Global Journal of Health Science; Vol. 10, No. 3; 2018
ISSN 1916-9736 E-ISSN 1916-9744
Published by Canadian Center of Science and Education

Environmental Health Risk Assessment Due to Exposure to Mercury in Artisanal and Small-Scale Gold Mining Area of Lebak District

Arinil Haq[1], Umar Fahmi Achmadi[1] & Anwar Mallongi[2]

[1] Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia

[2] Department of Environmental Health, Faculty of Public Health, Universitas Hasanuddin, Makassar, Indonesia

Correspondence: Arinil Haq, Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia.

Received: November 3, 2017 Accepted: January 8, 2018 Online Published: February 12, 2018

doi:10.5539/gjhs.v10n3p125 URL: https://doi.org/10.5539/gjhs.v10n3p125

Abstract

In Indonesia it is estimated that there are around 250,000 artisanal and small-scale gold mining (ASGM) and generally use mercury for amalgamation process and then release it to the environment during gold refining process. This study aims to analyze mercury levels in the environment around ASGM in Lebaksitu Sub-District, Lebak District, Banten Province and identify hazardous exposure that may occur. The study design used was descriptive observational with Environmental Health Risk Assessment (EHRA) method. Environmental data taken include water and food samples. Social-demographic and dietary interviews were conducted. The study population was 72 residents of Lebaksitu Sub-District obtained through sample size formula and selected by simple random sampling. The study was conducted from April to May 2017. Exposure assessment is an important part of risk assessment. Exposure is a process that causes contact with environmental hazards such as risk agents, as a bridge connecting 'hazards' to 'risks'. Exposure analysis needs to consider all routes (inhalation, ingestion, absorption) and media (air, water, soil, food, drinking water) so that the total intake can be calculated. Exposure route analysis usually generate a critical pathway, the dominant exposure path. This pathway concerns which environmental media is the vehicle of risk agent and how it enters the body. Once a critical pathway is found, other possibility pathways contribution may be small and can be ignored. Mercury is a toxic pollutant that bioaccumulated and biomagnetic continuously through the food chain. The levels of mercury at the research sites on rice, fish, and vegetables have average of 0.027 mg/kg; 0.283 mg/kg; and 0.410 mg/kg. The calculation of risk assessment obtained value of risk quotient (RQ) of 3.79 (RQ>1). The results of this calculation of risk assessment showed that mercury content in samples of rice, fish, and vegetables originating from Lebaksitu Sub-District potentially cause a health risk for the community surrounding the gold mining area who consume it.

Keywords: mercury, risk assessment, artisanal and small-scale gold mining

1. Introduction

In Indonesia it is estimated that there are around 250,000 artisanal and small-scale gold mining (ASGM) and generally use mercury for amalgamation process (Sembel, 2015). ASGM has many associated environmental and occupational health issues. The health and well-being of miners, their family members, and also nearby communities is often adversely affected (WHO, 2016).

Mercury is a natural element found in air, water, and soil, that has silvery white color, liquid, and volatile (Widowati, Sastiono, & Jusuf, 2008; United Nations Environment Programme, 2008). Mercury is commonly found at very low concentrations in the environment (Gohari, 2016). Although only be found in low concentrations in the earth's crust, this metal is heavily buried in mining areas (Agustina, 2010). ASGM usually use mercury in ore processing. Gold ore mining results are processed by amalgamation method, that is the process of binding of gold metal from ore by using mercury (Widodo, 2011).

Amalgam (a combination of gold/silver metal with mercury) is heated, vaporizes mercury from the mixture, and leaves the gold (Widodo, 2011; WHO, 2013). The use of this method of amalgamation results in the emergence of problems, namely the release of mercury is high enough to pollute the river water (Widodo, 2008). In addition, mercury wastes and other heavy metal waste are toxic and persistent and hazardous to humans and the environment (Kementerian Lingkungan Hidup, 2013).

The proposed route for mercury to enter the human body is only an indirect way through the food web of the inhabitants (Arifin, Sakakibara, & Sera, 2015).Diet hold an important role in individual exposure to environmental chemicals. Mercury contamination from the human food chain is a significant problem for human health and well-being. Methyl-mercury exposure is a clear example that the general population is exposed to this metal through the consumption of fish and other products of the aquatic environment (Schoeman, Bend, Hill, Nash, & Koren, 2009; Dewailly et al., 2012).

One of ASGM in Indonesia that is still active today is ASGM in Lebaksitu Sub-district, Lebak District, Banten. According to research that has been done in Lebaksitu Sub-district known mercury levels in water, soil, and fish taken from the area around ASGM of Lebaksitu Sub-district each of 0.00392 ppm, 5.709 ppm, and 0.5175 ppm. The results of these measurements indicate mercury levels that have exceeded the threshold and indicate that environmental pollution has occurred due to mercury (Agung & Hutamadi, 2012). This study aims to analyze mercury levels in the environment around ASGM in Lebaksitu Sub-District, Lebak District, Banten Province and identify hazardous exposure that may occur.

2. Materials and Methods

The study design used in this study is the Environmental Health Risk Assessment (EHRA) which consists of several steps, that is: 1) hazard identification, 2) dose-response analysis, 3) exposure assessment, and 4) risk characterization (Rahman, 2007). Environmental data taken include water and food samples (rice, fish, and cassava leaves). The population in the study were residents residing in Lebaksitu Sub-district with inclusion criteria: 1) residing around the location of small scale gold mining in Lebaksitu Sub-district; 2) men or women have equal opportunity in participating as respondents; 3) willing to be a respondent. The study population was 72 residents of Lebaksitu Sub-District obtained through sample size formula and selected by simple random sampling. The study was conducted from April to May 2017.

The calculation of mercury intake is obtained from the calculation of Intake (I), through the following equation (Rahman, 2007):

$$I = \frac{C \times R \times f_E \times D_t}{W_b \times t_{avg}}$$

Explanation:

I = Intake, mg/kg/day

C = Concentration of risk agent (mg/L for drinking water and mg/kg for food),

R = Rate of intake or consumption (L/dayfor drinking water and kg/dayfor food),

f_E = Frequencyof annual exposure (day/year),

D_t = Duration of exposure, year (real time or projection, 30 years for residential default value),

Wb = Weight (kg),

t_{avg} = Average time period (Dt x 365 days per year for non-carcinogenic substances, 70 years x 365 days per year for carcinogenic substances).

Estimation of the level of health risks derived from calculations using Risk Quotient (RQ) is calculated through the equation:

$$RQ = \frac{I}{RfD}$$

The interpretation of the RQ value obtained from the formula calculation is if RQ> 1 means having a health risk. RfD (Oral Reference Dose) is the amount of chemicals that can be consumed daily in a lifetime that is not anticipated to cause non-cancer health effects. The riskant contaminant studied, mercury, has a quantitative toxicity value (RfD) obtained from US EPA. Based on oral mercury inlet and non-carcinogenic character, the RfD value is 0.0001 mg/kg/day based on US EPA (US EPA, 2001).

3. Results

Based on Table 1, the frequency distribution of social, economic, and demographic characteristics of Lebaksitu residents, most of the respondents are women, namely 77.8%. Most of the respondents graduated from elementary school (38.9%). Most of the respondents are not miners / processors of gold that is equal to 77.8%.

Table 1. Frequency Distribution of Social, Economic, and Demographic Characteristics of Lebaksitu Sub-district, Lebak District, West Java 2017

Variable	Total	Percentage
Sex		
Male	16	22.2
Female	56	77.8
Education		
No school	24	33.3
Not completed in primary school	8	11.1
Finished primary school	28	38.9
Finished junior high school	12	16.7
Occupation		
Miners or gold processors	16	22.2
Not miners or gold processors	56	77.8
Total	**72**	**100.0**

Based on Table 2, the average age of respondents is 38.11 years old with a range of 20 years old to 80 years old. Average weight of respondents is 54.52 kg with a range of 39.20 kg to 81.00 kg. For height, the average height of respondents is 153,70 cm with range of 140 cm to 172 cm.

Table 2. Characteristics of Anthropometry, Activity Pattern, and Consumption Rate of Lebaksitu Sub-district Residents, Lebak Regency, West Java 2017

Variable	Mean ± SD	Median	Range	Distribution***
General anthropometry				
Age (year)	38.11 ± 15.12	33.50	20 - 80	Normal
Weight (kg)	54.52 ± 8.99	53.05	39.20 - 81.00	Normal
Height (cm)	153,70 ± 7,04	152,50	140 - 172	Normal
Activity pattern				
D_E (year)*	30	-	-	-
D_t (Real time) (year)**	20.11 ± 15.12	15.50	2 - 62	Normal
f_E (day/year)*	350	-	-	-
Consumption rate				
Drinking water (L/day)	1.23 ± 0.69	1.00	0.25 - 4.50	Abnormal
Beras (kg/hari)	0.26 ± 0.09	0.30	0.10 - 0.70	Abnormal
Ikan (kg/hari)	0.04 ± 0.01	0.03	0.00 - 0.18	Abnormal
Sayur (kg/hari)	0.03 ± 0.01	0.01	0.00 - 0.15	Abnormal

*use default value.

**Life span, calculated by the formula: current age - 18 years.

*** Normality (*Kolmogorov - Smirnov* (n ≥ 30) and *Shapiro - Wilk* (n < 30)).

Based on the results contained in Table 3, the average mercury (Hg) value found in rice derived from Lebaksitu Sub-district was 0.027 mg/kg with minimum and maximum values of 0.020 mg/kg and 0.030 mg/kg. The mercury contained in fish from Lebaks Sub-district has an average of 0.283 mg/kg, minimum of 0.220 mg/kg and maximum of 0.360 mg/kg. Based on the results listed in Table 3, the average mercury value found in vegetables (cassava leaves) consumed by Lebaksitu residents is 0.410 mg/kg, minimum 0.250 mg/kg and maximum 0.540 mg/kg.

Table 3. Concentration of Mercury on Three Types of Food Consumed by Lebaksitu Residents, Lebak District, West Java 2017

Parameter	Mean ± SD	Median	Range	Distribution*	Level of contamination**
Rice					
Hg (mg/kg)	0.027 ± 0.005	0.030	0.020 - 0.030	A	300
Fish					
Hg (mg/kg)	0.283 ± 0.063	0.270	0.220 - 0.360	N	2800
Vegetable					
Hg (mg/kg)	0.410 ± 0.132	0.440	0.250 - 0.540	N	4100

*A: Abnormal, N: Normal.

**Level of contamination calculated by:

Concentration of metal (Hg) ÷ RfD.

RfD *(*Reference Dose*)* Hg = 0,0001 mg/kg/day (US EPA).

Based on RQ calculations, estimates of health risks to mercury in rice, fish and vegetables (cassava leaves) in total show RQ>1 (RQ = 3.79) (Table 4). Estimation of health risk to mercury in rice with value RQ>1 that is equal to 1,58. For fish, estimate health risk to mercury with value RQ>1 that is equal to 1,49. While estimation of health risk to mercury in vegetable (cassava leaf) with value RQ<1 that is equal to 0, 72.

Table 4. Level of Risk of Mercury Exposure in Lebaksitu Village, Lebak Regency, West Java 2017

Source of Mercury	I* (mg/kg/day)	RfD (mg/kg/day)	RQ**
Hg			
Rice	0.0001583		1.58
Fish	0.0001493	0,0001	1.49
Vegetable	0.0000721		0.72
Total RQ			3.79

*I calculated by the formula: $I = \frac{C \times R \times f_E \times D_t}{W_b \times t_{avg}}$;

**RQ calculated by the formula: $RQ = \frac{I}{RfD}$.

4. Discussion

4.1 Mercury Contamination on Rice

Based on the results contained in Table 3, the average mercury (Hg) value found in rice derived from Lebaksitu Village was 0.027 mg/kg. From some available sources, there is no mercury content threshold value in rice. However, based on the Indonesian Food and Drug Supervisory Agency (BPOM RI) Regulation on the Determination of Maximum Limit of Microbial and Chemical Feeding in Food, maximum limit of mercury contamination in the permitted flour is maximum of 0.05 mg/kg (BPOM RI, 2009). Flour can be made from various types of vegetable materials such as whole grains so that the threshold value can be used as a reference. This means that the mercury content in rice that has been tested by the laboratory at the study site is still below the permissible level based on the BPOM RI regulation is seen from the average concentration, as well as the minimum (0.020 mg/kg) and the maximum (0.030 mg/kg) of mercury in the sample rice tested.

Bioaccumulation of mercury in the terrestrial food chain gets little attention and is considered unimportant. However, recent research has shown that rice can be an important route of methyl mercury exposure to residents in the Hg mining area in China. This study, for the first time, shows that rice is an intensive bioacumulator of MeHg, but not of IHg, which may be trapped by roots (Zhang, Feng, Larssen, Shang, & Li, 2010).

4.2 Mercury Contamination on Fish

The mercury contained in fish from Lebaksitu Sub-district has an average of 0.283 mg/kg. Based on the Indonesian Food and Drug Supervisory Agency Regulation (BPOM RI) on the Determination of Maximum Limit of Microbial and Chemical Feeding in Food, maximum limit of mercury contamination in fish is allowed maximum of 0.5 mg/kg (BPOM RI, 2009). This means that the mercury contents of fish that have been tested by the laboratory at the study sites are still below the permissible levels based on the BPOM RI regulation is seen from the average concentration, as well as the minimum (0.220 mg/kg) and the maximum (0.360 mg/kg) of mercury in the sample fish tested.

Methyl-mercury can be formed in water and soil by small organisms. The stockpiling of mercury by fish occurs because these animals consume planktonic organisms containing mercury ions in contaminated water. Methyl-mercury is formed in fish tissue. Bigger and older fish tend to have the highest mercury levels (Herman, 2006; ATSDR, 2010) As fish size increases and increases the residence time, their mercury levels rise roughly (Langeland, Hardin, & Neitzel, 2017).

4.3 Mercury Contamination on Vegetable (Cassava Leaves)

Based on the results listed in Table 3, the average mercury value found in vegetables (cassava leaves) consumed by Lebaksitu residents is 0.410 mg/kg. Like rice, there is no mercury threshold value found in cassava leaves. However, based on the Indonesian Food and Drug Supervisory Agency (BPOM RI) Regulation on the Determination of Maximum Limit of Microbial and Chemical Feeding in Food, maximum limit of mercury contamination in tomatoes is allowed maximum of 0.03 mg/kg (BPOM RI, 2009). Tomatoes are categorized as one type of vegetable so that the threshold value can be used as a reference. This means that the mercury content of cassava leaves that have been laboratory tested at the study sites exceeds the permissible levels based on the BPOM RI regulation is seen from the average concentration, as well as minimun (0.250 mg/kg) and the maximum (0.540 mg/kg) of mercury in the sample cassava leaves are tested.

Numerous studies have shown that vegetables and grains grown near various sources of mercury can be contaminated (R. Li, Wu, Ding, Fu, Gan, & Y. Li, 2017). Studies that examine the ratio of heavy metal accumulation to vegetables using irrigation with wastewater, clean water and river water have found that mercury concentrations are relatively high in leafy vegetables. The study also revealed that wastewater causes more accumulation to soil and vegetables than river water and tube well water (Hassan et al., 2016).

4.4 Mercury Contamination on Water

Water samples from Lebaksitu Village have been taken and laboratory tests are conducted. The results of laboratory tests show that no mercury contamination is detected in clean water samples. This indicates that the clean water used by the people of Lebaksitu Sub-district is within safe limits. Results of interviews with stakeholders and local residents, obtained information that clean water used by residents for everyday purposes such as drinking, cooking, bathing, and so forth comes from hilly water. The water is flowed to people's homes using hoses and water pipes. It can be concluded that the water source is far from the location of ASGM so it is not contaminated by mercury waste from the gold mining.

4.5 Estimated Risk Level

Based on RQ calculations, estimates of health risks to mercury in rice, fish and vegetables (cassava leaves) in total show $RQ>1$ ($RQ = 3.79$) (Table 4). Estimation of health risk to mercury in rice with value $RQ>1$ that is equal to 1,58. For fish, estimate health risk to mercury with value $RQ>1$ that is equal to 1,49. While estimation of health risk to mercury in vegetable (cassava leaf) with value $RQ<1$ that is equal to 0, 72. RQ value <1 this mean that intake mercury per day from vegetables still safe. However, after combined with rice and fish intake, there was a $RQ>1$ value, which means that the daily mercury intake of rice, fish, and vegetables is at risk of health problems to the people of Lebaksitu Sub-district who consume them.

Research conducted by Castilhos et al. (2015) calculate the value of hazard quotient. The hazard quotient (HQ) is a risk indicator which defines the ratio of the exposure level and the toxicological reference dose and was applied to determine the threat of MeHg exposure. For all sampling sites, HQ resulted from 1.5 to 28.5, except for the reference area. In Creporizinho, the values of HQ are close to 2 for most sites, whereas in São Chico, there is a hot spot of MeHg contamination in fish with the highest risk level ($HQ = 28$) associated with its human consumption (Castilhos et al., 2015).

5. Conclucions

The mercury content of rice and fish that has been tested by the laboratory is still below the permissible level based on BPOM RI Regulation (0.05 mg/kg). However, the mercury content in vegetable (cassava leaves) that have been laboratory tested exceeds the permissible levels based on BPOM RI Regulation (0.03 mg/kg). Estimation of health risk estimation to mercury in rice, fish and vegetables (cassava leaves) in total shows RQ>1 (RQ = 3.79). The value of RQ>1 indicates that the daily mercury intake of rice, fish, and vegetables is at risk of health problems to the people of Lebaksitu Sub-district.

Competing Interests Statement

The authors declare that theyhave no competing or potential conflicts of interest.

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