Mercury Contamination Levels in Small-scale Gold Mining Areas in Indonesia

(インドネシアの小規模金採掘地域における水銀汚染)

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Abstract

Due to the huge number of gold mining in Indonesia, small-scale gold mining becomes popular mining activities carried out using low technology, and applied mercury. This method was practiced by individuals, groups or communities illegally in most areas in Indonesia. Small-scale gold mining became one of the major sources of income. However, influence of mercury exhausted by heating the amalgam to human health was neglected by local people because of this economic reason, and Minamata Disease on 1956 seemed as unnecessary problem for the local miners.

Dealing with mercurial gold mining problems, this study was aimed to measure the mercury exposure level in Indonesia, especially in specific regions, such as Central Java and Central Sulawesi. This study monitored the mercury concentration that contaminated environment. Total mercury was measured in waste water, river water, soil, plant, foodstuff and also human hair. This study also addressed to measure the community resilience and community vulnerability to defend with mercury pollution that is unavoidable nowadays.

The first study was purposed to measure the community resilience in Cihonje, Central Java, where is the highest gold potential in North Serayu. There were 72 active miners produced tons of gold per year. This was a comparative study of gold mining and non-gold mining areas, using four community vulnerability indicators. Vulnerability indicators were exposure degree, contamination rate, chronic, and acute toxicity. Each indicator was used for different samples, such as wastewater from gold mining process, river water from Tajum river, human hair samples of people staying in Cihonje (gold mining area), and health questionnaire. For analysis, cold vapour atomic absorption spectrometry was used in this research to determine total mercury concentration. The result showed that concentration of total mercury

was 2420 times higher than the maximum content of mercury permitted in wastewater based on the Indonesian regulation. Moreover, the mercury concentration in river water reached 0.7 ng/ml, exceeding WHO quality threshold standards. The mercury concentration in hair samples obtained from the people living in the study area (Cihonje) was considered to identify the health quality level of the people and as a chronic toxicity indicator. The highest mercury concentration—i.e.17 ng/mg, was found in the gold mining respondent. Hence, based on the total mercury concentration in the four indicators, the community in the gold mining area (Cihonje) were more dangerous to mercury than communities in non-gold mining areas.

In another area, Poboya, Central Sulawesi is one of the primary sites used for small-scale gold mining activities in Indonesia too. The total area of Poboya is 7000 hectares. Operating since 2009, Poboya consumes 200-500 kg of mercury/day by amalgamation and the indicated spread of mercury Hg(0) is 12 times higher than the WHO standard up to 4.5 km from the edge of Poboya. Palu, the capital city of Central Sulawesi, is a city with a population of 0.35 million people and located around 11 km away from the edge of a small-scale gold mining area in Poboya. This situation makes Palu more susceptible to mercury contamination by gold mining activities in Poboya. Fifteen samples of upper layer soil and fifteen samples of plant (*Calotropis gigantean)* were taken along the road that connects from Poboya to Palu, at every 500 m. Mercury concentration in the soil samples showed a decrement as the distance from Poboya became greater. The plant samples also revealed a similar trend of the soil samples. The highest concentration of mercury in the soil was found at Poboya—i.e. 17.62 ng/mg, and the concentration of mercury in *Calotropis gigantean* grown at Poboya was 6.5 ng/mg. The results illustrated that at a distance of 1.5 km from Poboya, the values reached 3 ng/mg and 1.84 ng/mg of mercury in soil and plant, respectively. Based on the soil samples and pollution index showed that the Poboya had heavy pollution levels up to 4.5 km. Moreover, the transfer factor was in the range of 0.13-3.44 at distances of 0-4 km, respectively.

Approaching the community vulnerability, in this study area, other two types of sample were used; foodstuffs and human hair. Both samples were obtained in Poboya (gold mining area) and Palu. Twenty-two foodstuff samples were obtained from traditional markets in Poboya and an additional 22 obtained from Palu. Total mercury concentration in the collected foodstuffs was in the range of 0.003 to 0.31 ng/mg from Poboya, and from 0.001 to 0.13 ng/mg from Palu. The results also showed that the highest total mercury concentration was found in unripe banana, which is frequently consumed by the local people in Poboya. The mercury intake from foodstuffs, based on a group of people in Poboya was 180.3 μg/person/week from vegetables, 1.7 μg/person from processed food, 51.4 μg/person from seafood and 17.2 μg/person from meat. In Palu, the results showed 2.9 μg/person/week from vegetables group, 3.1 μg/person/week from processed food, 60.8 μg/person/week from seafood and 12.5 μg/person/week from meat. This condition delineated Poboya as a pollution area arising from mercury contamination. The results showed, dietary food intake, with mercury contaminated food, is influential in the results obtained from human hair. Total mercury in human hair at Poboya was 0.3 to 19.6 ng/mg.

Based on all indicators, it was concluded that the community in gold mining area was more dangerous to mercury contamination due to small-scale gold mining than the community in non-gold mining area. It risks chronic toxicity for people that exposure of mercury in Indonesia.

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Chapter I

Introduction

1.1 Background

Any effort of natural resource use deals with productivity improvement, establishing employment opportunities, life and welfare status enhancement, and social class improvement of the people affected by such effort. The use of resource available in nature complies with the resource potential. Following the discovery of gold mines in several places in Indonesia, there has been a growing trend in gold mining activities by several parties, including mining companies, co-operatives, and also small-scale mining.

Indonesia has a huge number of hotspots gold mining areas. Totally in 2006 to 2010, Indonesia has 63 hotspots of artisanal and small-scale gold mining areas (Ismawati, 2013). In North Sulawesi, 10000 workers were attracted to join the gold mining activities. Sekotong, southwest part of Mataram city involving 5000 workers. Palu was in Sulawesi area, reported 35000 workers in 2013 were collaborated in small-scale gold mining activities. This indicated the high employment opportunity for majority areas in Indonesia. Therefore, gold mining activities contributed one of the significant incomes for local people in Indonesia.

The simple method was applied in the most gold mining areas in Indonesia. This method was famous by amalgamation process. The main substance for gold extraction in this process is mercury. The mercury usage in amalgamation process exposes high risk of human health and

contaminates environment. This is because mercury is a high volatility and toxicity behavior. Minamata disease on 1956 was a big phenomenon of mercury contamination in human health. In that time, 2252 people have been contaminated and 1043 died (Minamata Disease Municipal, 2001). In another side, local people in Indonesia continuously use mercury to extract the gold from ore. It is reported that Indonesia imported 129 tons of mercury from Spain and China in 1999, then the total amount of mercury used in Indonesia continuously increasing (Iqbal & Inoue, 2011; Veiga, et al., 2006). BaliFokus reported, the increasing became 280 tons of illegal mercury imported on 2010, and a year later the number of illegal mercury was double of 2010. The main purpose of mercury import from other countries is most likely to supply small-scale gold mining demands in Indonesia.

Literally, mercury is a common substance in artisanal and small-scale gold mining. Mercury is used to extract gold in ore or soil because this alternative is the cheap, easy and quick method to extract the gold (UNEP, 2012). Miners and people in gold mining area are the highest risk receptor of mercury contamination in small-scale gold mining. The amalgam burning results in mercurial vapor in the air. When the vapor drops back to earth by the rain, it will contaminate soil, lakes, ponds, rivers, and ocean. Some of the mercurial contents are also bound to sediments, whereas the other materials are converted organisms and bacteria into toxic organic mercury. However, small-scale gold mining contributed 37% of mercury emission to the atmosphere (Gibb & O'Leary, 2014). This crucial condition calls the developing countries to re-plan their small-scale gold mining activities, which was addressed in Minamata Convention goals, including Indonesia.

1.2 General Information about Mercury

1.2.1 Mercury Forms

Mercury was naturally found in environment and has several forms (García-Sánchez, et al., 2009; Boening, 2000; Wu, et al., 2013), and have been used for thermometer, chlorine barometer, soda caustics and batteries. As an element, mercury takes the form of liquid matter with silver color at ambient temperature and pressures (Boening, 2000). Mercury has a chemical name of *hydrargyrum*, which means liquid. Mercury is called *Hg*. In the chemical periodical system Hg has Atomic Number of 80 with atomic weight of 200.59. Mercury has melting point at -38.87℃ and boiling point at 356.6℃. Mercury also has low solubility as a result of its high probability to coagulate. The mercury solubility depends on several factors; the forms of mercury present, and amounts of mercury and environmental conditions (Beak International Incorporated, 2002). However, fundamentally mercury only has three forms (Bernhoft, 2012), as follows:

a. Elemental mercury

As described above, elemental mercury is a shiny, silver-white liquid metal at room temperature (Gibb & O'Leary, 2014). Most mercury released from human activities is elemental mercury into the air due to ore mining, fossil fuels burning and incinerator. It volatilizes quickly to mercury vapor (Hg^0), which is the predominant form of mercury in the atmosphere (Gibb & O'Leary, 2014; WHO, 2007). Mercury also exists in the soil from fertilizers and fungicides usage.

b. Inorganic mercury

This includes metallic mercury and all inorganic compounds. It can be mercury vapor (Hg^0) and mercurous ($Hg^{2\,++}$) or mercuric (Hg^{++}) salts. It also is formed when mercury combines with other elements, such as

sulfur or oxygen (Japan Public Health Asoociation, 2001). The characteristics of inorganic mercury are white-colored, shiny metal, mostly powders or crystals at room temperature, and widely used for pharmaceuticals, fungicides and antiseptics. The common used compounds are mercury (II) chloride and mercury (II) oxide, where mercury (I) oxide has characteristics; unstable and easily decomposes into metallic mercury and divalent mercury.

c. Organic mercury

This includes compounds in which mercury is bonded to a structure containing carbon atoms. The compounds are derived from the mixture between mercury and carbons. The most popular one is methyl mercury, which caused health disasters in Minamata Bay, Japan on 1956. Mercury vapor of spreading due to amalgamation burning is transformed into methylmercury through anaerobic organism, then enters to food chain. This organic mercury (methylmercury) accumulates in body of predator. Another compound is phenyl mercury which is widely used for making several commercial products. Dimethyl mercury is usually used for reference standards of chemical tests. However, this form of mercury is the most toxic and harmful substance. Even if the concentration of organic mercury is low, it can attack the nervous system and causes various symptoms in human body.

1.2.2 Mercury Emissions

Mercury widely exists in environment naturally and from anthropogenic sources. Mercury is consisted in earth's surface. It can be distributed widely by natural phenomenon, such as volcanic activity and ocean emissions. It can be released to atmosphere, aquatic environment, and terrestrial environment. However, mercury that is existed in the air can spread thousands of miles in the atmosphere

before it is deposited back to the earth by rainfall or dry gaseous form.

As mention above, mercury is one of the primary materials that commonly used. These products, including batteries, thermometers, paints, electronic devices, blood-pressure gauges, fluorescent, pesticides, fungicides, medicines, and also cosmetics emit the mercury waste to river and land. In river, anaerobic process generates methylmercury and deposits into fish and all aquatic organisms. But, in landfills, mercury waste will be re-distributed to the environment and then by using incinerator, mercury waste re-form as mercury gaseous and emits to the atmosphere.

In Asia, mercury is mainly released from anthropogenic sources (Cairns, et al., 2011; Rothenberg, et al., 2007; Mason, et al., 1994) with the highest contributors being artisanal and small-scale gold mining which reached 38-54% of total global anthropogenic mercury emissions in 2010 (Liu, et al., 2014; Terán-Mita, et al., 2013; Rothenberg, et al., 2007; Pacyna, et al., 2006). Based on UNEP 2013, since industrialization era, Asia carried out 40% of global total mercury emissions. In addition, South area released 8% of the total mercury. Totally ASGM contributed 727 tons per year. Hence, the significant 50% contribution of total mercury in environment mainly was from ASGM in Asia (UNEP, 2013; García, et al., 2015).

The most often used method to extract gold from ore is the simple mercury amalgamation method (Terán-Mita, et al., 2013; Spiegel & Veiga, 2010; Telmer & Veiga, 2008; Veiga, et al., 2006). Metallic mercury, released from gold amalgam burning, has spread across a wide area (Cairns, et al., 2011) and deposits on aquatic and land areas (Liu, et al., 2014). Additionally, more than 98% of Hg^0 formed diffused into

the atmosphere (Liu, et al., 2014; Kotnik, et al., 2005; Lin & Pehkonen, 1999).

1.2.3 Impacts of Mercury on the Environment and Human Health

Derived from anthropogenic source, mercury emitted to atmosphere and transported globally. When mercury entered aquatic system and terrestrial, it can be formed to methylmercury. Inorganic mercury and methylmercury are toxic and harmful for the human health because it attacks the nervous system. Mercury infects human tissues, and will be accumulated in long term period. However, every people are exposed to low concentration of mercury, but in this case it cannot be the harmful disease, and safe for the human health.

There are several factors that influence the mercury exposure (IOMC, 2008; UNEP, 2008):

(a) chemical form of mercury;
Different form of mercury will infect different of symptoms in human body. The most dangerous form of mercury is organic mercury, especially methyl mercury.

(b) dose;
Where, the dosage of mercury that exposure in human body from contaminated media, such as food, fish, water etc.

(c) age of the person exposed
The effect of mercury in kids more risk than adult. It is caused mercury attack nervous system, where in kids, all the human systems still in growing phase.

(d) duration of exposure;
The period of mercury settled in human body. More longer duration of mercury exposure, more higher the mercury concentration in body, because mercury accumulates in human being.

(e) route of exposure;

It means that the pathway of mercury exposure in human body, such as inhalation. Ingestion or dermal contact, and;

(f) food consumption patterns,

The most toxic of mercury contaminated foods are fish and seafood. It is formed as methylmercury.

Below is the description of several symptoms that is caused by mercury in all forms:

a. Elemental mercury

Elemental mercury infects human health through inhalation as mercury vapor and will be settled in lungs. It accumulates in long term and causes chronic toxicity. Below, some symptoms may occur in human body when elemental mercury exposed:

Table 1.1 Elemental Mercury Symptoms

Symptoms	
• tremors	• headaches
• emotional changes extremely	• disturbances in sensations
• insomnia	• changes in nerve responses
• neuromuscular changes; such as weakness, muscle atrophy	• poor performance on tests of mental function

b. Inorganic mercury

Symptoms can occur when people infected by high concentration of inorganic mercury or exceeded the standards:

Table 1.2 Inorganic Mercury Symptoms

Symptoms	
• skin rashes and dermatitis • mood swings • memory loss	• mental disturbances • muscle weakness • kidney damage, when people drink mercury contaminated water excess the standard set by (Environmental Protection Agency, 2016).

c. Organic mercury (methylmercury)

As the most harmful compound in mercury, methylmercury can stimulate symptoms in human body. It commonly enters the food chain, and when people consume mercury contamination foods. Five symptoms can indicate the mercury infected in human body:

Table 1.3 Organic Mercury Symptoms

Symptoms	
• loss of peripheral vision • pins and needles feelings, usually in the hands, feet, and around the mouth • lack of coordination of movements	• impairment of speech, hearing, walking • muscle weakness

Worse, it happens in pregnant women. Methyl mercury poisons the infant to the brains and nervous system. It can cause unborn infant, cerebral palsy, and mental disorder in kids. However, infant and kids are more vulnerable than adult age.

1.3 Gold Mining

1.3.1 Mining Techniques and Process

Techniques of gold mining or *Pertambangan Emas Rakyat* (PER) in most areas in Indonesia (including West Kalimantan) are performed in several methods (Regional Environmental Impact Agency of West Kalimantan, 2007), as the followings:

a. Technique of Land Alluvial Sediment Mining

The people of West Kalimantan have applied land alluvial sediment mining by using spraying method, or known as hydraulic mining. Typically, this method uses two machines, one to get the water from the river and the other to spray the gold-contained sludge, which is filtered in sluice box. This filtered mud is added mercury to get amalgam (gold and mercury). The amalgam is directly processed at the mining site and removed from the sediment/sludge. For the next step, amalgam is getting to a burning process. This process aims to extract the gold. The sediment waste from amalgamation process is directly disposed into the river without any further processing.

b. Technique of River Alluvial Sediment Mining

This kind of method uses dredging machine on the vessels powered by compressor. This method was popular since 1998 in West Kalimantan. By using this method, the gold-contained sludge from the river bed is transported, and then filtered in sluice box. The mercurial added on this process may take place on the vessel as well as prepared ponds.

As the previous method, this process results amalgam (gold and mercury) and in order to get the pure gold from the amalgam, it has to be burnt at high temperature. This burning process is aimed to remove the mercurial substances and is usually done at the miner's houses or open areas. Similarly, sediment waste from the amalgamation process is directly thrown into the river so it affects the quality of aquatic system and terrestrial environment.

c. Technique of Primary Gold Mining

Technique of primary gold mining is applied at stony areas. The method was introduced in 1996 and is done by digging well or tunnel to get the gold sources. The tunnel have dimension of 1.5m x 1.5m with vary depth. Gold-containing stones are crushed into stone-powder by using road mill, then mixes with the mercury in ball-mills up to 4 hours. Sludge and tailing of this milling process are removed, whereas the amalgam is filtered. Some areas re-used the tailing before discharged to river. The amalgam is leached by pure water, then burns and releases mercury vapor. The whole works are performed on land inside the resident areas. Most of gold mining areas in Indonesia adopted primary gold mining technique to extract gold.

The ore excavated from the tunnel and continued for amalgamation process. Then, *bijih* processing is performed by amalgamation where mercury (Hg^0) is used as binding the gold. This process has been applied since industrial era and expected as the efficient and less environmentally damaging techniques than cyanide leaching. However, the continuously usage of mercury in small-scale gold mining, the released mercury vapor, sludge and tailing causes environmental problems and bothering the human health. Fundamentally, there are 4 processes in gold mining area, especially were applied in this study areas:

a. Gopher underground digging

To open the access for gaining the ore, miners dig the soil then making tunnel and shaft into particular depth. This method is simple and gopher, which is done unsystematically, without mechanical devices, unsupported excavation and irregular holes.

Figure 1.1. Tunnel of gopher underground digging

b. Ore milling

This process was familiar as amalgamation process. In this process, mercury was initially used. By adding approximately 1 kg for every 5 kg of ores in the ball mill and milling totally for 4 hours, amalgams will be formed.

Figure 1.2. Ball-mills

c. Amalgam leaching

In this process, miners wash the amalgam that formed in the previous stage. This is purposed to separate amalgam from sludge and other materials. The recycle water is used in this process. Impropriate equipment and area during the leaching process effluents the mercury contaminated waste water to environment, especially river.

Figure 1.3. Amalgam leaching

d. Amalgam burning

Figure 1.4. Amalgam burning

The final process of small-scale gold mining is burning or smelting. Burning is heading to remove the mercury and other materials in amalgams. The output of this process was pure gold and mercury vapor. Mercury vapor releases in the atmosphere then, re-mobilizes in environment through rainfall and evaporation process.

1.4 Dispersion of Mercury in the Environment

1.4.1 Mercury in Atmosphere

Small-scale gold mining contributes greatly mercury in environment, and the main source of mercury is atmosphere. Mercury released to atmosphere from several phenomenon, such as amalgamation burning, volcanic eruption, coal combustion, etc. The main form of mercury in atmosphere is gaseous elemental mercury, where it converts to gaseous oxidized mercury or mercury bound to particulates when shifted to water or land. Then, during evaporation process, the re-emissions of mercury will be converted back to elemental mercury. However, this elemental mercury exists in atmosphere in long period and distributed globally.

1.4.2 Mercury in Aquatic System

The gold mining process waste directly disposed to aquatic system. Waste water from gold mining process flows to river without pretreatment. But, it dominantly comes from another process, where miners burn the amalgam to get the gold. This is called atmospheric pathway.

Elemental mercury and inorganic mercury in aquatic system are methylated to be organic mercury by fish and any aquatic organisms, where is the most dangerous form of mercury for human health. The main human health risk of mercury is derived from seafood consumption, and

also the distribution of mercury in aquatic system by runoff causes mercury deposited in sediment. Therefore, fish, aquatic organisms, and sediment can be mercury indicators in aquatic system.

1.4.3 Mercury in Terrestrial

Similarly pathway of mercury in aquatic system, mercury in terrestrial is mercury mostly adopted from atmospheric mercury. Gaseous elemental mercury deposits on the top layer of soil, where mercury concentration in soil decreases with an increase in depth. The distribution of mercury in soil is affected by rain runoff. Probably, mercury in soil transports to the plant by root and accumulates in stem and leaf.

1.5 Mercury Exposure Indicator

1.5.1 Mercury in Soil

Various mercury compounds exist in soil, such as elemental mercury, inorganic mercury, and also organic mercury (Revis, et al., 1990). Even though, total mercury is commonly used to determine mercury exposure level. Relatively, soil contains 0.2 mg/kg of total mercury. When the total mercury is higher than 0.2 mg/kg, mercury is transported to other sectors (Ministry of Environment, 2004). Therefore, the advance investigation is necessary, such as mercury in plant and river water. Mercury contaminates soil from phase of mercury vapor in atmosphere. Surface soil has the highest risk of mercury contamination. Boening (2000) found that the increasing of mercury in soil was followed with the incrasing of mercury in plant and reflected the higher mercury concentration in atmosphere. It means atmosphere became the major pathway of mercury spreading in environment.

1.5.2 Mercury in Plant

Plant is used as bio-indicator of mercury in atmosphere. Plant uptakes the mercury vapor during the respiration process through stomata or foliar adsorption (Fernández-Martínez, et al., 2015). Mercury will deposit in the leaves (Patra & Sharma, 2000). Another possible way is the transportation of mercury from soil to plant via steam and deposited in the roots, although it is not as efficient as through atmosphere (Lodenius, 2013; Sierra, et al., 2009). It is caused several forms of mercury, such as Hg^0 and HgS cannot be transfer via roots (García-Sánchez, et al., 2009). Therefore, mercury concentration in plants can be used to indicate the level of mercury atmospheric pollution in an area.

1.5.3 Mercury in Food

Gastrointestinal tract is source of mercury contamination in human body. Almost 95% methylmercury absorb during this gastrointestinal process by eating fish, seafood and other mercury contaminated foodstuffs (Wang, et al., 2011). The mercury absorption spreads rapidly in human body through blood circulation. In another case, organic mercury compound transported to human body through inhalation tract. When it enters the human body, organic mercury disperses to the tissues and immediately transfers to the brain. However, organic mercury and methylmercury can reform as inorganic mercury and it will accumulate in brain or blood for long time, then inorganic mercury secretes from human body in form of faces and breast milk (U.S. Departement of Health and Human Services, 1999).

Based on the explanation above, it is so important to monitor the mercury concentration in foods, because almost mercury form in foods accumulates in human body and affects the harmful disease and symptoms. According to Ministry of Environment, Japan (2004), the monitoring of

biological samples including fish, seafood, and other foods are needed to monitoring the mercury exposure level in community. It can be useful to evaluate the mercury daily intake through gastrointestinal tract. The research has to focus on risk areas, such as gold mining area. However, total mercury in foods cannot exceed 0.4 mg/kg (wet weight) for the safety food consumption.

1.5.4 Mercury in Human Hair

Nowadays, many studies applied human hair as the most frequent bio-marker to measure the degree of mercury exposure in human. Mercury that dispersed in human accumulates and is stable in human hair, where the half-life of mercury in human hair is up to 2 months (Díez, et al., 2011). Mostly, 90% of mercury in human hair was methylmercury, which is the most dangerous mercury compound for human health. Then, the dominant pathway of methylmercury is by consuming seafood, especially fish. Thus, measuring mercury in human hair has significant relevant with the food consumption pattern.

Additionally, another advantage by using human hair to evaluate mercury in human body is the growth of 1 cm hair in a month. Therefore, the mercury concentration in human hair is the past condition of mercury absorption in human body. Ministry of Environment in Japan claimed that mercury concentration in human hair is 250 up to 300 times higher than mercury concentration in blood. (Abad, et al., 2016). Generally, mercury concentration in human hair of Japanese is the range of 1 to 5 ppm.

1.6 Community Vulnerability

1.6.1 Vulnerability Concept

Initially, vulnerability is derived to solve the destructions from natural hazards or disaster. But nowadays, vulnerability developed widely towards more comprehensive assessment. Recently, vulnerability is used to concern in all researches related to natural impacts. Vulnerability is a degree or level that represents a condition due to hazard exposure (Nguyen, et al., 2016). Referred to Minamata Disease, mercury became the health disaster on 1956. It should be the concern of vulnerability studies, especially for gold mining area, as the active user of elemental mercury. Avoiding the health impacts of mercury, a community vulnerability assessment is needed with the fundamental dimensions of vulnerable concepts, such as (Füssel & Klein, 2006):

a. System, including subject to analysis, a population, and a region or area;
b. The hazard, it refers to contaminant (mercury), which is potential to damage the system or reduce the quality of a system.

Community vulnerability was established by three main concepts (Smit & Wandel, 2006; Fronzek, et al., 2012). The interaction among three concepts will determine the condition of a system. When, contaminant (mercury) exposed a system, the sensitivity reflects the condition which is influenced by exposure and the abilities of the system will cope, adapt even recover the impacts of contaminant (Birkman, 2007). However, exposure and sensitivity hierarchy shape the adaptive capacity and approach the community vulnerability due to gold mining activities.

1.6.2 Vulnerability Indicator

Among the important efforts for reducing the risk of the mining activities, development, testing and determining indicators to identify and to examine the vulnerability and capacity of traditional gold mining turn into the most crucial part in this research. It becomes

more important at most rivers in Indonesia since it plays a very significant role to fulfill the need of the local people. Hence, it is important to promote the change in paradigm of the risk quantification and focus on technical solutions in order to identify the vulnerability rate from social, economic, and environmental aspects.

In the 2005 World Conference Disaster Reduction (WCDR) held in Kobe, Japan, the needs for developing indicators of vulnerability are critical to allow decision-making of assessing any potential danger (UN/ISDR, 2005).

Adger et al (2004) suggests that the use of inappropriate indicators to examine the vulnerability must be avoided in order to give correct results by using systematical indicators. The term indicator is more widely known in economic and environmental analyses. According to the discourse of sustainable development (Adger, et al., 2004), indicator is defined as indicator variable (not value), that represents operational attributes, such as quality and/or characteristics of particular system. The indicator relevance in predicting quality or characteristics of a system from any interpretation made for indicators and their relationship with the existing condition. It means that the assessment of vulnerability rate determines variables and defines partial existing data (Birkmann, J. (Ed.), 2006).

In another hand, the quality indicator is determined through the ability to demonstrate the characteristic function of a system that is relevant to the underlying interest determined by a goal or vision research.

Vulnerability indicators focus on the direction of development or the comparison between current "vulnerable status" and "status in the past". It is possible to evaluate whether to increase or decrease vulnerability. Similarly, the indicators approach to vulnerability assessment and damage that focus on appropriate goals in determining vulnerability (UNDP 2004).

According to Wisner, et al. (2003) identification and understanding of the exposure and the indicators are an important function of measuring community vulnerability. Birkmann (2006) underlines the point of view of practitioners that vulnerability indicators are needed to practice decision-making process, such as hazard management plan for the infrastructure of the most vulnerable.

Based on research on the environmental assessment, indicator development process can be classified into nine different phases. Additionally, based on concept of Mileti (1999) indicators are starting with the definition or selection of the relevant objectives. Once the scoping process to explain the scope of the indicators by identifying target groups and objectives related to the indicators to be used as well as the limits of temporal and spatial, which means identifying the time frame in which the indicators to be measured and determine the spatial limits of the reporting unit.

In the next phase of the conceptual framework, it should be formulated within the framework of the structure of potential indicators, then selects criteria for potential indicators. In this context an important task for all approaches to measure vulnerability is to find the right balance between the accuracy of the data and the data availability.

The final stage is a list of potential indicators, while in the phase of the final set of selected indicators. Data analysis and application of indicators in selected areas, it is extremely difficult, especially because many of the characteristics of vulnerability associated with intangible factors and aspects that are difficult to estimate. The final stages of development indicators can be seen in the preparation of reports and assessment of performance indicators.

1.7 Purpose of the Research

Therefore, this study aims (1) to investigate the contamination level of mercury spreading in environment, especially in research areas due to gold mining activities, (2) to assess mercury daily intake for local people in gold mining area and (3) to measure the vulnerability indicators, owing of illegally mercury usage in small-scale gold mining. This study is also expected as the monitoring guidance for local government, environmentalist and academia to raise the health awareness of people and/or miner due to mercury in gold mining. At least, it contributes the human health assessment to reduce the mercury effect and symptoms, and finally, it approaches Minamata Convention.

1.8 Structure of Thesis

This thesis, **Mercury Contamination Levels in Small-scale Gold Mining Areas in Indonesia is** designed into six chapters:

a. Chapter I

   This chapter describes background of the research, general information about mercury as the gold mining activities waste in Indonesia.

b. Chapter II

Study areas explanation, sampling, and also analytical methodology are handled in this chapter, especially for Central Java and Central Sulawesi, Indonesia.

c. Chapter III

In this chapter, total mercury concentration in Central Java is measured to address the community vulnerability based on exposure degree indicator, contamination rate indicator, chronic and acute toxicity indicators.

d. Chapter IV

This chapter explains the total mercury in soil and plant as the mercury pollution monitoring due to gold mining activities at the biggest hotspot in Central Sulawesi.

e. Chapter V

This chapter designs to measure mercury daily intake in dietary food consumption as the estimation of the mercury exposure level in gold mining area. It showed the human health condition of mercury pollution.

f. Chapter VI

This chapter attempts to explain vulnerability indicators for both areas. The indicators described the mercury contamination levels in Indonesia through representative areas.

g. Chapter VII

This last chapter compiles all the necessary findings in this study as the conclusion.

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Chapter II

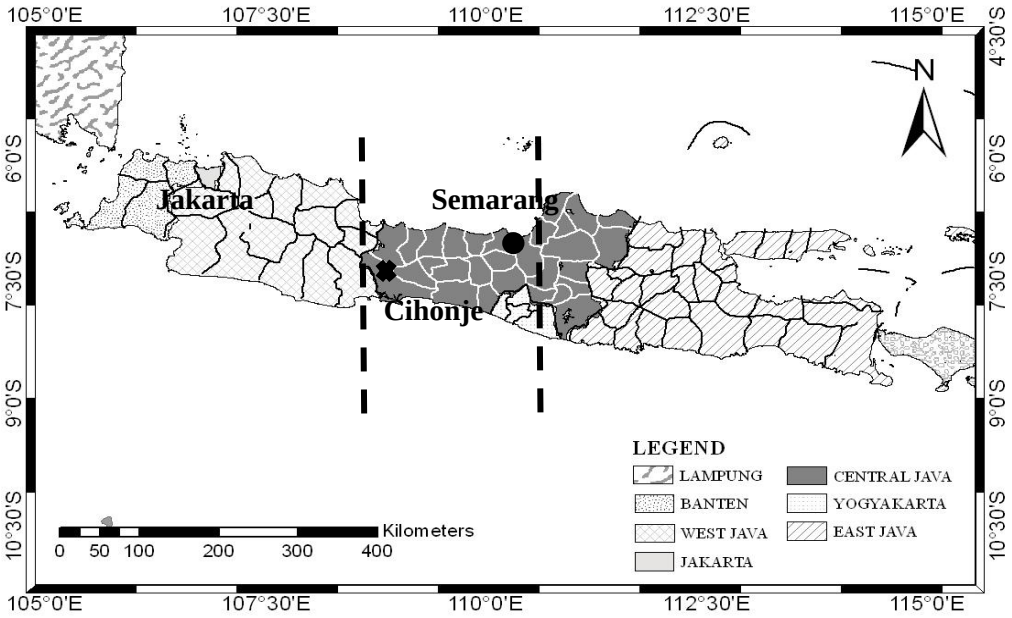
Study Area, Sampling and Methodology

2.1 Mercury Exposure due to Gold Mining Activities in Central Java

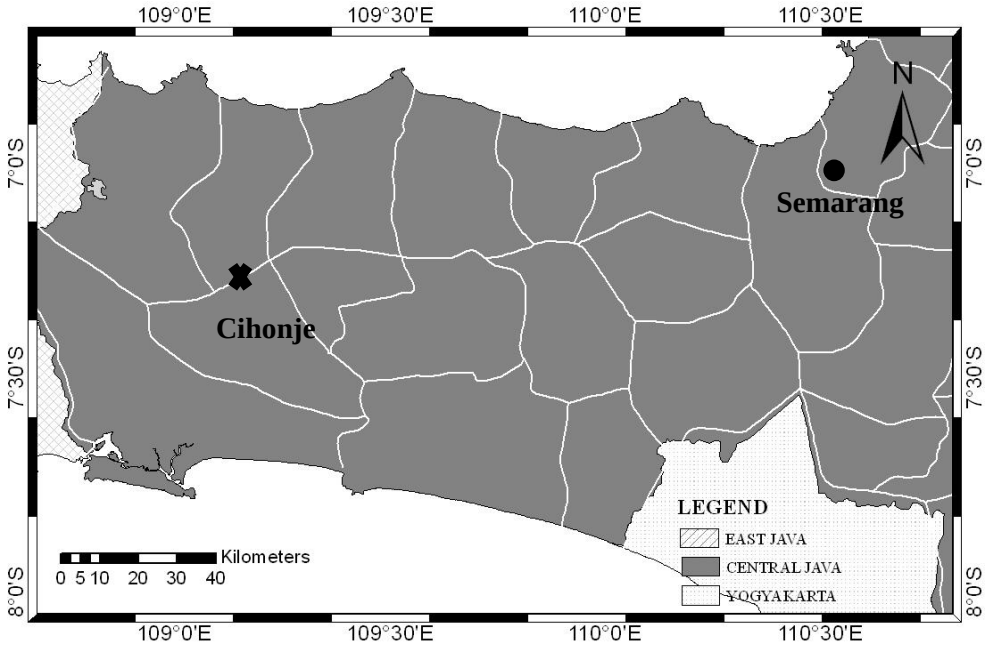
2.1.1 Study Area

One of the study areas is the village of Cihonje, which is a part of the Gumelar district administration in the Banyumas regency of Central Java province, Indonesia (see Figure 2.1). This region has one of the highest potentials for gold mining activities in the region of the North Serayu Mountains (Ansori & Eko, 2009). Based on data from 2012, Cihonje has 72 active miners.

In another hand, Semarang is located 256 km from the village of Cihonje. This region is the capital city. Semarang was chosen as a comparison area for the Cihonje village because this location is not an artisanal and small-scale gold mining area. Therefore, it is assumed that mercury do not support their daily life. Location of Semarang is described in Figure 2.1(b).



(a) Java Island, Indonesia



(b) Location of Cihonje and Semarang

Figure 2.1 Study areas in Central Java, Indonesia

2.1.2 Sampling and Analytical Methods

2.1.2.1 Mercury Exposure in River Water Sample

The river water sampling technique utilized was pursuant to the National Standards for Indonesia 03-7016-2004 on Monitoring Sampling Technique for Water Quality, which mentioned that river water should be taken at three major points. The first point is located in the upstream of the river, followed by the second point in the river body close to the center of human activities, with the last point of sampling being at the rivers downstream area at Point 7. For this area, samples were collected at the Tajum's river flows in the Gumelar district in Banyumas in 2012.

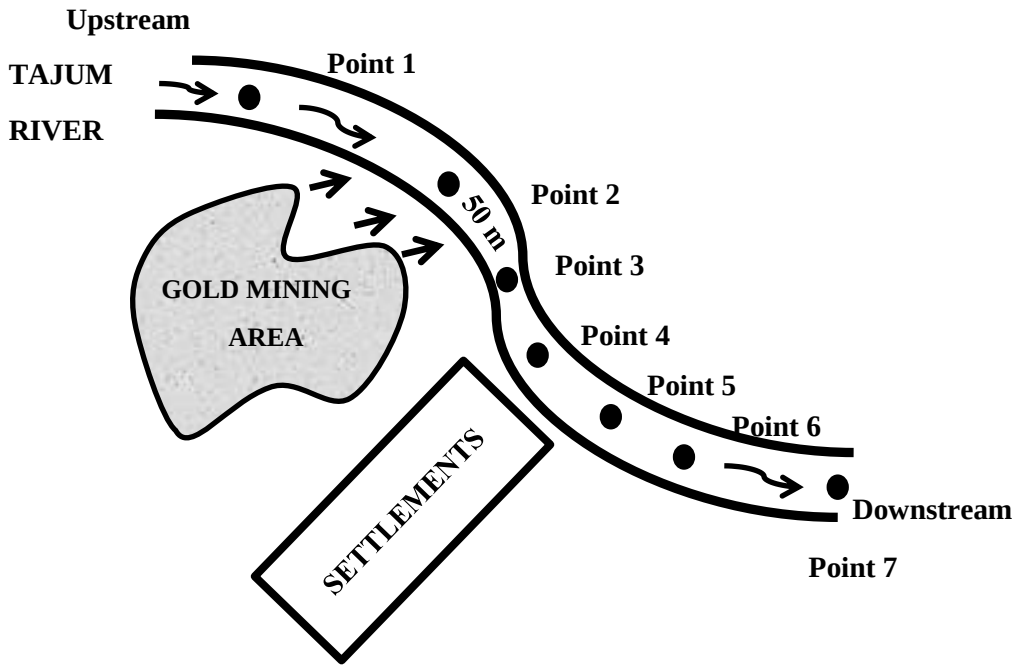


Figure 2.2. River water sample collection

Figure 2.2 shows the sampling points of Tajum river. Point one was at the portion upstream of artisanal and small-scale gold mining (as a comparison point) with the next point located 100 m from point 1, which was the first original gold mining area and represented as point 2.

Later on, the distance between each point up to point 6 is 50 m. The last point was 100 m from the point 6 and located at downstream. All of the river water samples were collected using 100 ml-polyethylene bottles which were washed three times with river water. The river water samples were collected at two points, first point set on 1/3 of river width and second point on 2/3 of river width in the middle of the river heights. For the experimental analysis, mercury in the river water was measured using Mercury Analyzer RA-3 (Nippon Instruments Corp., Japan).

2.1.2.2 Analytical Methods of River Water Sample

Mercury Analyzer RA-3 uses cold vapor atomic absorption spectrometry (CVAAS) to determine the total mercury concentration in river water (Tomiyasu, et al., 2013). In principle, this method will reduce the Hg^{2+} ions in the sample, and generate Hg^{0} using stannous chloride, then measure the absorbance by introducing Hg^{0} into a photo-absorption cell (Ministry of Environment, 2004).There are several steps of mercury analysis in river water:

a. Dissolve 5 mg of L-Cysteine HCl in 500 ml distilled water then add 1 ml of HNO_3,
b. Dissolve 2.5 g of $K_2S_2O_8$ to 50 ml of distilled water, and 1.2 g of $(NH_3OH)Cl$ in 15 ml of distilled water, then shake it,
c. Prepare the blank solution and standard solutions in 3 test tubes per solutions,
d. Transfer 3 ml of river water samples to the test tube, where every sample needs 3 times measurement,
e. Add 0.4 ml of H_2SO_4-64%, 1 ml of HNO_3, and 0.4 ml of $KMnO_4$ to blank solutions, standard solutions and all river water samples. Shake it well and let stand for 15 minutes,
f. Then, add 0.2 ml of $K_2S_2O_8$ solution and heat all the test tubes in the water bath with temperature $95^{0}C$ in 2 hours.

g. After cool down, add 0.2 ml of $(NH_3OH)Cl$ solution, and shake it,
h. Add the distilled water up to 5 ml per test tube,
i. Test the samples with mercury analyzer RA-3, using Tin (II) Chloride and HCl-64% solutions.

2.1.2.3 Mercury Exposure in Waste Water Sample

Below figure (see Figure 2.3) shows the sampling points at the gold mining area where the samples were taken in 2012. The outputs of the gold mining processes were waste water, mercury vapor and gold. The effluent measurement was an indicator of vulnerability regarding the degree of mercury exposure. Similar to the river water samples, wastewater samples were collected using 100 ml-polyethylene bottles, which were rinsed three times with waste water.

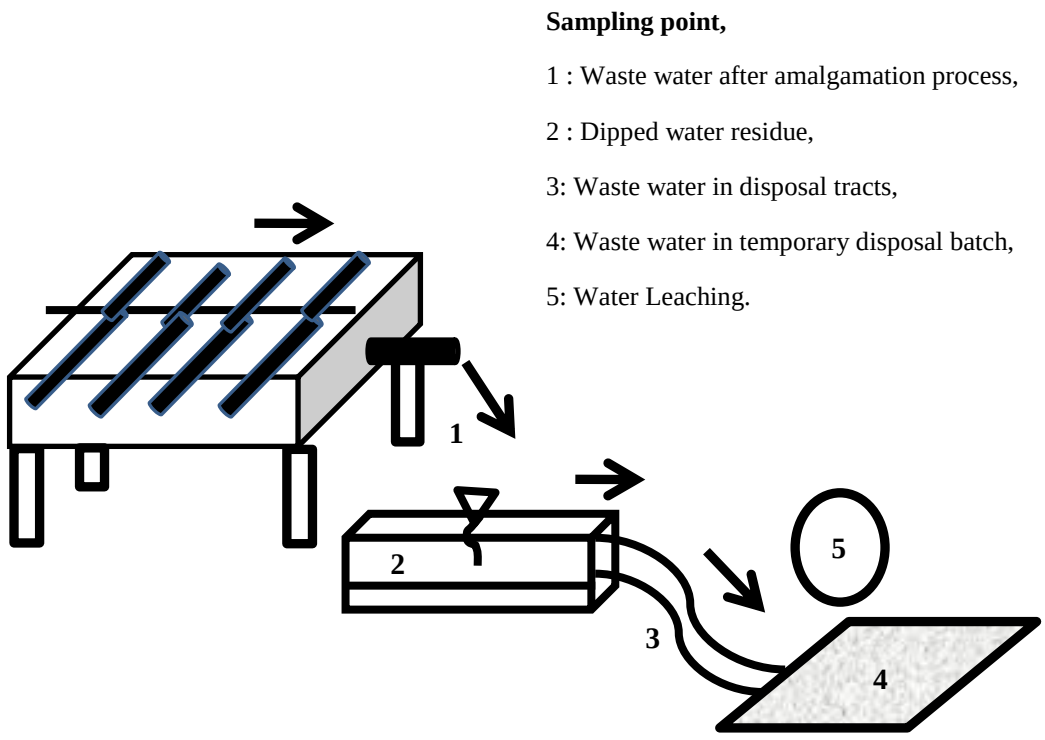


Figure 2.3. Waste water sample collection

2.1.2.4 Analytical Methods of Waste Water Sample

Fundamentally, the analysis of mercury in waste water was similar with river water sample. Due to the high concentration of mercury, the dilution in waste water samples up to 10000 times before the analytical method procedures.

Similar with the previous samples (river water sample), analysis of the total mercury in waste water was used mercury analyzer RA-3 (Nippon Instruments Corp., Japan) with cold vapor atomic absorption spectrometry (CVAAS) system. Mercury analysis steps adopted from the mercury analysis in river water sample. It was excerpted in Mercury Analysis Manual (Ministry of Environment, 2004).

2.1.2.5 Mercury Exposure in Human Hair Sample

The total mercury concentration in human hair was used for studying the degree of people's exposure of mercury. The respondents were communities living in the area and randomly collected from the Artisanal and Small-scale Gold Mining (ASGM) area in Cihonje. Fifteen samples were collected and demonstrated the characteristics of the respondents from the non-gold mining area. They were classified into male and female within four age ranges.

As the comparison of mercury exposure, fifteen human hair samples were also collected in Semarang as the representative of communities living in non-gold mining area. It was divided into four age categories; 15-30; 31-45; 46-60; and 61-75 years old.

2.1.2.6 Analytical Methods of Human Hair Sample

The primary data was obtained from mercury analysis of the human hair samples. The human hair samples were analysed by Mercury Analyzer RA-3 (Nippon Instruments Corp., Japan) too, which adopted the CVAAS system.

The human hair samples were cleaned, finely chopped, and kept in a freezer before laboratory analysis. Less than 10 mg of a human hair sample was prepared into the flask. Later, 1 ml of distilled water was added to the sample and then 2 ml of HNO_3-$HClO_4$ (1+1) followed by 5 ml of H_2SO_4. The human hair samples were placed onto a hot plate for 30 minutes at 200-230°C. Twenty minutes was required for cooling before application of the next treatment. Finally, the sample was diluted with 50 ml of distilled water and 5 ml of the sample was placed into a test tube (Ministry of Environment, 2004).

2.1.2.7 Health Questionnaire

The interview consists of the sex, age, health symptoms, and the location of the respondents obtained through a health questionnaire prepared for randomly selected respondents at both areas. These data were used for analysing the prone of local people in Cihonje and Semarang.

The data was analysed in terms of such vulnerability indicators as exposure degree, mercurial contamination rate, health status, and illness or disease frequency (acute toxicity and chronic toxicity). Furthermore, indicators were evaluated according to very rare; rare; moderate; often; and very often. Below is the sample of questionnaire:

QUESTIONNAIRE

Instruction :

Fill the questions below (.....) and mark (√) in each column that corresponded to your answer.

A. CHARACTERISTICS OF RESPONDENT

1. Name : .....
2. Age : .....
3. Sex : M / F
4. Occupation : .....
5. Location : .....

B. HEALTH SYMPTOMS DUE TO GOLD MINING ACTIVITIES

How often are you bothered by the following illnesses?

No	Health Symptom	Very Rare (1)	Rare (2)	Moderate (3)	Often (4)	Very Often (5)
1	Nausea and vomiting					
2	Stomach ache and diarrhea					
3	Pain in the lips and tongue					
4	Pain in the ankle and hands					
5	Insomnia					
6	Headache					
7	Breathing difficulty					
8	Red spots on skin					
9	Sores on the skin					
10	Swelling on the eyes, feet or hands					
TOTAL						

Figure 2.4. Health questionnaire

2.2 Mercury Exposure due to Gold Mining Activities in Central Sulawesi

2.2.1 Study Area

In this case, the research was taken in two study areas. First area was Poboya village, Central Sulawesi, Indonesia. Poboya is one of the primary sites for small-scale gold mining activities in Indonesia, having 35000 miners working in an area of 7000 hectares (Ismawati, 2013; Nakazawa, et al., 2016). It commenced operation in 2009 (Albasar, et al., 2013). Poboya has high levels of gold mining protduction and contributes around 200-500 kg/day of mercury through gold mining processes into the environment (Ismawati, 2013).

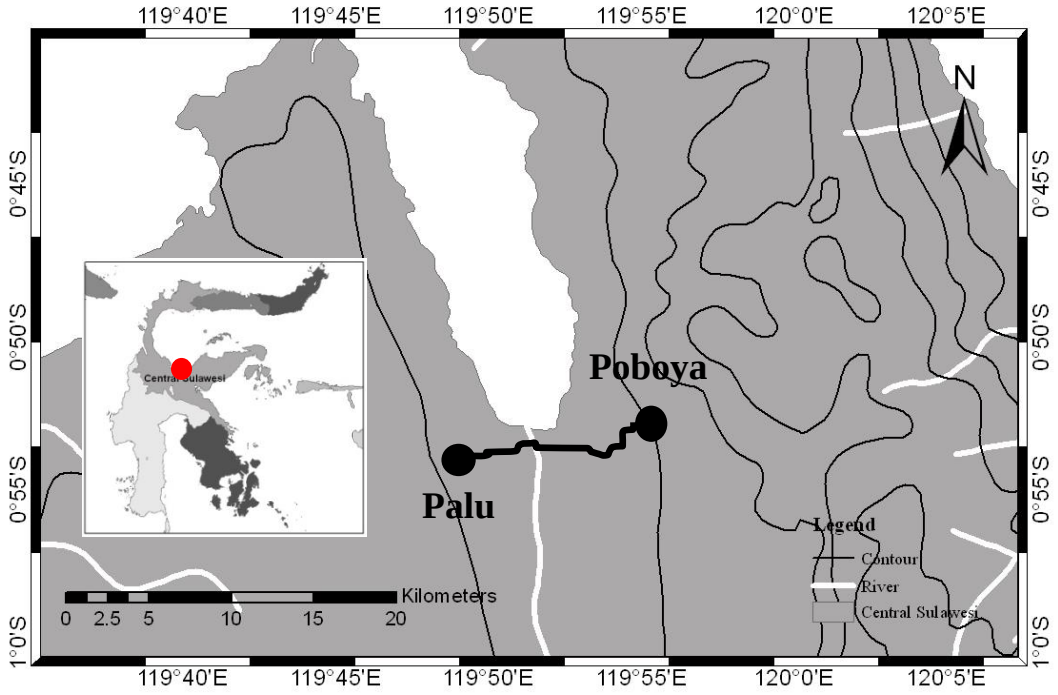


Figure 2.5. Study area in Central Sulawesi

Another study area was Palu city. It assumed as one of the areas that possibly may be impacted by mercury due to the gold mining site in Poboya because Palu city is located around 11 km away from Poboya (see Figure 2.6). Palu city is the capital city of Central Sulawesi, Indonesia, which is also the center of community activities and has a population of 0.35 million people.

2.2.2 Sampling and Analytical Methods

2.2.2.1 Mercury Exposure in Soil and Plant Samples

The research was conducted to observe the total mercury concentration (THg) in Poboya, Central Sulawesi, Indonesia in October 2014. There were two types of samples; soil and plant. Firstly, soil samples were taken at regular intervals, at every 500 m up to 7 km from the edge of a small-scale gold mining area in Poboya to Palu, where the surrounding areas included settlements, and the sampling points are shown in Figure 2.7. The 1st sampling point was located 0 m from the edge of the small-scale gold mining area, and the 2nd one was at a distance of 500 m from the 1st sampling point. The last sampling point was the 15th sampling point, which was located approximately 7 km from the initial one (see Fig. 2.7). So, 15 soil samples were collected. A 50 gram sample of soil for each sampling point was taken from the topsoil layer. The soil samples were placed in 50 ml polypropylene bottles and sealed tightly using transparent tape.

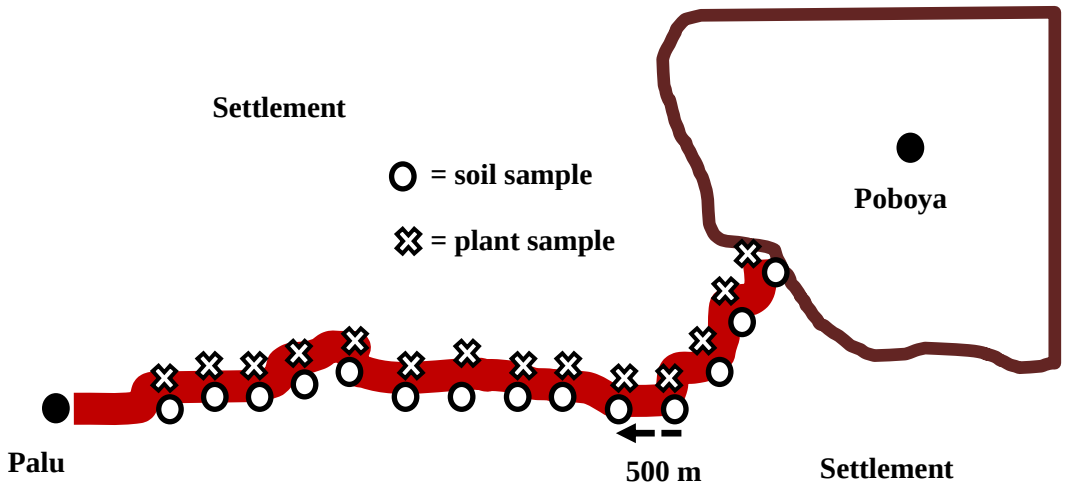


Figure 2.6. Sampling Points

Secondly, the plant sample taken was *Calotropis gigantea,* a local plant, which spreads across the landscape of Central Sulawesi. The vegetative

structures (leaves) of *Calotropis gigantea* were used to represent the total mercury in plant sample. The quantity of plant samples (leaves) were cleaned using distilled water and kept in sealed bags. As well as to the soil samples, the plant samples were taken at 15 sites spaced 500 m apart from the mining site to downtown, Poboya to Palu.

2.2.2.2 Analytical Methods of Soil and Plant Samples

The mercury analysis used cold vapor atomic absorption spectrometry (CVAAS) to determine the total mercury in soil. In principle, this method will reduce Hg^{2+} ions in the soil sample, and generate Hg^{0} using stannous chloride, then it measures the absorbance by introducing Hg^{0} into the photo-absorption cells. The test procedures for the soil samples followed the mercury analysis manual as set by the Japanese Ministry of the Environment, 2004.

There were several treatments undertaken to analyze the soil samples, which included the addition of 1 ml of distilled water, 2 ml of HNO_3-$HClO_4$ (1+1), and 5 ml of H_2SO_4 in a maximum 500 mg of soil wet weight in a flask, then heated for 30 minutes at 200-230℃ on a hot plate, then mercury was extracted. After cooling down for a few minutes, the solution was diluted with distilled water using up to 50 ml. Only a 5 ml solution was analyzed using Mercury RA-3 (RA-3, NIC Company). This was repeated three times for each soil sample for the purposes of accuracy. For comparison, we used the measured human hair standard from National Institute of Environmental Studies Japan, where the value was 3.95 ng/mg. As a reference, this also analyzed concentration of nitrogen and carbon in soil samples using an NC coder (SUMIGRAPH NCH-22A, Sumika Chemical Analysis Service Ltd, Japan). This NC coder is a semi-automatic device that uses an oxygen circulating combustion system.

A similar analysis was used for both soil samples and plant samples. The plant samples were analyzed using a CVAAS system. The plant samples were cleaned and rinsed several times, dried at 40° C for 24 hours and finely chopped, before laboratory analysis. Next, the same analytical methods were used as in the soil samples analysis, where less than 500 mg of plant sample was balanced for analyzing.

2.2.2.3 Mercury Exposure in Food Sample

The 22 kinds of foods obtained from Poboya and from Palu are listed in Table 2.1. The foods selected were those consumed at a high frequency by people living in these areas. The foods were allocated to four groups: seafoods (squid, shrimp, tuna, mackerel, and anchovy); meat (chicken and beef) and eggs; vegetables (bananas, carrots, green beans, sprouts, scallions, string beans, spinach, mustard greens, corn, cabbage, and water spinach); and processed foods (tofu, bean cake, and rice).

Table 2.1. Foods sampled

1. Seafoods	2. Meat and eggs	3. Vegetables	4. Processed foods
a Squid	a Chicken	a Banana	a Tofu
b Shrimp	b Beef	b Carrots	b Bean cake
c Tuna	c Eggs	c Green beans	c Rice
d Mackerel		d Sprouts	
e Anchovy		e Scallions	
		f String beans	
		g Spinach	
		h Mustard greens	
		i Corn	
		j Cabbage	
		k Water spinach	

We assumed that the people in both areas had similar consumption patterns. By determining these consumption patterns and the THg content of each food, we were thus able to estimate weekly mercury intakes via the gastrointestinal system. To our knowledge, this is the first assessment of weekly mercury intake in a gold-mining area in Indonesia.

2.2.2.4 Analytical Methods of Food Sample

We used cold vapor atomic absorption spectrometry to quantify the total mercury (THg) present in foods. In this method, Hg^{2+} ions in the food sample are reduced, and Hg^{0} is generated by using stannous chloride. The absorbance is then measured by introducing Hg^{0} into a photo-absorption cell. The test procedures for the food samples, and the mercury analysis that follows, are set out in a manual from the Japanese Ministry of the Environment (2004). Several treatments were used to analyze the samples. Each sample was finely sliced, measured to a weight of less than 500 mg, and then placed into a flask. We next added 1 ml of distilled water, 2 ml of HNO_3 - $HClO_4$ (1+1), and 5 ml of H_2SO_4 to a maximum wet weight of 500 mg, and then heated the mixture for 30 min on a hotplate at 200 to 230° C, to extract the mercury. After the solution had been cooled for a few minutes, it was diluted with distilled water to 50 ml. We then analyzed 5 ml of the solution from each sample by using a Mercury RA-3 mercury analyzer (RA-3, NIC Company Japan). This analysis was performed three times on each type of sample. For quality assurance, we measured the mercury levels four times in human hair standard (Certified Reference Material) No. 13 from the National Institute of Environmental Studies Japan; this standard has a quality assurance range of 4.42 ± 0.20 ng/mg. We obtained a range of 4.16 to 4.33 ng/mg , thus assuring us of the accuracy of our

laboratory experiments on the foods. All samples were sliced into small sizes and stored in refrigerator till analysis.

2.2.2.5 Mercury Exposure in Human Hair Sample

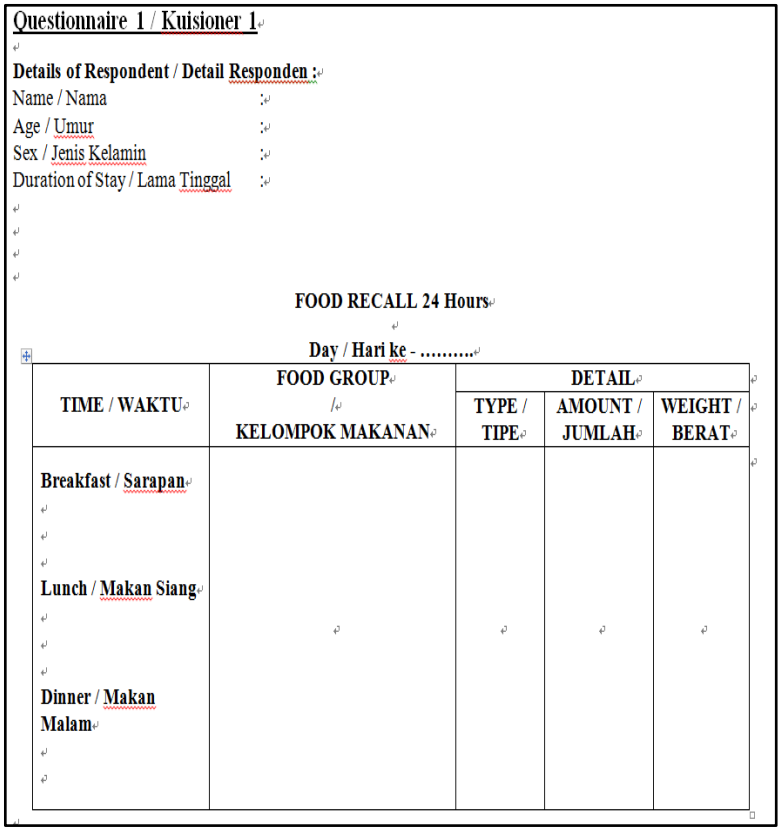
Human hair samples were taken only at Poboya. Twenty respondents each donated about 20 strands of hair. Because hair grows at about 1 cm/month, the hair was cut close to the scalp to reflect accurately the recent mercury concentration in the body (Ministry of Environment, 2004). The hair samples were kept in sealed polyethylene bags at room temperature. Actually, the human hair samples were used to measure the total mercury present in the human body due to mercury intake through the gastrointestinal system.

2.2.2.6 Analytical Methods of Human Hair Sample

Hair samples were taken from the Poboya respondents during the food intake survey. Twenty strands per person were obtained from three families. Each family had between five and nine members (age range 6 to 63 years). Strands were taken 2 cm from the scalp. The results were considered to indicate the THg content of the body due to mercury intake via the gastrointestinal system. THg was measured by cold vapor atomic absorption spectrometry. First, the strands of hair were cleaned with pure water and then dried in an oven at 50 ° C for 12 h. The strands were then chopped into a fine powder with scissor. No more than 10 mg of sample was then placed in a flask. We added 1 mL of distilled water, followed by 2 mL of 1:1 $HNO_3/HClO_4$ and then 5 mL of H_2SO_4. The sample was then placed on a hotplate for 30 min at 200 to 230 ° C and cooled for 20 min before mercury analysis. Finally, the sample was diluted with 50 mL of distilled water, and 5 mL of the sample was placed into a test tube (Ministry of Environment, 2004).

2.2.2.7 Daily Food Intake Survey

Various kinds of daily food intake assessments, including dietary history, dietary records, food frequency and 24-hour recall, are used to assess human health (Tran, et al., 2004). We combined three types of food intake assessments above into a single assessment to gather data on the patterns of food consumption by people living near Poboya and in the center of Palu. We recorded dietary histories by using an interactive method to determine the kinds of food intake in the region. Interviews are a necessary part of this assessment. The accuracy of the assessment depends on the food intake memories of the interviewees. Each interview took 30 to 40 min per day, during which time members of the family recorded all of the daily food eaten in the household within the last week. There were nine families, with a total of 40 respondents over the two areas; 24 respondents were female and 16 male, with an age range from 1 to 63 years.



Questionnaire 1 / Kuisioner 1

Details of Respondent / Detail Responden :

Name / Nama :
Age / Umur :
Sex / Jenis Kelamin :
Duration of Stay / Lama Tinggal :

FOOD RECALL 24 Hours

Day / Hari ke - .....

TIME / WAKTU	FOOD GROUP / KELOMPOK MAKANAN	DETAIL		
		TYPE / TIPE	AMOUNT / JUMLAH	WEIGHT / BERAT
Breakfast / Sarapan				
Lunch / Makan Siang				
Dinner / Makan Malam				

Figure 2.7. Daily Food Intake Questionnaire

Food intake frequency was estimated indirectly during the interviews. After we had obtained information on the kinds of foods consumed in each household over the past 7 days (through dietary history recording by the respondents), we recorded the weights of all food items consumed at three mealtimes across 7 days. The interviewer then used the frequency of consumption of each item per respondent every day for a week and the weights of foods consumed to derive a pattern for the range of foods consumed in both areas. To quantify the foods, respondents used simple household measures such as teaspoons and tablespoons. This method had the advantages of low cost, minimal time consumption, and suitability for extrapolation of the results to a large population.

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Chapter III

Measuring Total Mercury due to Small-scale Gold Mining Activities in Cihonje, Central Java, Indonesia

3.1 Introduction

Cihonje village is one of gold mining spot in Central Java. Gold mining activities in this area are carried out three times a day. Each process produces 5.54 grams of gold with approximately 1 kg of ore per day produced for the total area. The Tajum river that located close to Cihonje village has been potentially affected by mercury from gold mining process, therefore this river is seen as having a negative impact. The Tajum river is used as a disposal location from artisanal and small-scale gold mining in the Cihonje village. Incidentally, the Tajum river is the main water resource for the locals meeting the daily needs of the local community, such as bathing, clothes washing, and for watering vegetables. These activities act as intermediaries for the entry of mercury into the human body, either through inhalation or ingestion.

When mercury is released into our environment during the gold mining process, people become at risk by this phenomenon. The degree of human life support systems lessens with the decreasing of the environmental quality of the Cihonje village. Fundamentally, the purpose of collaborative research is to achieve sustainability. Sustainability is suggested to be the provisioning of society with increasing

environmental life support and cognizing the capacity of people (TurnerII, 2010). However, part of the vulnerability research community is strongly aligned with sustainability and environmental degradation (Eakin & Luers, 2006). Vulnerability is a concept derived from social science and is suggested as a response to heightened danger, in this case being the mercurial contamination (Sinha & Goyal, 2004). The basic development of a vulnerability analysis in social science is to analyse any events related to natural danger. In short, a vulnerability analysis lays emphasis not only on natural disasters but also on the environmental damage caused by artisanal and small-scale gold mining area.

Finally, the aim of chapter 3 is to determine the level of vulnerability of the local people due to the mercury usage in gold mining activities. The result of this research work addressed that the government should measure the vulnerability and the capacity of local people when gold mining occurs in that area. This research would prove useful as environmental monitoring guidelines using the four vulnerability indicators.

3.2 Total Mercury Analysis of Wastewater from Gold Processing as Exposure Degree Indicator

The exposure degree indicator was shown as the level of the contaminant (mercury) where pollution of the environment occurred. Wastewater was used to investigate the exposure degree indicator. The main source of mercury in ASGM process is amalgamation, which produces amalgam and wastewater. Each process requires 1 kg of mercury per 40 kg of soil three times a day.

Table 3.1. Total mercury concentration of wastewater as exposure degree indicator

Sample	Location	Total Mercury Concentration ng/ml
1	Water after amalgamation process	37.3×10^{3}
2	Dipped water residue	19.7
3	Water in disposal tracts	22.4×10^{3}
4	Water in temporary disposal container	72.1
5	Water leaching	72.2×10^{1}

Table 3.1 describes the mercury concentration in each gold mining process as shown in Figure 2.3. The highest concentration was found in Sample 1: Wastewater taken after the amalgamation process. It was $37.3x10^{3}$ ng/ml. The lowest concentration of mercury (19.7 ng/ml) was found in wastewater from the small-scale gold mining process in the form of sediment.

The high concentrations of samples 1 and 3 were caused by the water turbidity and it contained abundant visible suspended particulates in the flow. This confirms that sediment conditions are typically favourable for the mercury formation, which form complexes with organic matters and it is susceptible to wash out in runoff only when attached to suspended particulates. It is for these reasons that mercury has a long retention time in sediment (UNEP, 2013). Appendix II of the Decree of the Minister of Environment of Indonesia No. 202/2004 wrote that the quality threshold of the maximum concentration for mercury in waste water from gold processing was 5 ng/ml.

3.3 Total Mercury Analysis of Water Quality of the Tajum River as Contamination Rate Indicator

Measuring mercury concentration in environment, such as soil, water and air, addressed the contamination rate. In this area, wastewater from artisanal and small-scale gold mining was disposed-off into the Tajum river. This caused an increase of the mercury concentration in the river water. The increase of mercury concentration in the Tajum river has negative impacts on the locals because water from the Tajum river is very important for their daily activities. Although they do not drink the water, the mercury-containing water still affected the quality of life in other aspects, such as in agriculture and skin health. Therefore, river water was devastating vital sample to investigate the impact of mining (Miserendo, et al., 2013; Bakar, et al., 2014).

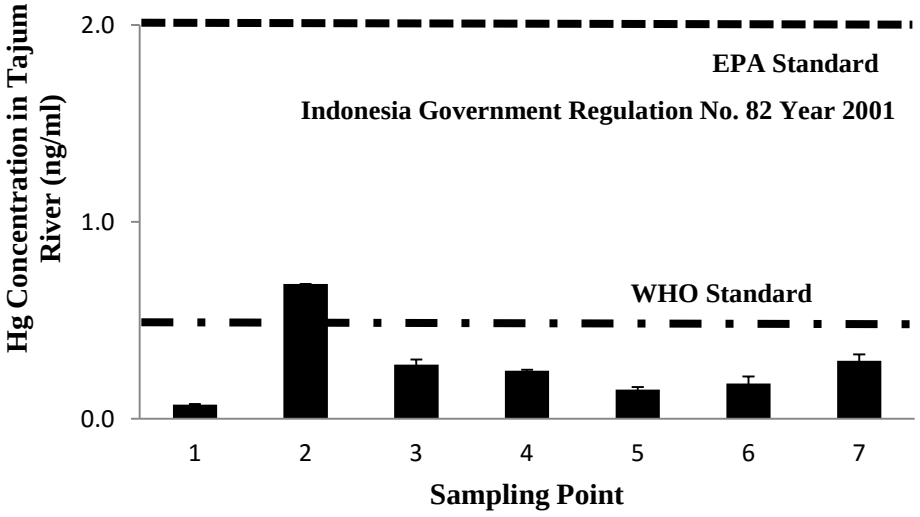


Figure 3.1. Total mercury concentration of river water as a contamination rate indicator

The average mercury concentration of the Tajum river was 0.27 ng/ml. According to Figure 3.1, the largest mercury concentration in the Tajum river was seen in the point two (see Figure 2.2), which is the original location of the gold mining area. The area closest to gold mining activities has a high potential for mercury contamination (Elvince, et al., 2008). Additionally, mercury concentration deposited on suspended particles will settle down onto the river bed rapidly (Limbong, et al., 2003). Therefore, the research assumed that the perceived mercury concentration derived from small-scale gold mining activities in Cihonje.

Three quality thresholds standards can be applied to the mercury concentration in Tajum river and compared. Among others were river classification based on water quality criteria pursuant to Government Act No. 82/2001 and standards from the WHO and the United States Environmental Protection Agency (US-EPA). To decide whether the river water function is adequate, the actual condition at the particular location may extend the evaluation according to the quality thresholds. Therefore, the determination of the river water's preferable rate using the quality threshold approach is as important as those using the actual condition of the river water. According to the quality threshold standards presented in the Government Act of the Republic of Indonesia, mercury concentration in the Tajum river is still acceptable because it has not exceeded the quality threshold of 2 ng/ml (for mercury concentration in Class II rivers). However, the actual and physical condition of the river in addition to the health quality of the affected people who are the users of this water, leads one to categorize that the Tajum river's quality standards as inadequate. This difference in measurement is due to very high water quality threshold standards applied to Indonesia. Furthermore, the WHO standards declare that an acceptable level of mercury content in river

water should be below 0.5 ng/ml. The final standard used was that of the US-EPA, which requires a maximum of 2 ng/ml for river water. According to field observation, the water quality of the Tajum river had a high vulnerability rate because it was adjacent to the mining area. This research found the mercury concentration in this area to be higher than 0.5 ng/ml (WHO standard).

3.4 Human Hair as an Indicator for Total Mercury Concentration in the Human Body (Chronic Toxicity Indicator) and the Health Questionnaire as an Acute Toxicity Indicator

Figure 3.2 shows the characteristic of the respondents that classified into four age groups:

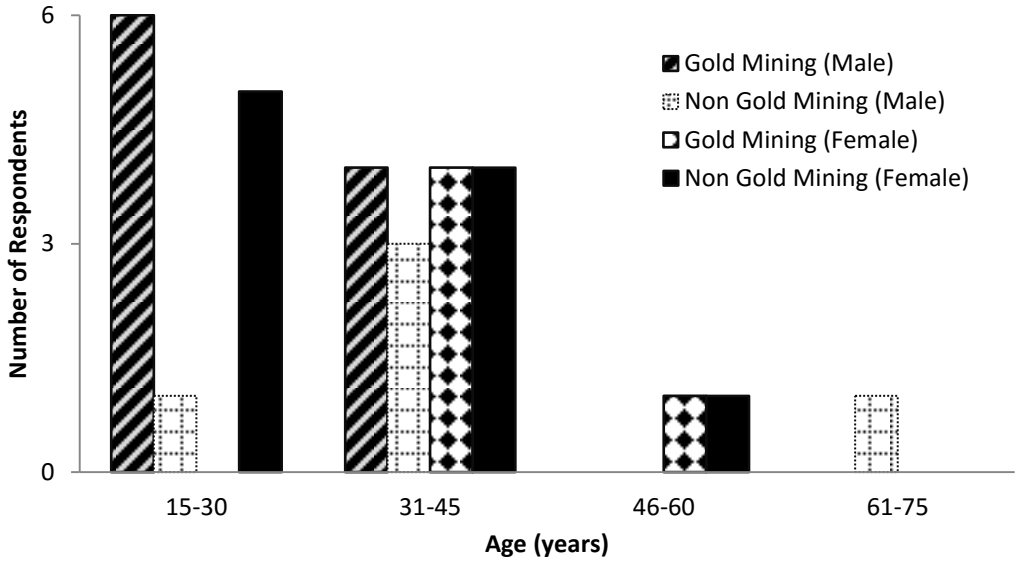


Figure 3.2. Classification of respondents

Chronic toxicity is determined as long term toxicity of contaminant (mercury) in the human body in small and repeated doses. When mercury enters, it accumulates in the human body (Akagi & Akira, 2000; Johansen, et al., 2007). The study of hair samples of the affected people in a particular location is performed to establish the health quality rate of the people (Takagi, et al., 1986). Human hair is also often used as a biomarker for methylmercury exposure because it reflects the concentration in the blood at the same time (Ministry of Environment, 2004). The health quality rate of a group of people is determined by their activities. A decrease in health quality may be caused by an exposition of a pollutant as residuals or disposals from these activities.

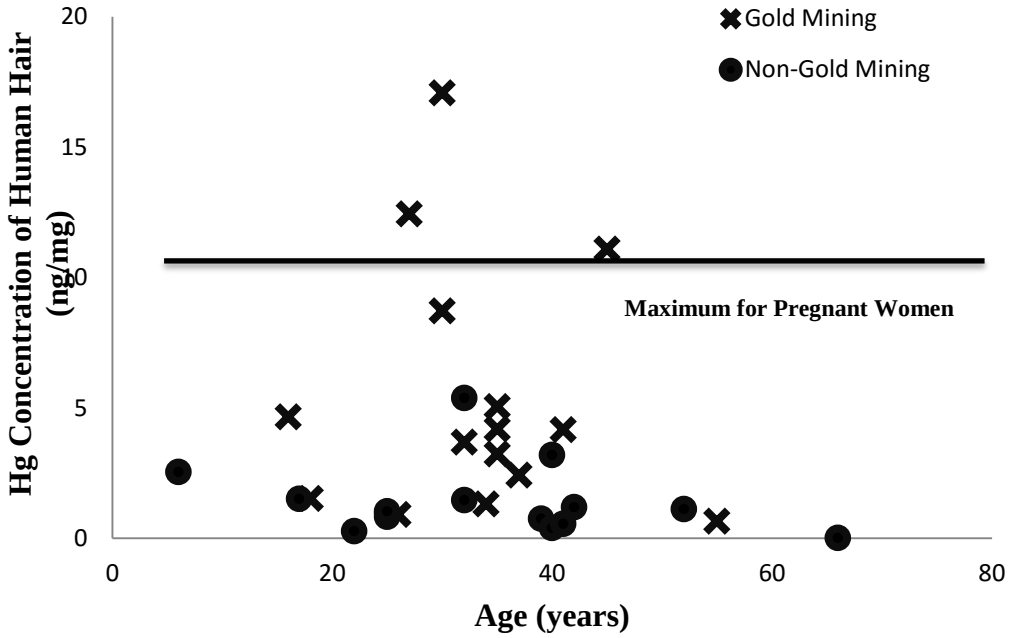


Figure 3.3. Total mercury concentration of human hair as chronic toxicity indicator

The cross markers in Figure 3.3 explain the laboratory analysis of hair samples from the respondents who lived at the mining site. The average mercury concentration of the respondents was 5.40 ng/mg. The highest concentration was 17.07 ng/mg, found in sample nine with the following characteristics: 30 years old, male. Meanwhile, the lowest mercury concentration was 0.65 ng/mg in respondent 12 with the following characteristics: 55 years old, male (Figure 3.3). The highest and the average concentrations did not provide explanation for a situation where the respondents experienced significant symptoms such as headache, amnesia, and other neural disorders.

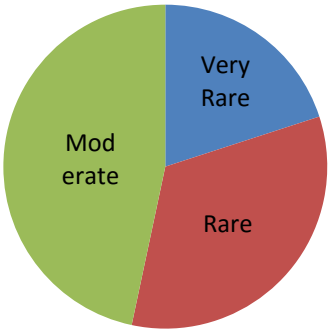
The results of the laboratory testing of hair samples obtained from Cihonje can be compared with the results of a similar test in the non-gold mining area.

Dots in Figure 3.3 illustrate that the average mercury concentration in the hair of the respondents from the non-gold mining area was 1.43 ng/mg—i.e. 3.97 ng/mg less than the mercury content of those living in the gold mining area (5.40 ng/mg). The range of mercury concentration in human hair for the non-gold mining area was 0.01 ng/mg – 5.38 ng/mg. It was significantly different from the gold mining area, 0.90 ng/mg – 17.07 ng/mg.

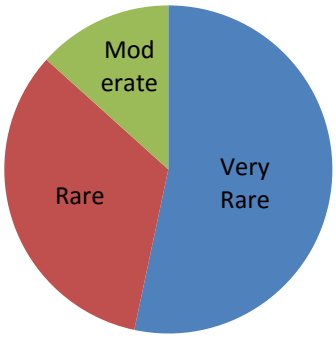
The effects of mercury metals are difficult to detect directly. So, a further examination is necessary. Other supporting instruments are also important, such as interviews for the health questionnaire (see Figure 3.4) with people living near the mining area. In this case, the health symptoms reported by the locals were recorded. The symptoms were assumed to be the effect of the mercury concentration in the body as an acute toxicity indicator, even though, in practice, the sensitivity

rate and adaptation level of the affected people had significant effects.

Gold Mining Area

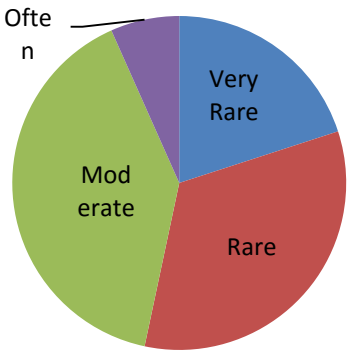


Non-gold Mining Area

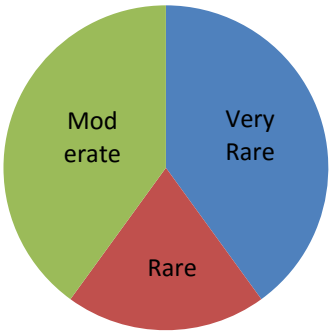


a. Nausea and Vomiting

Gold Mining Area

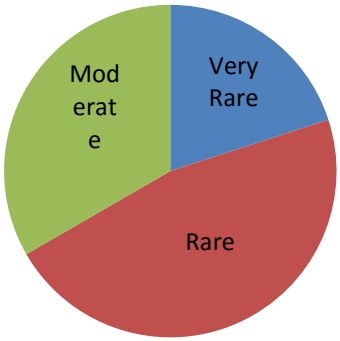


Non-gold Mining Area

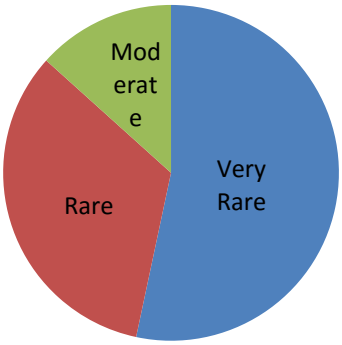


b. Stomach ache and diarrhoea

Gold Mining Area

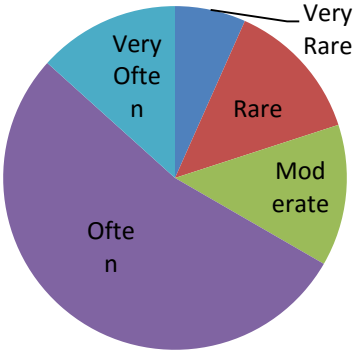


Non-gold Mining Area

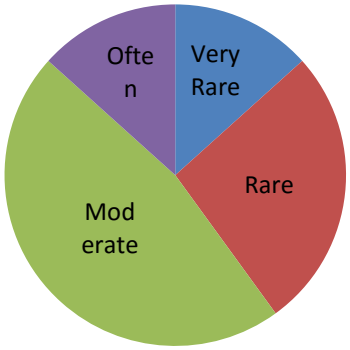


c. Pain in The Lips and Tongue

Gold Mining Area

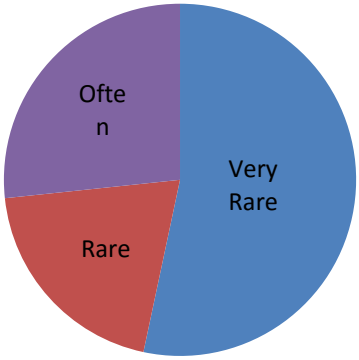


Non-gold Mining Area

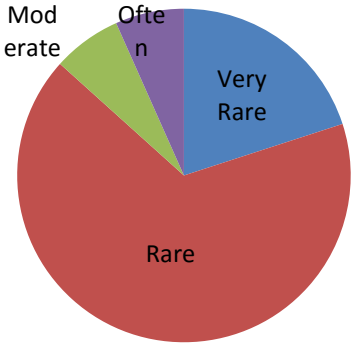


d. Pain in The Ankle and Hands

Gold Mining Area

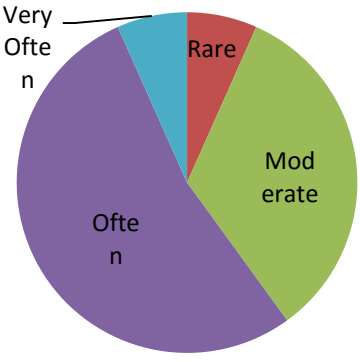


Non-gold Mining Area

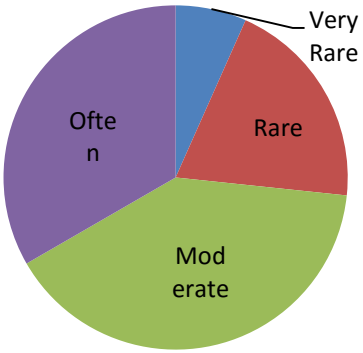


e. Insomnia

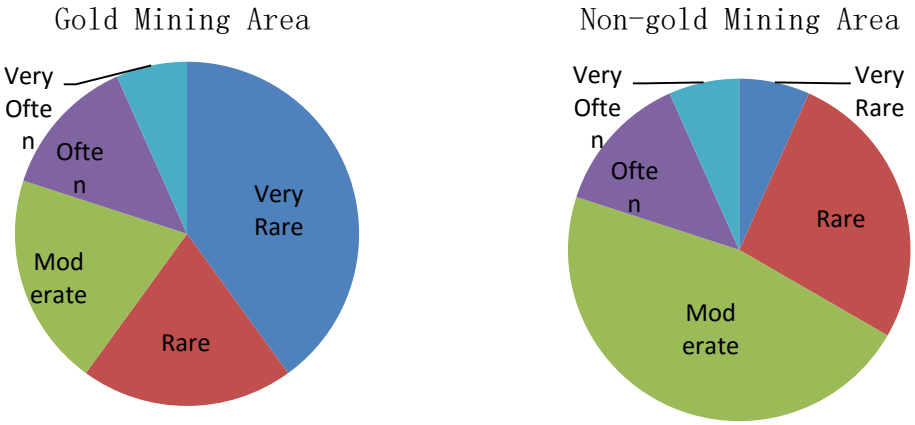
Gold Mining Area



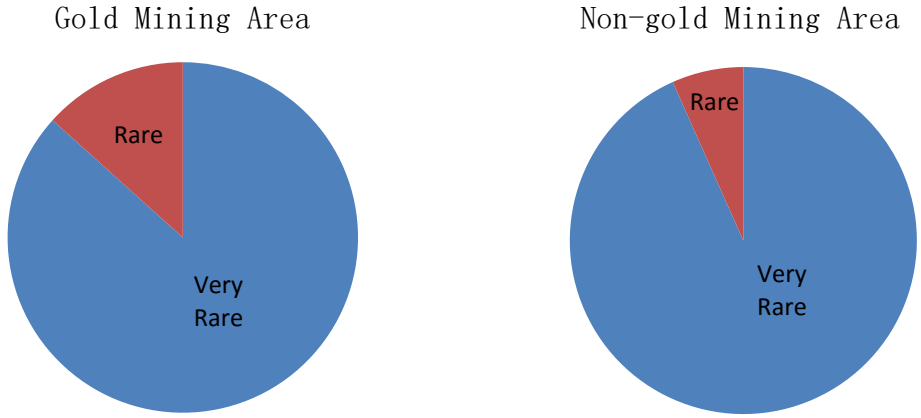
Non-gold Mining Area



f. Headache



g. Breathing difficulty



h. Red Spots on Skin

Figure 3.4. The frequency of health symptoms as mercury effect

According to the Arctic Water Resource Vulnerability Index (AWRVI) with a scale between one and five (Alessa, et al., 2008), the frequency of health symptoms were more often found in the respondents who lived near the Cihonje gold mining area. As the case is very rare = *1,* where the symptoms happen zero-one times in a week; rare = *2,* happen two-three times in a week; moderate = *3,* possibly three-four times a week; often = *4,* occurred six-seven times a week and very often = *5,* occurred more than seven times a week, for the 15 respondents in each area. Figure

3.5 consists of a calculation analysis from the health symptoms of the affected people as recorded from the interviews.

The result shows that health symptoms, such as pain in the motor organs, headache, and breathing difficulty, occur often. Insomnia, stomach ache, and diarrhoea were also typical disorders suffered by respondents living near the gold mining area. But, for skin inflammation on skin and swelling were not found in both areas.

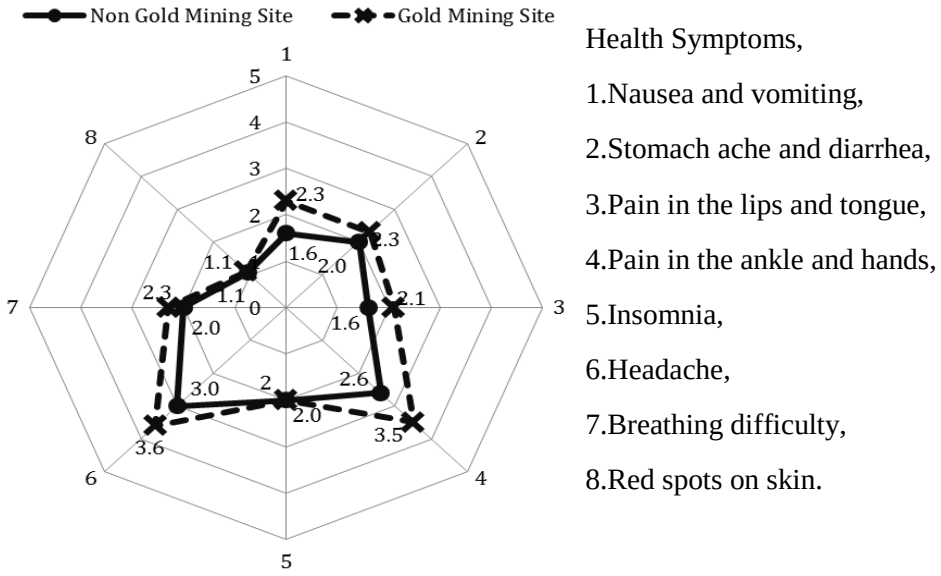


Figure 3.5. Health symptoms frequency of respondents as acute toxicity indicator

Figure 3.5 illustrates also the analysis of frequency using AWRVI for the non-gold mining area. Comparing the health symptoms between the respondents near the gold mining area and the non-gold mining area, it can be concluded that ASGM activities had a large impact on the mercury content present in the human body. In other words, the health vulnerability of the affected people towards mercury toxicity was high. This is because the people of Cihonje consumed water from the Tajum

river for fulfilling their daily needs, such as irrigation, bathing, and washing. The transmission of mercury into the body occurred through indirect contact.

3.5 Summary

This chapter analysed water quality and people's vulnerability due to ASGM using mercury in Cihonje and resulted in the following conclusions:

a. Water quality at the Tajum river, which is the main supplier for the daily needs of the local people, was still adequate but had the potential to be contaminated by mercury from the gold mining activities. The study reported that the mercury concentration in this area was 0.685 ng/ml, thereby exceeding the WHO's quality threshold standards.
b. People's vulnerability related to the water quality of the Tajum river could be studied using four different indicators: exposure degree, contamination rate and toxicity indicators which were divided into chronic and acute toxicity. According to the indicators of contamination rate, exposure degree, and chronic toxicity, the people affected by gold mining activities in Cihonje were considered highly vulnerable. All of these three indicators exceeded the mercury quality threshold. However, the result of the fourth indicator, acute toxicity, showed that it was limited for the respondents from Cihonje who participated in the research study.

Moreover, based on the total mercury concentration in three indicators; exposure degree, contamination rate, toxicity—i.e.chronic toxicity indicator and the analysis of health symptoms in acute toxicity indicator, the community in the gold mining

area is more vulnerable to effects from mercury than the community in the non-gold mining area.

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Chapter IV

Assessing a mercury affected area from small-scale gold mining in Poboya, Central Sulawesi, Indonesia

4.1 Introduction

Mercury from atmosphere is perennial and is more easily absorbed in the soil than into an aquatic environment and a high concentration of mercury in the soil, exceeding the ability of the soil to eliminate mercury, causes soil pollution (Xu, et al., 2015). Moreover, an excess concentration in the soil transfers to surrounding environmental media (Ministry of Environment, 2004), such as plants. It is also possible that mercury can robustly transmit to plants through absorption by the plant's breathing apparatus (Liu, et al., 2014; Santos-Francés, et al., 2011; García-Sánchez, et al., 2009; Lodenius, et al., 2003).

It has been reported that 70 tons of mercury is released into the environment annually (Sharma, 2007). Even more, another source reported that 100-150 tons of mercury is discharged per year (Veiga, et al., 2006; Veiga, 2003). The spread of mercury released into the atmosphere also causes contamination of surrounding areas besides the initial area (Cairns, et al., 2011). Huckabee et al. (1983) in (Boening, 2000) reported that a high mercury concentration—i.e. 0.2 mg/kg was found in vegetation up to 25 km from a mining area in Spain. Based on the researches, Palu was assumed as a contaminated area due to gold mining activities in Poboya, Central Sulawesi, Indonesia, where the

distance of Palu and Poboya is about 11 km. Therefore, the main objective of this chapter is to assess the affected area from the edge of a gold mining area (Poboya) to the center of the city (Palu) of mercury contamination by small-scale gold mining using soil and plant.

4.2 Mercury Exposure in Soil

Soil is one of the media used to monitor the concentration of mercury in the environment. Mercury in the atmosphere from amalgamation burning deposits in the top layer of soil. Top soil was used to analyze the total mercury in this research and total mercury in soil decreased from the top layer to the bottom layer vertically (Santos-Francés, et al., 2011).

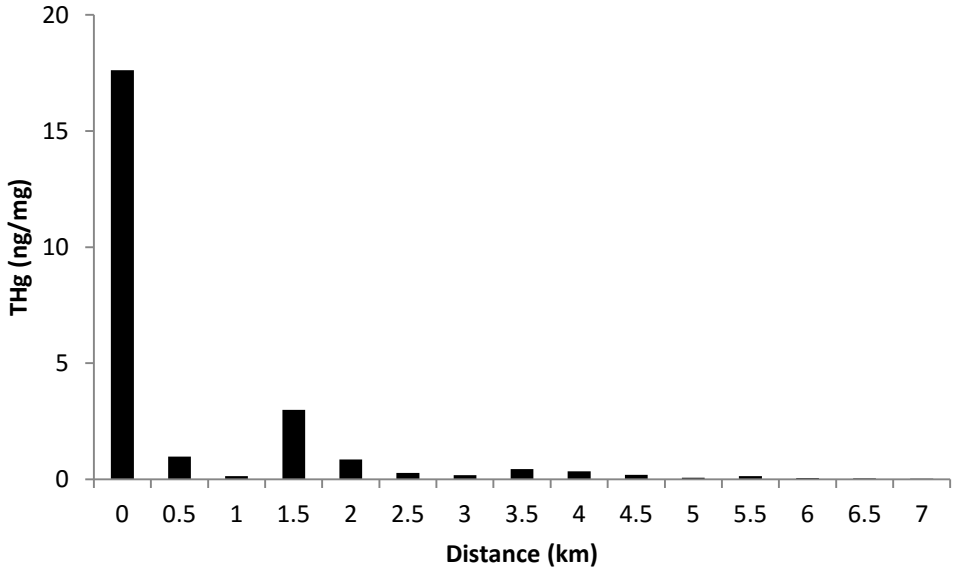


Figure 4.1. Total mercury concentration in soil

The results show in Figure 4.1 that the total mercury in soil had a range from 0.04 – 17.62 ng/mg within 7-0 km distance to the mercury source (edge of the gold mining area). The highest concentration of mercury was at the edge of the gold mining area—i.e. 17.62 ng/mg. It

was higher than 0.2 ng/mg, which is the level in general mercurial soil in Japan (Ministry of Environment, 2004). Within 4.5-7 km, all of the concentrations became less than 0.2 ng/mg. The mercury concentrations were 1 ng/mg and 3 ng/mg for 0.5 km and 1.5 km, respectively, from the source, which was the second highest place. After 1 km, it decreased to 0.1 ng/mg. However, mercury concentration in Poboya's soils is above the mercury concentration in Brazil, which was in the range of 0.05-0.21 ng/mg (Roulet, et al., 1998).

Generally, the total mercury concentrations decrease as the distance to the gold mining area increases. A similar trend is also reported in Chongqing City, China, where soil mercury contents in the range of 0.0064-0.881 ng/mg at a distance of 0 up to 4 km from the gold mining area (Wang, et al., 2003).

Related to this maximum standard of total mercury in soil, and the total mercury concentration in the research area, we can assess the pollution index (Pi), where the concentration of total mercury in soil is divided by the respective total mercury standards set in Japan (0.2 ng/mg) (Esterhuizen, et al., 2012; Wang, et al., 2011). The results categorize into five pollution levels:

$Pi \leq 0.7 = excellent$

$0.7 \leq Pi \leq 1.0 = safe$

$1.0 \leq Pi \leq 2.0 = lightly\ polluted$

$2.0 \leq Pi \leq 3.0 = pollution$

$Pi \geq 3.0 = heavily\ polluted$

(Fu & Ma, 2013)

Table 4.1. Pollution index of total mercury concentration in soil

Distance (km)	THg of soil (ng/mg)	Pi	*pollution level*
0	17.62	88.09	*heavily polluted*
0.5	0.98	4.92	*heavily polluted*
1	0.14	0.69	*excellent*
1.5	2.99	14.95	*heavily polluted*
2	0.85	4.27	*heavily polluted*
2.5	0.27	1.36	*lightly polluted*
3	0.18	0.88	*safe*
3.5	0.44	2.21	*pollution*
4	0.34	1.71	*lightly polluted*
4.5	0.19	0.97	*safe*
5	0.07	0.37	*excellent*
5.5	0.14	0.68	*excellent*
6	0.06	0.30	*excellent*
6.5	0.05	0.24	*excellent*
7	0.03	0.17	*excellent*

The result (see Table 4.1) reflected that the most affected area of mercury is at 0 up to 4 km, where the pollution index showed heavy pollution levels for those distances. It verified the previous research, in that the high concentration of Hg(0) in atmosphere for a distance of less than 5 km away from Poboya, ranged from 2096 to 3299 ng/m^{-3} (Nakazawa, et al., 2016). The total mercury concentration for 0 up to 4 km away from Poboya also indicated a higher soil mercury concentration than normal—i.e., 0.01-0.03 ng/mg (Terán-Mita, et al.,

2013; Senesi, et al., 1999). Figure 4.2 shows that the highest total carbon was found at a distance of 3.5 km from the gold mining area (Poboya) and the highest total nitrogen was at a distance of 5.5 km from Poboya. The lowest carbon and nitrogen levels were found at the gold mining area (Poboya), with a rate of 0.8 and 0.05, respectively.

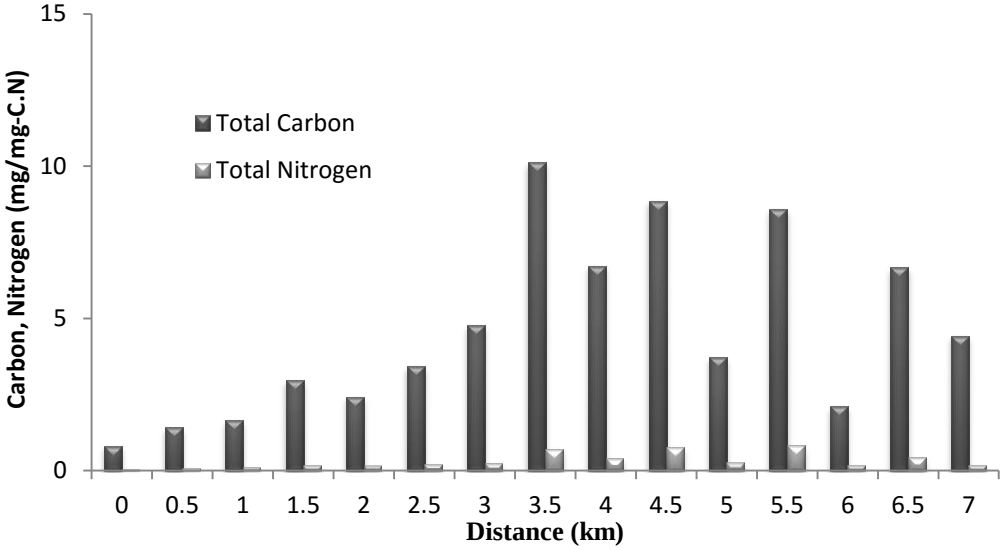


Figure 4.2. Total Carbon & Nitrogen in soil

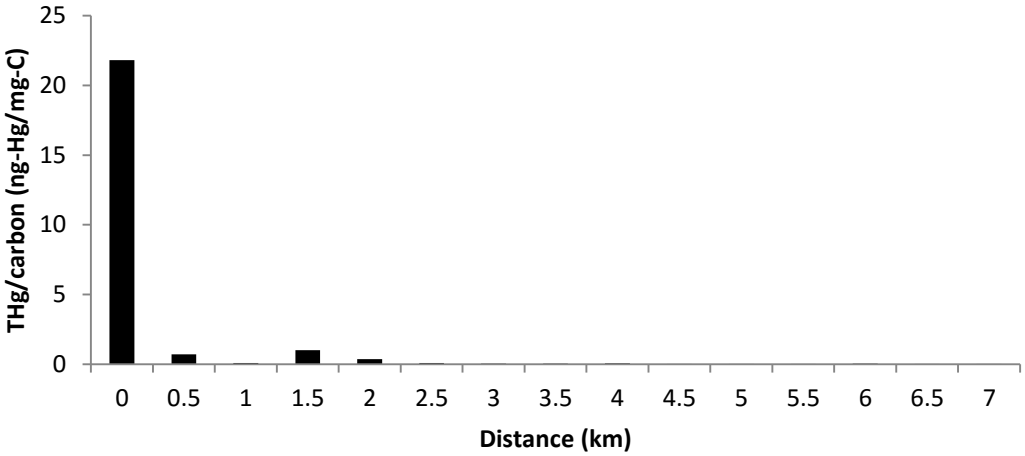


Figure 4.3(a). Total mercury per carbon in soil for 0-7 km

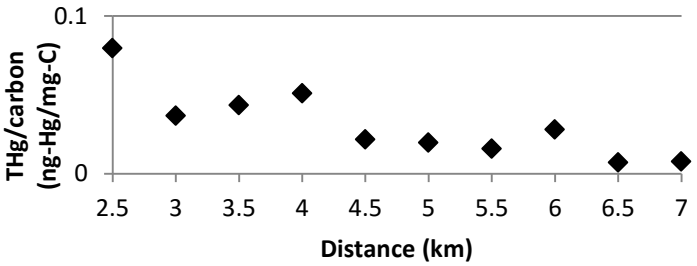


Figure. 4.3(b). Total mercury per carbon in soil for 2.5-7 km

Organic matters can be an influencing factor in the distribution of mercury in soil (Wu, et al., 2013). The Figure 4.3 describes the total mercury concentration in soil per carbon. It shows that high mercurial soil contained low carbon levelsin. The highest rate was found at the first point having 21.8 ng-Hg/mg-C and decreasing up to 1.5 km from the edge of the gold mining area. A further 2.5 km away, the total mercury per carbon in soil was shown to be gradually decreasing with an average of 0.03 ng-Hg/mg-C. This was in the range of 0.007-0.08 ng-Hg/mg-C. However, in this case the organic matters did not correlated with the concentration of Hg in soil. This result was verified by an obtained result in Gõta River, Sweden, where r=0.4 was identified between the organic matter and total Hg (Chen, et al., 2015; Xu, et al., 2014). It is dependent on the quality of soil, such as the binding strength of Hg and pH, rather than the organic matters contained in soil (Xu, et al., 2014; Nordic Council of Ministers, 1992; New Jersey Department of Environmental Protection and Energy, 1995).

4.3 Mercury Exposure in Plant

Plant is one of the commonly used bio-indicators to enable monitoring in the level of mercury present in the environment (Lodenius, 2013) and reports of Rasmussen et al. (1991) showed that the leaf contains the highest mercury concentration in vegetative structures. *Calotropis gigantea* was used as the plant sample to discover the total

mercury concentration in Palu. As expected, plant samples in Palu also followed a similar trend to that of the soil samples.

Figure 4.4 illustrates that mercury concentration in plant was in a range of 0.05 – 6.5 ng/mg at 0 up to 7 km. As a comparison, mercurial plant data in Northwestern Ontario shows a similar range 0.035-0.0512 ng/mg in 16 plant species (Mailman & Bodaly, 2005). Additionally, in the Usagre village, Almadén mining area and Idrija, the total mercury concentration is in the ranges of 0.057-37.6 ng/mg in 22 plant species (García-Sánchez, et al., 2009), 0.45-43.7 ng/mg in 26 plant species (Millán, et al., 2006), and 0.21-51.8 ng/mg (García-Sánchez, et al., 2009) respectively, which are almost higher than the mercury concentration in Palu. Nevertheless, all those data described a similar tendency with regard to distance and the mercury concentration in soil.

The data in Fig. 4.4 clarified that the total mercury in soil was 2-9 times higher than the total mercury in plant. At the initial point (0 km) the total mercury in plant was 6.5 ng/mg while the total mercury in soil was twice that of mercury in plants.

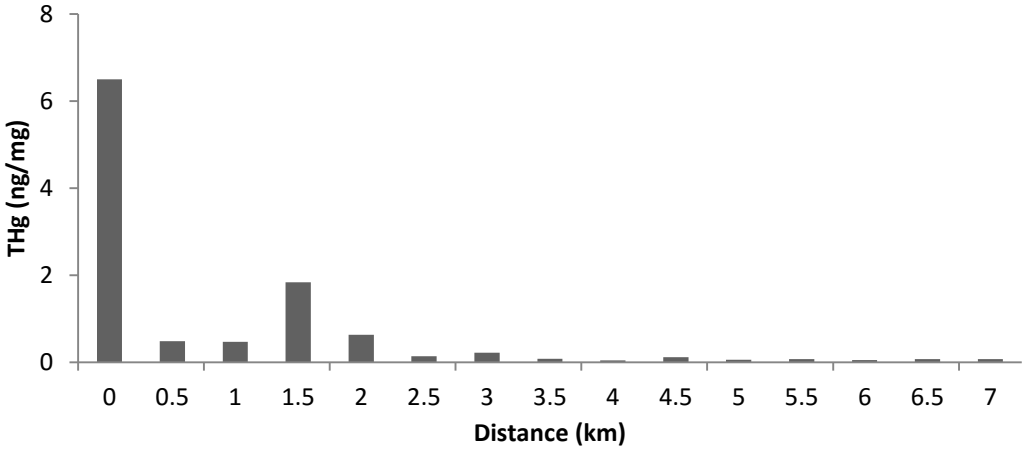
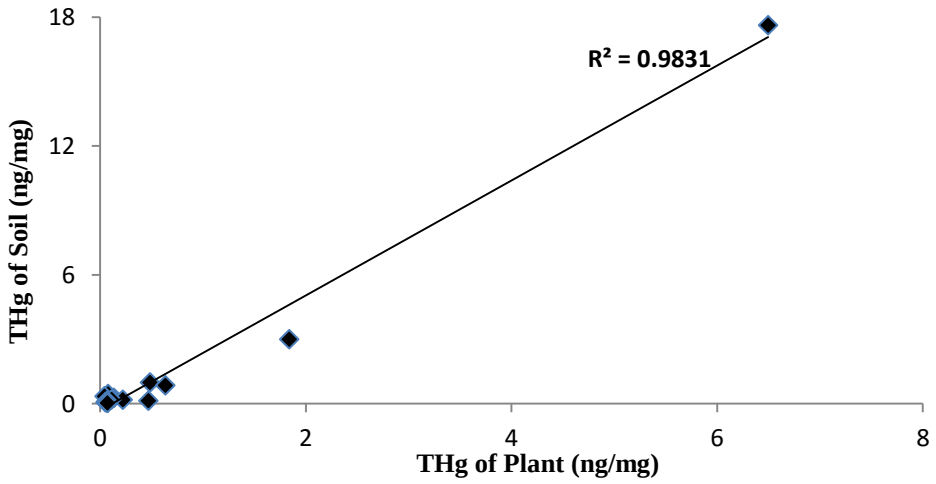


Figure 4.4. Total mercury concentration in plant

Based on statistical analysis, the total mercury concentration in soil has a strong correlation with total mercury concentration in plant, which is r = 0.98. When the mercury concentration in the soil decreases, mercurial concentration in plant gradually decreases as well. However, some data showed a reverse relation. For example, at a distance of 1 km from the source (gold mining area) the total mercury concentration in plant was three times higher than in soil, which was 0.47 ng/mg. This was caused by the mercurial atmosphere at these distances, less than 1 km from the edge of the gold mining area, that was extremely high according to an identification of mercury dispersion in Poboya, Palu (Isrun, 2014) and also *Calotropis gigantea* (plant sample) is one of the taller plants, therefore to volatilize from air through the leaves is more adequate than absorption from soil through roots (Patra & Sharma, 2000).

The transfer factor is a calculation to know the distribution of total mercury in soil to plant. The equation is a division of the total mercury in plant by the total mercury in soil (Mahmood & Malik, 2014). The value of the transfer factor is described in Figure 4.5.



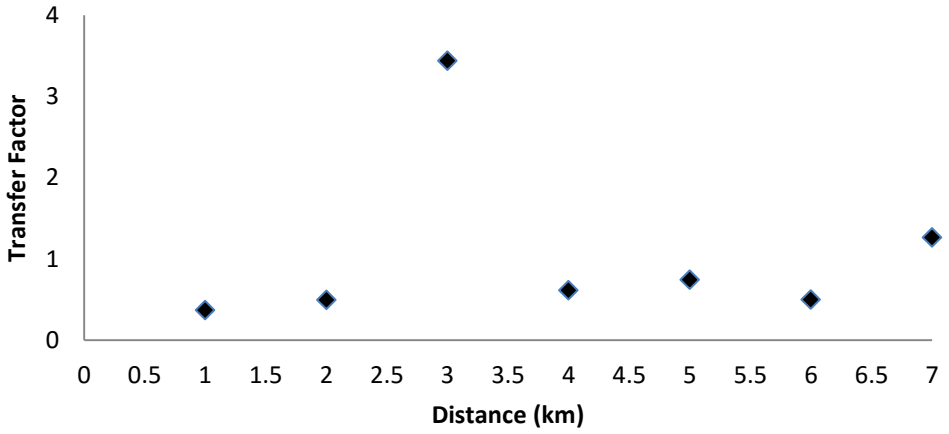


Figure 4.5. Transfer factor of THg in plant & soil

The result assumed that the total mercury in plant was influenced by atmospheric factors. The transfer factor showed in range of 0.13-3.44. Some studies reported that atmosphere is the most common mechanism for mercury absorption in plants (Patra & Sharma, 2000). Emitted mercury from amalgam burning is transmitted to the plant leaf via stomata or breathing apparatus (Liu, et al., 2014; Santos-Francés, et al., 2011; García-Sánchez, et al., 2009; Lodenius, et al., 2003). Kotnik et al. (2005) found that the high concentrations of mercury in vegetation in the River Idrija resulted from 35,000 tons of mercury being released into the environment due to smelting processes. Other evidences were found in several cases, such as plant-tissues in moss and Rye grass that had absorbed mercury from air intensely and stably during the observation day within 8 days (Lodenius, et al., 2003). De Temmerman (2009) used leafy vegetables in order to compare mercury concentration in atmosphere. It was reported that the determination coefficient of regression between total gaseous mercury concentration in ambient air and mercury concentration in vegetables was 0.73-0.95 mg/kg.

In another possible way, mercury in soil is released to the leaf via the root system and distributed to all parts of the plant, including

leaf mercury deposition (Patra & Sharma, 2000). However, the mercurial absorbance of the plant from soil through its roots is low. Some research showed that the mercury concentration in leaf was lower than soil. Zhang et al. (2010) reported 0.129-28.182 mg/kg and 0.001-2.673 mg/kg of mercury concentrations in soil and leaf, respectively. The highest mercury concentration in plant which accumulated in leaf is shown in data from the San Joaquín mining site, Mexico, which is 0.1-8.2 mg/kg (Martínez-Trinidad, et al., 2013). This phenomenon occurred with the total mercury absorption in plant at a distance of between 0-7 km from the edge of the gold mining area to Palu.

4.4 Summary

The pollution level in the research area was shown to be very high, because the total mercury concentration in soil was in the range of 0.04 – 17.62 ng/mg, which is 90 times higher than the commonly present soil in Japan. Based on soil samples, the mercurial affected area was within 4 km, because beyond 4 km the total mercury concentration was lower than 0.2 ng/mg. A similar result was also observed for the plant samples. The range of total mercury concentration was 0.05 – 6.5 ng/mg. The transfer factor illustrated that the ratio was in range of 0.13-3.44. It showed that the mercury in plant also depends on the total mercury in the atmosphere and not only that transmitted from the soil. Accordingly, soil samples and plants samples reflected a strong relationship between the total mercury concentration and the distance from its source.

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Chapter V

Food and hair analysis of mercury exposure levels in Poboya, Central Sulawesi, Indonesia

5.1 Introduction

Since 2009, Poboya has been the main center of small-scale gold mining in Central Sulawesi, Indonesia (Albasar, et al., 2013). Poboya covers a total of 7000 ha and has a miner workforce of approximately 35,000 (Ismawati, 2013). Each day, around 200 to 500 kg of mercury is released into the environment as a result of gold mining (Ismawati, 2013). More than 500 μg/g mercury has accumulated in the soil (Isrun, 2014). However, there is currently a lack of data on mercury concentrations in the local population even though under these high-risk conditions. Mercury is likely to be transmitted to people living in the surrounding area through long-term food exposure (Tran, et al., 2004).

Long-term (i.e. chronic) consumption of mercury-contaminated foods damages the nervous system (Bortey-Sam, et al., 2015), and regular consumption of contaminated food can lead to the accumulation of mercury in the body (Gbaruko & Friday, 2007).

Hence, our aims were to 1) determine weekly mercury intakes in the Poboya gold-mining area via various food consumption pathways; 2) examine total levels of mercury contamination of people in the surrounding area by analyzing hair samples; and 3) evaluate the overall

degree of mercury exposure by analyzing the combined data on food and human hair contamination

5.2 Food Consumption Pattern

By recording the food intake, which assesses the total weekly mercury intake in the human body, the mercury intake will depend on the frequency of foodstuff consumption.

Mercury intake depended on the frequency of consumption of each food. Figure 5.1 shows the total daily frequencies of consumption of each food, along with the daily maximum and minimum frequencies, as determined from the 7-day dietary interview with 20 respondents in Poboya and 20 in Palu. Presumably the results are not per person, but per group of 20.

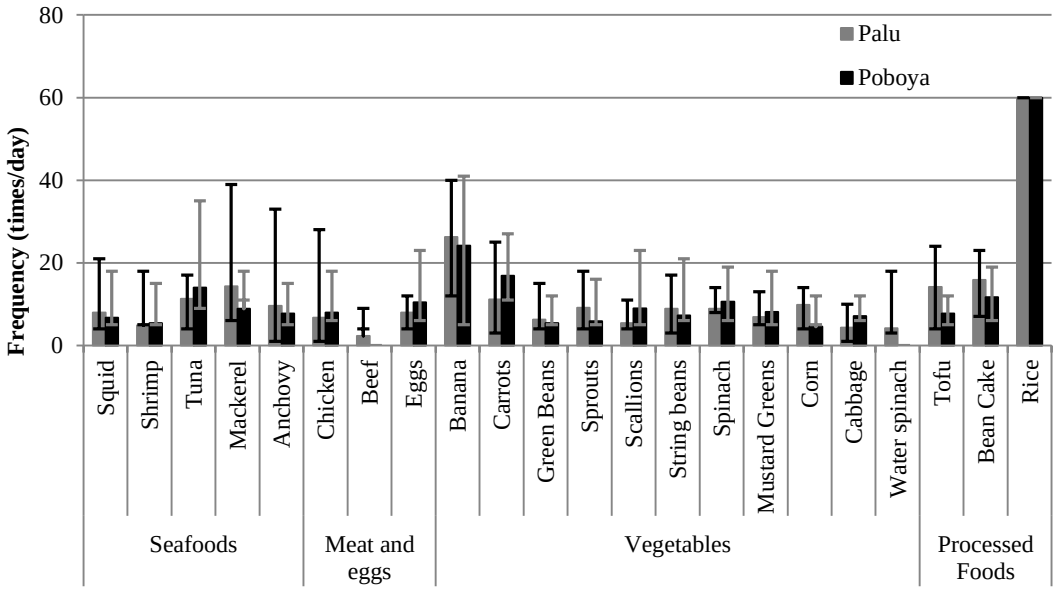

Figure 5.1. Daily intake frequencies of each food in Poboya and Palu (n = 20 per location)

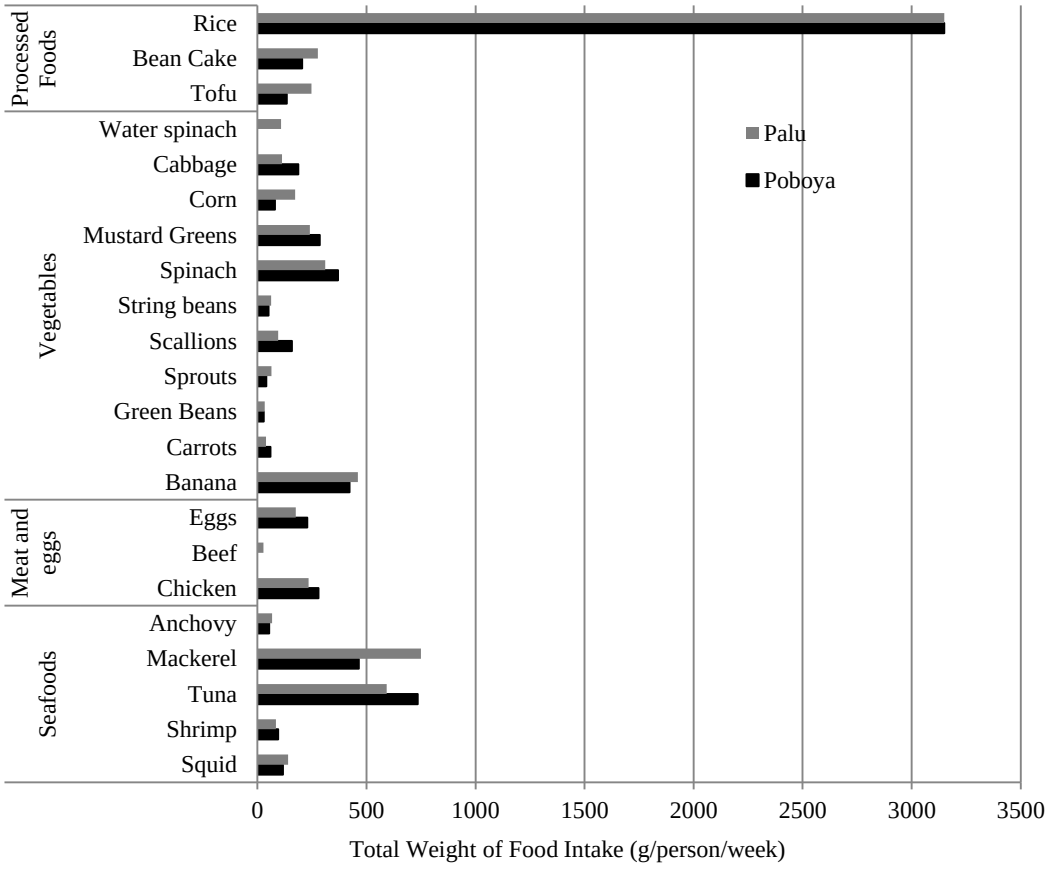

Figure 5.2. Average weight of food consumed each week (n = 20 per location)

Rice is the staple food in most areas of Indonesia, including in Poboya and Palu; at a per-person consumption rate of three times a day. It was the most frequently consumed food in both areas. In Poboya, banana was the second most frequently consumed food, with an average frequency of consumption of 24 times/day per 20 respondents: it was consumed at least once per day by each person. Beef and water spinach were not consumed in Poboya (see Fig. 5.1).

In Palu, banana was also the second most frequently consumed food, 460 g/person over 1 week (Fig. 5.2). It was consumed a maximum of 40 times/day per 20 respondents, with a minimum consumption frequency of

12 times/day. In the seafood group, mackerel was the most frequently consumed food, at about 14 times/day per 20 respondents. Beef was consumed at 2 times/day and water spinach at 4 times/day per 20 respondents.

Multiplying the average weekly frequency of consumption of each food by the average food weight per serving gave us the total weight of food consumed per person per week (Fig. 5.2). Of the vegetables, banana was consumed in the greatest weight per person in both areas. In Poboya, vegetable consumption ranged from 29 (green bean) to 423 (banana) g/person over 1 week. In Palu, vegetable consumption ranged from 33 (green bean) to 460 (banana) g/person over 1 week. In the case of the seafood group, Poboya respondents consumed from 54 (anchovy) to 735 (tuna) g/person weekly, whereas Palu respondents had slightly greater range consumption, from 67 (anchovy) to 750 (mackerel) g/person weekly.

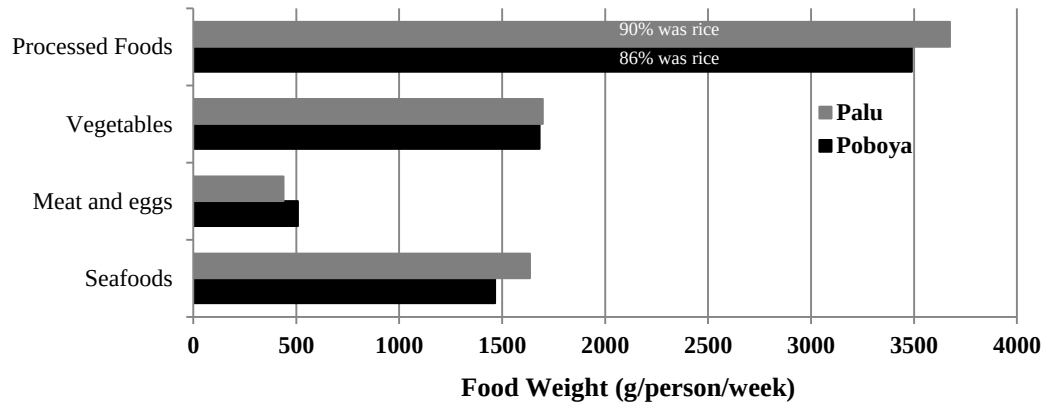

Figure 5.3. Average weights of consumption of foods in each group

The weekly food intake in Poboya was 1682 g/person of vegetables, 3490 g/person of processed foods, 1467 g/person of seafoods, and 508 g/person of meat and eggs (Fig. 5.3). In a similar pattern, the weekly food intake in Palu was 1697 g/person of vegetables, 3675 g/person of

processed foods, 1635 g/person of seafoods, and 438 g/person of meat or eggs. Therefore, the total weight of the weekly vegetable intake in the non-gold-mining area (Palu) was about 34 × 10^3 g per 20 respondents. Seafoods were consumed at a total of 33 × 10^3 g per 20 respondents in Palu—a value slightly higher (by 3.4 × 10^3 g) than in Poboya. Overall, however, the food consumption patterns in the two areas were similar.

5.3 Mercury Exposure in Foods

Figure 5.4 shows that the average for total mercury concentration

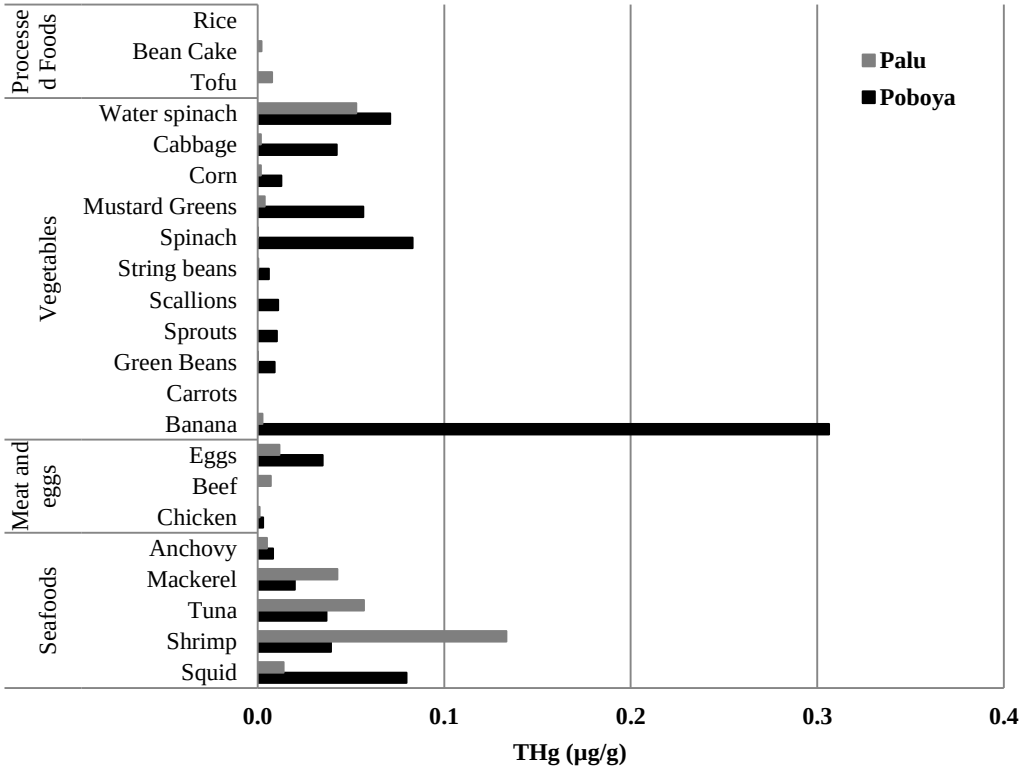

Figure 5.4. Average total mercury concentrations in foods (n = 3), by food and food group

The highest average THg concentration in foods in Palu was 0.13 μg/g (in shrimp), whereas the THg concentration in Poboya ranged from a low

of 0.003 (for chicken) to a high of 0.31 μg/g (for banana) (Fig. 5.4). The next highest values were for spinach in Poboya (0.08 μg/g) and tuna in Palu (0.06 μg/g). Mercury concentration was undetectable in some foods, such as rice and carrot. Overall, the food mercury concentration in Poboya was higher than that in Palu. The lower levels of total mercury in both sample areas were found in bean cake, tofu, corn, string beans, scallions, sprouts, green beans, beef, chicken and anchovy, which were detected as the safely consumed foods. In comparison, in another research area (Sindh, in Pakistan), the highest THg levels in foods ranged from 0.003 to 0.01 μg/g, although these values were still below the standard 0.03 μg/g, as set by the WHO (Ali & Al-Qahtani, 2012; Abbas, et al., 2010).

Some types of food, such as rice, can be useful indicators for risk assessment (Guédron, et al., 2014). According to the Chinese National Standard Agency, the maximum THg level in crops (rice) should be 0.02 μg/g (Wang, et al., 2011); we found that the highest rice mercury level was in the Palu area, but it was still lower than this standard (0.007 μg/g). Rice in Poboya and Palu was as acceptable as rice grown in Vientiane, where levels of 0.006 to 0.007 μg/g of THg have been recorded (Guédron, et al., 2014). The mean THg concentration in vegetables in the mining area of Wanshan, China, has been measured at 0.034 μg/g (Wang, et al., 2011).

Similar pathways were discovered in Palu and Poboya, where, apart from rice, the vegetable group was the most frequently consumed. In Palu, the THg level in vegetables was less than 0.004 μg/g. However, levels at Poboya were markedly higher (0.006 to 0.31 μg/g), and the average THg concentration in the vegetable group in Poboya was 48 times that in Palu. The concentration of THg in the vegetable group at Poboya thus exceeded the 0.01 μg/g specified by the Chinese food hygiene standard

(Wang, et al., 2011). On the basis of a comparison of THg levels (as a pollution index) in foods and the standard set by WHO (0.03 μg/g), some foods in Poboya (squid, shrimp, tuna, anchovy, egg, mustard green, and cabbage) were categorized as being lightly polluted, whereas heavy pollution was present in banana. In Palu, the lightly polluted foods were tuna, mackerel, and egg, and the heavily polluted food was shrimp.

5.4 Total Mercury Intake

Multiplying the THg concentration (μg/g) in food by the weekly food consumption (g) each food per person in Poboya and Palu (Guédron, et al., 2014; Horvat, et al., 2003)yielded the total weekly intake of mercury (Guédron, et al., 2014; Mahmood & Malik, 2014; Zhang, et al., 2009; Santos-Francés, et al., 2011). Figure 5.5 shows the weekly intakes of mercury per person based on the 7-day dietary food interview across the 22 foods and four food groups.

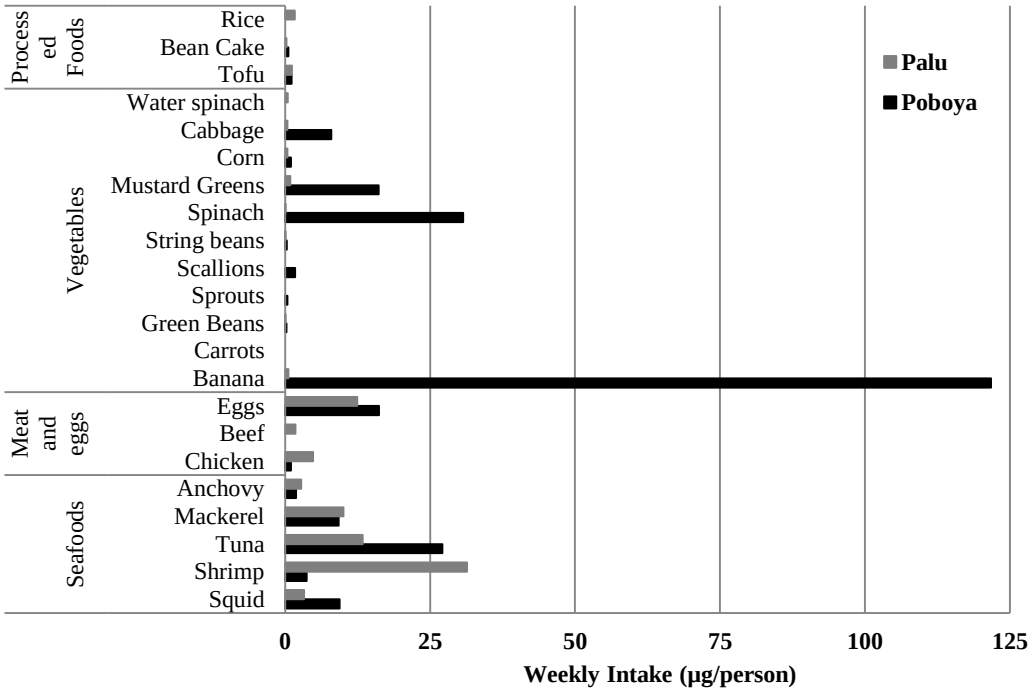

Figure 5.5. Estimated weekly intakes of mercury (n = 3), by food and food group

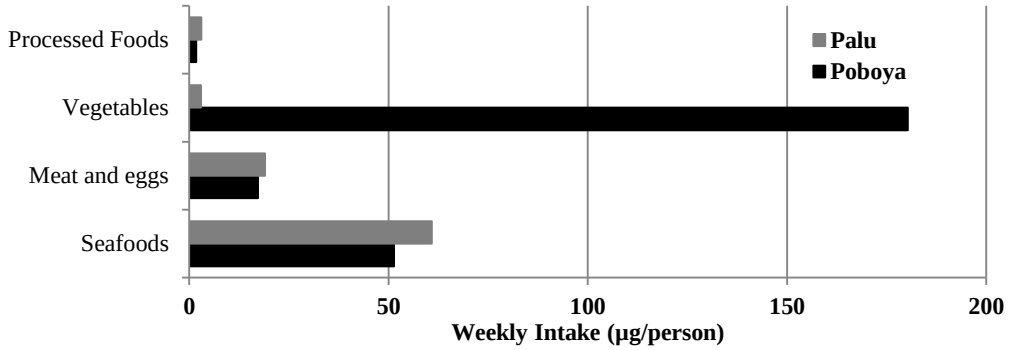

Figure 5.6. Estimated mercury weekly intakes, by food group

The estimated weekly THg intake in foods in Poboya ranged from 0.3 to 121.7 μg/person (Fig. 5.5). The three highest weekly THg intakes in the vegetable group were in banana (weekly intake 121.7 μg person), then spinach (31 μg/person), then mustard greens (16 μg/person). THg intake in egg was similar to that in mustard greens. In the seafood group, tuna gave the highest weekly THg intake (27 μg/person). This was followed by squid and mackerel (9 μg/person).

Palu gave different results. The weekly THg intake ranged from 0.01 to 31.4 μg/person. The highest weekly THg intake was in shrimp, in the seafood group, at 31.4 μg/person. Tuna intake in Palu gave 13.4 μg/person weekly, whereas egg gave 12.4 μg/person. The vegetable group in Palu gave low weekly THg intakes (less than 1 μg/person for each food, with only 0.6 μg/person for banana).

For the vegetable group, the Poboya area had a much higher mercury intake than Palu area (Fig. 5.6). The weekly THg intake from the vegetable group in Poboya reached 180.3 μg/person, whereas in Palu it was only 2.9 μg/person. This difference was likely because the vegetable group in Poboya consisted of local products (such as banana) that were contaminated by mercury from gold mining. For the meat and

egg group, the weekly mercury intake in Poboya was 17.2 μg/person, and in Palu it was similar at 19 μg/person. The data on mercury intake from seafoods revealed different pathways: the weekly intake in Palu was 60.8 μg/person, which was about 16% higher than that in Poboya (51.4 μg/person). The most dangerous mercury impacted to human health was methylmercury, where consumed seafood contains methylmercury at 93% to 95% of the THg (Tang, et al., 2015; Agah, et al., 2006). However, most of the seafood products sold in both the sampled markets did not come from the Poboya or Palu area. They were distributed from other cities where there was no contamination from the Poboya gold mining. The data on mercury intake in the processed foods were similar to those for the seafood group. The THg intake in Palu was substantially higher than that in Poboya although the levels in processed foods in both areas were much lower than the levels in seafoods. In Palu, the THg intake from processed foods was 3.1 μg/person, whereas in Poboya it was only 1.7 μg/person. However, the processed food group, including rice, contained 45% to 47% methylmercury as a percentage of THg (Tang, et al., 2015; Horvat, et al., 2003).

Generally, the vegetable group was the main mercury dietary pathway contaminating people in Poboya, whereas the seafood group was the main pathway in Palu (Fig. 5.6). Similarly, in Wanshan, China, the main source of potentially harmful mercury was the vegetable group, from which the weekly intake reached 160 μg/kg body weight (Wang, et al., 2011). This amount is higher than the weekly THg intake in European Union member states (SCOOP, 2004).

In relation to the maximum standards of THg and the total estimated weekly intakes in Poboya and Palu, we can calculate a relative pollution index, whereby the weekly THg intake is divided by a tolerable weekly intake standard (Fu & Ma, 2013; Esterhuizen, et al.,

2012; Wang, et al., 2011). The total weekly intake in Poboya (250.6 μg/person) was three times that in Palu (79.3 μg/person). By using the Scientific Cooperation (SCOOP, 2004)data, we determined the tolerable weekly THg intake to be 350 μg/person. The resulting calculated pollution index was 0.7 in Poboya and 0.2 in Palu.

For international guidance, the (WHO, 2007) estimated the weekly tolerable THg intake at 840 μg/person. The pollution indexes based on the WHO estimate were low in both areas, at 0.3 for Poboya and 0.1 for Palu. Another standard, which has been issued by the Ministry of Environment, Japan, prescribes a tolerable weekly THg intake of 111 μg/person (Ministry of Environment, 2014). This gives higher pollution indexes: dividing the total weekly intakes in the two towns by the Japanese standard gives pollution indexes of 2.3 in Poboya and 0.7 in Palu (Table 5.1).

Table 5.1. Pollution indexes of total mercury intake, as calculated by using different standards

	Weekly intake (μg/person)	Standard		
		SCOOP 2004 (350 μg/person/week)	WHO 2007 (840 μg/person/week)	Japan 2014 (111 μg/person/week)
		Pollution index		
Poboya	250.6	0.7	0.3	**2.3**
Palu	79.3	0.2	0.1	0.7

According to the SCOOP standard, Poboya and Palu were categorized as having safely consumable foods, because the mercury intakes in both areas were below the SCOOP standard and the pollution indexes were less

than 1. Similarly, using the WHO guideline, foods in Poboya and Palu were safe to consume. In contrast, the pollution index calculated by using the most recent standard (Ministry of Environment, 2014) meant that Poboya had highly contaminated foods: the pollution index for mercury was 2.3—more than twice those under the previous standards. This means that people living in Poboya are at risk of mercury contamination from the foods they consume. However, Palu has a safe level of mercury intake in foods, because its pollution index was less than 1 and the intake was lower than the average for the Japanese people: in Tokyo during the years 2005 to 2010 the average weekly intake of THg ranged from 87 to 92 μg/person (Japanese Ministry of Environment, 2004).

Therefore, with their high pollution index, we can assume that the people living in Poboya have been contaminated by mercury through dietary consumption. Similarly, a recent study of the human health risks posed by mercury vapor in Palu and Poboya indicated that Poboya had a very high health risk from exposure to Hg. The hazard quotient ratio was 1206, and 93% of the population was at risk of mercury poisoning (Nakazawa, et al., 2016).

According to the Japanese Ministry of the Environment's 2004 manual, human hair levels of mercury can be used as an indicator of THg concentrations from the diet. Mercury is distributed in the body and settles in the hair. The human hair samples we tested were obtained from three families, with a total of 20 members, in Poboya. These three families had weekly THg intakes of 187.2 to 333.4 μg/family.

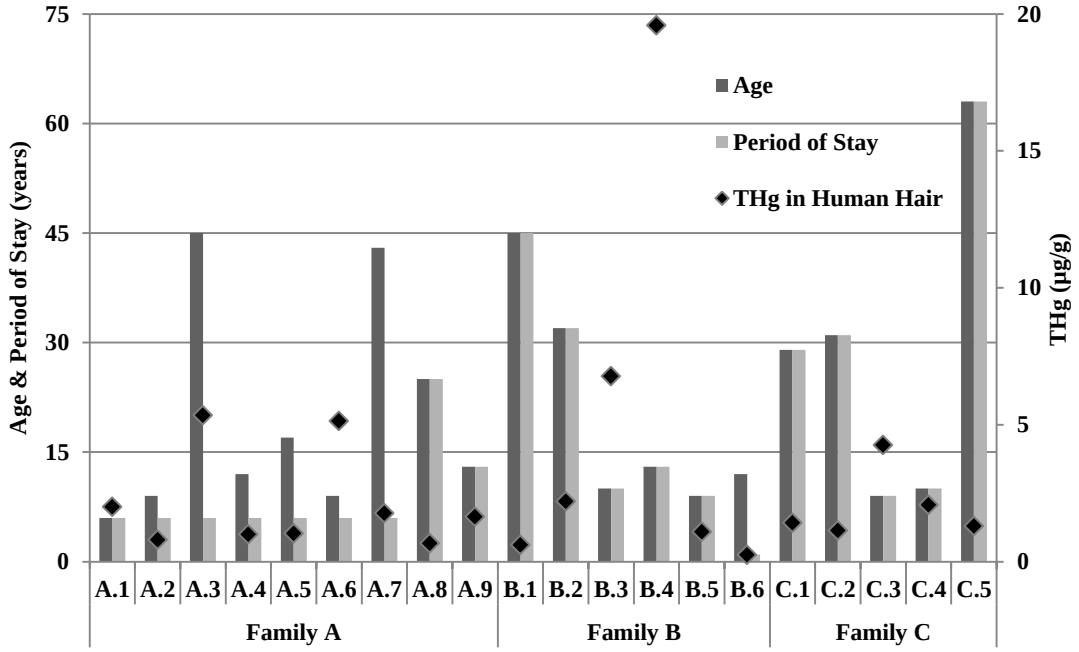

Figure 5.7. Total mercury levels in the hair of respondents (n = 20; Period of stay was length of time the respondents had been in the test area)

The average THg contents in hair from families A, B, and C were 3.95, 1.53, and 3.07 μg/g, respectively, and the overall range was 0.3 to 19.6 μg/g (Fig. 5.7). The highest mercury concentration in hair was 19.6 μg/g, in a member of family B who was male, aged 13 years, and had been in the area for 13 years. In family A, the highest hair mercury concentration was 5.4 μg/g, in a female aged 45 years who had been in the area for 6 years. In family C, a male aged 9 years old who had been in Poboya for 9 years had a hair THg level of 4.3 μg/g (Fig. 8). These results were higher than the range in human hair from Hainan Island (0.06 to 0.48 μg/g of THg) (Liu, et al., 2014). They are also higher than that prescribed by Human Bio-Monitoring (above 1 μg/g) (Bose-O'Reilly, et al., 2010). Both weekly intake and THg in hair therefore revealed high levels of mercury pollution in Poboya and safe levels in Palu.

5.5 Summary

Poboya is an area of high-level mercury exposure because of the local gold-mining activities. Some foods, such as banana (in the vegetable group), had high levels of mercury contamination. The THg in banana was measured at 0.31 μg/g, and banana was consumed weekly at 423 g/person. In total, each week the people of Poboya consumed 250.6 μg/person of THg in their food, consisting of 51.4 μg/person from the seafood group, 17.2 μg/person from the meat and eggs group, 180.3 μg/person from the vegetable group, and 1.7 μg/person from the processed foods group. The total amount was 2.3 times the Japanese standard, where the total mercury levels in hair, which ranged from 0.3 to 19.6 μg/g. Consumption of some foods should be avoided by the people of Poboya; they include squid, shrimp, tuna, eggs, spinach, mustard greens, cabbage, water spinach and (especially) banana.

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Chapter VI

Mercury contamination levels based on vulnerability indicator

6.1 Introduction

Based on result in the previous chapter,two representative areas, Cihonje and Poboya were indicated as the high potential of mercury contamination areas due to the gold mining activities in Indonesia. Data exceeded the mercury standards. This condition supposes to be vulnerable for the local people. It affects the human health condition. The exposure of mercury for long term causes several health symptoms, such as headache, nausea, and the others (Bose O'Reilly, et al., 2016).

It is so necessary to analyze mercury levels that contained in each vulnerability indicator, to measure the community vulnerability of the local people. By used the properly indicators, potential danger could be determined. Some mercury indicators were exposure degree indicator, contamination rate indicator, chronic and acute toxicity indicators.

This chapter is designed to review mercury contamination in Indonesia due to gold mining activities. It categorized into four indicators, where each indicator contained many types of sample. Since 2002, less than 20 published papers that concerned about mercury in Indonesia. Then, only 7 of 63 hotspots became the study areas. Therefore, the actual condition of mercury in Indonesia did not provide properly.

6.2 Exposure Degree Indicator

Exposure degree of mercury level into environment can be determined by wastewater and tailing waste from the mining processes. The high values of wastewater and tailing indicate the huge amount of mercury usage in the mining. Table 6.1 showed the mercury contamination levels in gold mining areas in Indonesia.

Table 6.1. Mercury contamination levels in exposure degree indicator

Indicator	Location	Mercury Concentration
Wastewater	Cihonje, Central Java	19.7 – 37.3×10^3 ng/ml (Sari, et al., 2016)
Tailing waste	Bogor, West Java	87.16 – 90.69 ng/mg (Tomiyasu, et al., 2013)

In mining site, Bogor, tailing waste observed 380 ng/mg of total mercury, and decreased gradually along the distance. The highly contaminated tailing waste discharged in range of 87.16 – 90.69 ng/mg, with average of 89.28 ng/mg (Tomiyasu, et al., 2013). In another mining site of Indonesia, total mercury in wastewater illustrated in range of 19.7 – 37.3 × 10^3 ng/ml (Sari, et al., 2016). This highest contaminated wastewater was transported to the river. Based on the Indonesian regulation that maximum of mercury concentration in mining waste is 0.005 ppm.

Data showed that the exposure degree indicator ranging between 4 and 7460-fold higher than Decree of Indonesian Environment Ministry, No. 202/2004 in Central Java and range between 174 to 182 times in West Java, respectively. However, the highly mercury concentration in exposure degree indicator released the high contamination of mercury in contamination rate indicator as the receptor of mercury discharge.

Therefore, based on exposure degree indicator signed that Indonesia was high vulnerable of mercury pollution from gold mining.

6.3 Contamination Rate Indicator

Contamination rate indicated the mercury levels in environment, such as soil, water, air, and plant. It receipted the mercury from gold mining process.

Table 6.2. Mercury contamination levels in contamination rate indicator

Sample	Location	THg	Reference
Soil	Bogor	0.11-73 ng/mg	(Tomiyasu, et al., 2013)
	Central Sulawesi	0.03-17.62 ng/mg	(Sari, et al., 2016)
Sediment	Bogor	0.093-85.2 ng/mg	(Tomiyasu, et al., 2013)
	North Sulawesi	<23 ng/mg	(Limbong, et al., 2003)
	Maluku	0.55-918 ng/mg	(Male, et al., 2013)
Water	North Sulawesi (Talawan)	<14 ng/ml	(Limbong, et al., 2003)
	North Sulawesi (Tatelu)	0.05-3.26 ng/ml	(Palapa & Maramis, 2015)
	Central Java	0.27 ng/ml	(Sari, et al., 2016)
Vapor	West Java	5.6-1800 ng/m^3	(Kono, et al., 2012)
	Central Sulawesi	2096-12782 ng/m^3	(Nakazawa, et al., 2016)
Plant	Banten	0.07-1.19 ng/mg	(Bose O'Reilly, et al., 2016)
	West Java	0.07-5.4 ng/mg	(Kono, et al., 2012)
	Central Sulawesi	0.05-6.5 ng/mg	(Sari, et al., 2016)

Table 6.2 summarized the mercury contamination in environment. The analysis had been done in six gold mining areas in Indonesia. Due to Table 6.2, North Sulawesi was contaminated by mercury due to gold mining activities. Mercury in sediment was 15 times higher than Ministry of Environment in Japan's guideline-i.e 0.2 ng/mg.Another data of water showed that mercury reached 0.05 ng/ml to 14 ng/ml. Comparing with the US-EPA for freshwater quality in 0.012 ng/ml, water in North Sulawesi was indicated as high level of mercury contamination, which is 4 to 1167-fold higher than guideline level.

Geographically, Bogor was located in West Java. So, the sample results represented the mercury condition in West Java. Based on the Table 6.2, West Java contained 0.11-73 ng/mg of total mercury in soil, 0.093-85.2 ng/mg of mercury in sediment, 5.6-1800 ng/m^3 in atmosphere and 0.07-5.4 ng/mg in plant. Unfortunately, data of mercury in water was not available. In distance 300 km away from West Java, paddy in Banten was analyzed at 0.07-1.19 ng/mg of mercury contamination level. These data showed the high level of mercury, which exceeded each guideline.

In Maluku, only data of mercury concentration in sediment was analyzed. It was 0.55-918 ng/mg, more than 4500 times higher than normal sediment in Japan. This result determined that Maluku was polluted by mercury since 2012. As the main fish stocks in Indonesia, collaboration research is needed to reduce mercury use in gold mining activities in Maluku.

According to previous chapters, mercury concentrations were found in soil and plant. It concluded that mercury affected up to 4 km away of the gold mining site, in range of 0.04 – 17.62 ng/mg and 0.05-6.5 ng/mg of soil and plant, respectively.

There were several data of mercury contamination in soil, sediment, water, vapor, and plant which presented high mercury contamination level. So, based on contamination rate indicator indicates that Indonesia is risk area due to mercury in mining use.

6.4 Chronic Toxicity Indicator

Mercury can be detected in human body. Chronic toxicity can be found in human hair, blood, and urine. Because of the dangerous of mercury in human body, there was several publications determined total mercury in human specimens in gold mining areas. Four researches in this chapter described the critical condition of mercury contamination in Indonesia.

On 2010, Bose O' Reilly et al found 0.33 to 792.45 ng/mg of total mercury in human hair in Central Kalimantan mining' s site and range of 0.58 to 239.04 ng/mg in North Sulawesi, respectively. Another study in Cisitu, located Banten Province, contaminated 13 individuals being alert level of mercury, in range between 1 ng/mg and 5 ng/mg based on exposure limit value of German Human-Biomonitoring (HBM) (Drasch, et al., 2001). Then, five individuals contaminated mercury in high level, which was above 5 ng/mg in human hair.

Additionally, in Central Java of Indonesia, it showed that average of total mercury concentration was 5.40 ng/mg. This value exceeded the alert level of HBM. The maximum concentration of mercury reached 17.07 ng/mg, included in high level contamination (Sari, et al., 2016). In another part of Indonesia, Palu and Poboya (Central Sulawesi), indicated human hairs contained 0.25 ng/mg to 19.58 ng/mg of total mercury for people in Poboya and 0.12 ng/mg to 68.52 ng/mg of people in Palu. Comparing the mercury concentration results of 20 respondents

in Central Sulawesi with HBM, 75% of respondents being alert to high level of mercury contamination in Poboya and 50% of respondents in Palu. The average of mercury concentrations were 3 ng/mg and 5.62 ng/mg in Poboya and Palu, respectively.

Tracking chronic toxicity through urine and blood can be significant proof of mercury contamination in human (Bose O'Reilly, et al., 2016). Urine and blood can be bio-monitor of mercury that inhaled in gaseous form. Two researches provided the data of mercury concentration in urine for three different gold mining areas.

First, Banten, an area with approximately 10000 people work in gold mining, increased significantly opened gold mining site in 2003 to 2004. This area recorded mercury levels above the exposure threshold, where 5 respondents were within alert level and 3 respondents were in high level range. Second was in Central Kalimantan. It was in range of 0.29 ng/ml to 5240 g/ml, and the average was 78.87 ng/ml. Based on HBM, mercury concentration in urine was high level.

Third mining area was North Sulawesi. It was 20 km from the capital city, Manado. There was 15 to 20 group miners excavated this mining. In this area, total mercury in urine above the exposure threshold. The range of mercury concentration was in range 0.1 ng/ml up to 564 ng/ml. Based on the study by Bose O' Reilly 2016 , people in North Sulawesi was contaminated by mercury due to gold mining in high level.

6.5 Acute Toxicity Indicator

Acute toxicity indicator was the way to identify the level of mercury in human health. Acute toxicity could be measured in food consumption and health questionnaire (Bose O'Reilly, et al., 2016). Several gold

mining areas in Indonesia recorded the acute toxicity levels, for example in Banten, North Sulawesi, Central Java, Central Kalimantan and Central Sulawesi.

Mercury identification on fish in Banten was done on 2012. The results mentioned that fish in Banten contained mercury in range of 0.13 to 1.3 μg/g, with average was 0.46 μg/g. This value was higher than WHO's guideline (0.03 μg/g) (Ali & Al-Qahtani, 2012; Abbas, et al., 2010).

Another area in North Sulawesi, 201 fish specimens were analyzed and having mercury level in average of 1.86 μg/g (Castilhos, et al., 2006; Limbong, et al., 2003). This mercury concentration was higher than Banten. As comparison, mercury level in Central Kalimantan. From 263 of fishes contained 0.25 μg/g of mercury which was 8 times higher than 0.03 μg/g (Castilhos, et al., 2006). However, all fish specimens in gold mining areas potentially harmful consumption for local people.

Central Java was discussed in previous chapter, the mercury concentration was shown in health questionnaire as the acute toxicity indicator. Comparing two different characteristic areas indicated that gold mining area (Cihonje) more frequent symptoms happened. The potential symptoms that very often happened were pain in the ankle and hands; headache; and breathing difficulty (Sari, et al., 2016). Significant result showed in non-gold mining area, only 1 person felt breathing difficulty as the effect of mercury use. In addition, neurological test had been examined of 18 patients in Banten.

At least 10 tests applied to the respondent, and the results presented that sleep disturbances, tremor, ataxia of gait, and dysdiadochokinesia were occurred in more than 11 respondents (Bose O'Reilly, et al., 2016). Food consumption was measured in Central

Sulawesi. Totally, 22 foods of 4 groups were mercury analyzed. It has the range from 0.003 to 0.31 μg/g. The lowest mercury concentration was contained in chicken and the highest level food in Central Sulawesi was banana, which is growing in local area. The mercury intake in Central Sulawesi was 0.3 to 121.7 μg/person in a week for each food, and total mercury intake in a week was 250.6 μg/person. It was above the standard of total mercury intake in Japan-i.e. 111 μg/person/week.

6.6 Summary

The mercury contamination levels in each indicator represented the alert level to high level in 7 gold mining areas in Indonesia. Due to the high oxidation of mercury, when mercury vaporized in atmosphere, it spread in all over Indonesia and absorbed easily, not only in gold mining area. Therefore, community becomes the potential target of mercury pollution. Community in Indonesia has been categorized as the high vulnerable community based on exposure degree, contamination rate, chronic toxicity and acute toxicity indicator. Furthermore, reducing mercury effects for the community by control the community food consumption and increase the monitoring of mercury in environment should be held in 56 more hotspots in Indonesia. Additionally, Indonesian Government has to take part to re-regulate the mercury use in gold mining processes.

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Chapter VII

Conclusions

The dangerous of mercury was discovered on 1956, when Minamata diseases poisoned the people in Minamata caused by mercury. At least 12000 people have been victims officially. However, the usage of mercury becomes wider nowadays. Indonesia adopted mercury amalgamation technique to extract at 63 hotspots. Therefore, mercury waste cannot be avoided in our environment. Then, the final impact of mercury accumulates in human body, and decrease the human health condition or quality.

This study obtained some important results due to the small-scale gold mining in Indonesia. The result can be useful for the environment monitoring, evaluation and also substantial for environmental assessment. This study also provided the community vulnerability assessment to determine the resilience of people in the small-scale gold mining areas. Following points are the important results of this study.

1. Small-scale gold mining is the most source of mercury in Indonesia. Amalgamation process in gold mining wastes almost 99% of mercury in environment. The forms of mercury waste are liquid, where river, lake and other aquatic system become the disposal area. Second, air that can be evaporated to the atmosphere through amalgam burning.

2. Mercury spreads widely to environment via atmosphere. Amalgam burning exhausted mercury vapor and deposited in surface aquatic

system, soil and plant. Mercury that contaminated aquatic organism, soil and plant enter the human body through food chain. And, human hair can be used as the mercury biomonitoring sample of human health.

3. Mostly, areas in Indonesia were infected by mercury. As the representative areas, Cihonje and Poboya were measured. The effluent of gold mining process was used as the exposure rate indicator, which exceeded the mercury standard set by Ministry of Environment, Indonesia. It was 7460 times higher than the standard. This high mercury effluent discharged into river, and contaminated the aquatic livings.

4. Contamination rate indicator used river water, soil and plant to measure mercury concentration. In both areas showed that mercury in range that potential to affect the environmental quality. Some points determined the mercury concentration was higher than Pollution Index, such as in Cihonje, the river water was higher than 0.5 ng/ml.

5. Chronic toxicity indicator used human hair to indicate the mercury exposure levels in human body. Study showed that people who are staying in gold mining areas have higher mercury concentration than non-gold mining area. The concentrations were reached 17.07 ng/mg and 19.6 ng/mg for Cihonje and Poboya mining area, respectively.

6. Health questionnaire was essential part to indicate the short term toxicity in human body of mercury. The health symptoms comparison in this study described that; head ache, pain in the ankle, nausea, stomach ache, lips pain, and breathing difficulty were perceived more frequent in gold mining area people. In addition of human

health assessment, mercury intake was measured in Poboya. It resulted 250.6 μg/person/week, which was twice of Japanese standard set by Ministry of Environment.

7. All the indicators showed that Indonesia, especially gold mining areas were vulnerable and high risk of mercury pollution. This condition obligates a collaborative research that concerns in monitoring, people awareness, and mercury-free mining approaches.