. This is happen because the ore used by artisanal miners mostly silica-carbonate deposit as the soil structure of the hilly area of Ratatotok is composed of clay and rocky soil (JICA, 2002). In addition, due to technical limitations, the depths of nearly all of the mine shafts were less than 50 m, while sulfate deposits are more abundant at deeper layers, as indicated from the ore taken by the Newmont Minahasa Raya Company. If small amount of sulfide deposit present in mine wastes it form mercury-enriched acid mine drainage. In this form mercury is initially transported as dissolved and colloids. As the acidity of this stream is buffered by country rocks, the adsorption of mercury species on iron oxide phases, and clays removes the dissolved mercury species, and then particle transport becomes dominant. Accumulated mercury-enriched sediment at the mouth of the Totok River will be shaken by small to medium scale of sea wave and current in Totok Bay, then besides of horizontal dispersion, heavier mercury content particles moved down deeper into the sediment as indicated in Fig. 6 (Kramer 1988). Mercury levels in water and sediment from the mouth of the Buyat River are significantly small, agreeing closely with the field observation data indicating that no artisanal gold mining activities take place within the catchments area of this river.

The biological samples collected from Totok Bay consisted of fish (12 specimens) and mollusk (3 specimens). Fish samples were composed of five species while only one species of mollusk was collected. The result in Fig. 7 strongly demonstrated that the long accumulation of mercury-enriched sediment at the mouth of the Totok River has been transforming in to biological system, as 80–90% of the total mercury in fish tissue is organic mercury or methyl mercury (Samoiloff

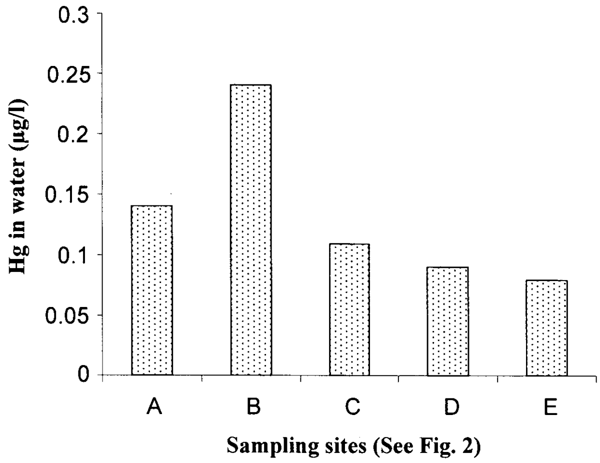

Fig. 5. Mercury content in water from the Totok River and the Buyat River.

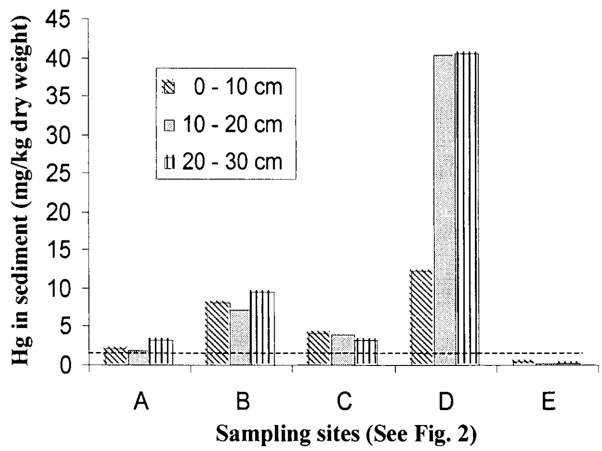

Fig. 6. Mercury content in sediment from the Totok River and the Buyat River.

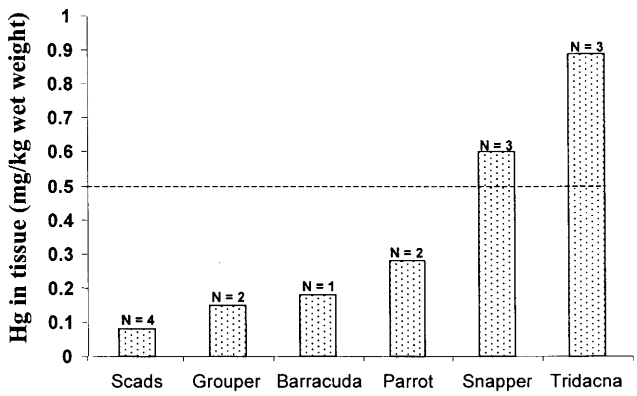

Fig. 7. Mercury content in fish and bivalves from Totok Bay.

1989). Taking into account that the tridacna is a filter feeder organism, mean value of the mercury level in tridacna samples, which is almost two-fold of the recommended safety level, provides an indication of the occurrence of mercury bio-accumulation on the bay. Moreover, a quite high level of mercury in carnivorous fish such as snapper must be a noticeable sign of the bio-magnification process through the aquatic food chain (Viswanathan et al. 1988, Akagi and Nishimura 1991).

Conclusion and Future Perspectives

The gold processing practices of artisanal miners in the Ratatotok area have been responsible for discharge of a substantial amount of metallic mercury into the catchment area of the Totok River. Primarily during high flow, the mercury-enriched sediment had been transported through the river system and accumulated at the river mouth in Totok Bay. The agitation of sea wave and current may have played essential roles in the accumulation of mercury in deeper sediment layers as well as in its spatial distribution in the bay.

The bioaccumulation and bio-magnification of mercury through the food chain in Totok Bay may be significant. The rate of the process may be small at present; however, the amount of mercury present in sediment must has an important implication, less visible but potentially the most damaging impact and severe that will extend for many years in the future.

An organized response to the mercury pollution problem must be prepared by the Provincial Government of North Sulawesi and its representatives in the South Minahasa Regency and the District of Belang. Integrated official determination by all responsible authorities or stakeholders should be sought and obtained immediately. The safety problems inherent in the current environmental issues associated with the mercury contamination of soil, water, sediment, and living organisms, create a lebel of risk in the Ratatotok area that no legitimate investor can reasonably be expected to assume.

The gold processing practices themselves should be improved or changed to clean technologies in order to guarantee the minimal risk of poisoning the miners as well as the community. Simple measures involving education, improvement of the tailing system, and the use of retort for amalgam burning should be implemented immediately. Establishment of an amalgamation center for the entire artisanal miners is a further effort to be considered for better control the on-going mercury pollution.

The spatial distribution and bio-geo-chemical transformation of mercury in the sediment within Totok Bay are critical to be evaluated. Considering that fish is the main protein source for the local community, it is vital to have a more detail understanding of the mercury contamination of fish species surrounding Totok Bay in order to provide fish consumption guidelines.

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