Mercury concentrations in Kayeli Bay, Buru Island of Indonesia: The update of possible effect of land-based gold mining

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Abstract. Since late 2011 mercury has been used to extract the gold requiring in artisanal gold mining in Mt. Botak (Buru Island) and resulting in deposition of mercury into Kayeli Bay. In this project, we reported the updated total mercury (THg) concentration in marine sediment and nine species of demersal fish from Kayeli Bay. Nine coastal sampling sites were selected in the Kayeli Bay by purposive sampling. The fish are collected from a traditional market in Buru Island. The total mercury (THg) concentrations in marine sediment were found in all sites, ranging from 0.035 to 4.802 mg.kg\textsuperscript{-1} DW). The THg concentrations in sediments from all sites measured were found has exceeded to those shown in the National Oceanic and Atmospheric Administration (NOAA) value. Among fish, the highest THg concentration of 1.667 mg.kg\textsuperscript{-1} was measured in the muscle species Myripristis kuntee and the lowest THg concentration detected for Lutjanus Lutjanus (0.016 mg.kg\textsuperscript{-1} DW). The distribution of total mercury (THg) concentrations found in the marine sediment of Kayeli Bay shows a very closed relationship to the artisanal gold mining activity in Mt Botak.

Keywords: mercury, artisanal gold mining, marine sediment, fish, Kayeli Bay

1. Introduction
The artisanal and small-scale gold mining (ASGM) is a gold mining activity managed by individual miners or small groups with limited properties [1]. The mining located in Buru Island was started at the end of 2011 in Mt. Botak and another smaller-scale gold mining site was opened in Gogorea a year after. The distance between these two sites is only about 50 km. These two activities use mercury (Hg) to extract the gold from the ore by using trommel (a mechanical screening machine used to separate materials). This is a common procedure of gold recovery used by artisanal miners in over 70 countries, and approximately, 1400 tons mercury is used in the ASGM activity per year [2]. However, Hg is highly toxic, and harmful to the environment including living organisms [3,4,5], the health of miners and their communities [6].
The Hg containing waste material of Buru Island mining activity readily discharges to rivers to which a huge volume of water flushing from the trommel processes release. Several rivers around the Mt. Botak which probably receive the material discharge are Anahoni River, Waeapo River and Kayeli River ending towards the Kayeli Bay. This bay is also the entrance of the stream flow from the Gogorea site. The Kayeli Bay is an important area for the fishing catchment since it supports the daily life of about 50,000 coastal village people [6] through fishing and their economic life.

However, only a few data concerning total mercury (THg) in the mining sites or Kayeli Bay are published after the operation of ASGM in Mt. Botak and Gogorea site. Previous study conducted in July 2012 found the high THg level (0.548-3.564 mg·kg⁻¹ DW) around Kayeli Bay [6]. Another sampling in 2013 reported that Hg has increased more than 20 times than previous data in 2012 [7]. Their study also reported the THg in some marine biota from Kayeli Bay, and the concentrations have exceeded that shown in the guideline issued by the Food Standards Australia New Zealand (FSANZ) [8]. In this paper, we reported further evidence of THg concentrations in coastal sediment and 9 species of demersal fish samples of Kayeli Bay.

2. Methods and Materials

2.1. Description of the study area

Nine coastal sampling sites were selected in the Kayeli Bay by purposive sampling based on the possible dispersion of Hg concentrations from the river mouth of land-based source to the bay. Anahoni Estuary (Station 6) is the closest watershed area to Mount Botak as the most affected area. Waeapo Estuary (site 5) close to Anahony Station is also a river flow adjacent to Mount Botak, and this estuary is close to resettlement area where many domestic activities using river water occur. Station 3 is a small river flowing from the Gogorea mining area. Other stations represented Hg distribution area within the Kayeli Bay.

2.2. Sampling and Handling Procedure

The field sampling was conducted on November 2017, and its location position was tracked by Global Positioning System (GPS)-Garmin, Model 76CSx. The three replicate coastal sediments were collected at 9 stations using a stainless-steel grab sampler (about 10 cm depth of sediment) at 10 to 12 m depth. About 1 kg of sediments collected from each site were labelled and stored in the cool box before transfer into the laboratory [9]. The 3 replicate fish samples were taken directly from the fisherman together with those from the market that catches from Kayeli Bay. These samples were marked and stored in the cool box during transport to laboratory.

This study measured the mercury level of 9 (Parupeneus indicus, liza subviridis, Pomadasys sp., Siganus canaliculatus, Lutjanus argentimaculatus, Myripristis kante, Pempheris oualensis, Abudedefduf sexfasciatus, Caesio cuning) species of demersal fish. The fish were not differentiated by sex, in order to get a spreading picture of the actual of Cd concentration and were taken at random with the assumption that each experimental unit had the same opportunities [10]. All fish samples were collected from local fishermen in the vicinity of the Kayeli Bay. Each fish was identified and measured (total length where possible). A section of muscle tissue was taken for analysis from just behind the head to the tail side of each fish and store frozen prior to analysis.

2.3. Sample processing

The THg in the sediments and fish samples was determined by means of all the samples. The detection of THg was done by using a Direct Mercury Analyzer in Research Center for Oceanography, Indonesian Institute of Sciences. Using a direct mercury analyser, we do not need to do the sample preparation with any solution [11]. Samples were first dried to a constant weight at 60°C. The dried
samples were then homogenized with a ceramic mortar and homogenized by using a mortar. The mercury in the solid was quantitated directly without any sample dissolution or manipulation. The sample was thermally decomposed and atomized in the heater at 850 °C. The free mercury in the gas was collected by a gold amalgam. The amalgam was then heated to release the mercury, which was detected by atomic absorption at a wavelength of 253.7 nm.

The reported results are expressed as mg.kg⁻¹ dry weight. All sample data was presented using Microsoft Excel. Provisional statistical testing was conducted using Excel. All of the results were compared to the existing standards as determined by National Oceanic and Atmospheric Administration guidelines [12] for coastal sediment and Food Standards Australia and New Zealand (FSANZ) for fish samples [13].

![Fig. 1. Map of the sampling site surrounding the coast of Kayeli Bay](image)

3. Result and Dissussion

3.1. THg concentration in marine surface sediment

The recapitulation of The THg concentration observed for coastal sediments and fish samples is showed in Fig. 2. The THg concentrations in marine sediment were found in all sites, ranging from 0.035 to 4.802 mg.kg⁻¹ DW. The highest level of THg was detected in Anahony Estuary, whereas the lowest concentration was found in site Jikumerasa (site 1). The higher THg level found in site 6 can be related to the input of material derived from the artisanal gold mining activity in Mt. Botak. This site is suspected as the most affected area because one of ASGM activity around Mt. Botak is located in upstream of the Anahony Rivers. The THg concentrations in most of the selected sites have exceeded those of the level tolerable for marine sediment by NOAA (0.15 mg.kg⁻¹ DW) [12].

The higher THg concentrations found in the marine sediment of river mouth and the lowest THg concentration found far from the estuary in this study highlight the significant proportion of mercury is
released in to the environment to extract the gold in the Buru Island. Artisanal small-scale gold mining is known as the world’s largest anthropogenic source of mercury emission [14].

In comparison to previous studies that have been conducted after artisanal gold mining operated in Buru Island, THg concentrations found in this study were below than those measured in 2013, but higher than those observed in 2012 [7,8]. The levels of THg observation in 2012 were 0.548-3.564 mg.kg$^{-1}$ DW, a year after, these concentrations increased to be more than 20 times [7,8]. The lower levels of THg recorded in the Kayeli Bay compared to the report sampling on 2013 could probably be related to the numbers of mining activity between the year 2013 and 2017. During 2012, it was noted a large increase of population in this island and created a new community near in the operation site [8]. However, based on our observation in 2017, lot of miners has left Gunung Botak after the instruction the government in 2015 to closed the artisanal gold mining in Buru Island due to the environmentally issues.

The level of THg that found far exceeded the limits permitted by NOAA in the river mouth in this study also confirmed again that Hg and other heavy metals such as Cadmium (Cd), Lead (Pb) that release into the marine environment are not dissolved easily in a short time; they will stay in the environment for a long time. Instead, they tend to accumulate in the sediment or within the body of the marine life. Therefore, the heavy metals are considered to be in the most dangerous category of pollutants. Meanwhile, Hg with Cd and Pb are known as the most dangerous of heavy metals to the human life [6]. A concrete example of an environmental problem that leads to heavy metal was Minimata disease in Japan. This disease was caused by consuming fish and shrimp contaminated by methyl mercury from the wastewater discharged by factories [15].

![Fig. 2. The average and variations of THg concentrations (in mg.kg$^{-1}$ DW) in marine sediment collected from Kayeli Bay, Buru Island, Indonesia.](image-url)
Unfortunately, very limited data available about heavy metals concentration recorded around Kayeli Bay. For our knowledge, there no data available about Hg concentration from Kayeli Bay before the artisanal gold mining was operated in Buru Island on 2011. Both previous studies and this study have conducted on coastal waters focusing on surface sediments samples. Hence, to better understand about the effect of gold mining activity in Buru Island, further studies in the offshore area and deeper marine sediment sampling is strongly recommended.

3.2. THg concentration in fish sample

The mercury concentrations in the fish are depicted in Figure 3. A total of 9 species of demersal fish was analysed for level of THg. The THg concentrations found in the muscle of fish samples were in the following ranges (in mg.kg\(^{-1}\) DW): 0.016 for \(P.\) indicus, 0.344 ±0.034 for \(L.\) subviridis, 0.576±0.083 for \(Pomadasys\) sp., 0.102±0.008 for \(S.\) canaliculatus, 0.853±0.044 for \(L.\) argentimaculatus, 1.667±0.45 for \(M.\) kantee, 1.294±0.671 for \(P.\) oualensis, 0.294±0.083 for \(A.\) sexfasciatus and 0.365±0.004 for \(C.\) cuning. Among fish, the highest THg concentration of 1.667 mg.kg\(^{-1}\) DW was measured in the muscle species \(M.\) kuntee and the lowest THg concentration detected for \(L.\) lutjanus.

The THg concentration on fish in this study was below than the previous study from Kayeli Bay [8]. The previous study reported 11 demersal fish (\(Channa\) striata, \(Terapon\) theraps, \(Epinephelus\) fuscoguttatus, \(Equalites\) leuciscus, \(Lutjanus\) rufolineatus, \(Upeneus\) vittatus, \(Dussumieria\) sp., \(E.\) fasciatus, \(Alectis\) ciliaris, \(Auxis\) rochei, \(Stolephorus\) indicus) and one plankton fish (\(Decapterus\) macrosoma) from Kayeli Bay have been contaminated by mercury in range 0.001-3.44 mg.kg\(^{-1}\) DW [8]. However, their study had the THg from whole body, included the internal organs. The liver and kidney tended to accumulate the highest quantities of mercury [16].

![Fig 3](image-url). The average and variation of THg concentrations (mg.kg\(^{-1}\) DW) of fish species samples from Kayeli Bay, Buru Island, Indonesia.

The Hg concentration on 4 out of 9 fish species observed in this study (\(Pomadasys\) sp., \(L.\) argentimaculatus, \(M.\) kantee, \(P.\) oualensis) has exceeded to those of guideline issued by the Food Standards Australia New Zealand (FSANZ) [13]. This could be alarming since those fishes are commonly consumed by local people. The eating frequency of such Hg contaminated fishes is critical. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established provisional tolerable weekly intake (PTWI) about 4µgkg\(^{-1}\) body weight per week [17]. Therefore, assuming the
average Indonesian adult man weight of 60 kg, their THg intake about 240 μg.kg⁻¹/week has to be avoided. Considering the high level of THg on 9 fish recorded in this study and the reliance of local people on seafood as a protein source [8], they are very vulnerable to be contaminated. Unfortunately, most of the local residents are unaware of the risk of mercury. Therefore, long term monitoring the Hg concentration and education for community are crucial need to be conducted in Buru Island.

4. Conclusion
The THg concentrations in the marine sediments of Kayeli Bay showed a closed relationship with gold mining activities in the upstream area in Buru Island. This contaminant has been accumulated in fishes living within the bay. The level of THg on marine surface sediment and some fishes spesies from Kayeli Bay had exceeded the level permissible by NOAA and FSANZ. Long term investigation about mercury concentration including background level of the selected area in Kayeli Bay and education for community are necessary.

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