



ITMAR-14

Health risk estimates from exposure to minerals in artisanal gold mining site in Gunung Pongkor, Bogor, Indonesia

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Abstract

Elevated level of minerals has been detected in gold mining sites. To estimate health risk from exposure to these minerals, an environmental health risk assessment has been conducted in artisanal gold mining site of Gunung Pongkor, Bogor, Indonesia. Fifteen transition metals, heavy metals, metalloids, and anionic contaminants were analyzed from 200 drinking water and 19 local food samples. It was found that mean concentration of 10 contaminants complied with the Indonesian drinking water standard, whereas cyanide, fluoride, chromium, nitrite, and arsenic exceeded the standard by 1.2 to 700 folds. Arsenic was detected in rice, vegetables, cassava, banana, and fish. Cadmium was only detected in fish and mercury in rice, while lead was detected in rice, vegetables, cassava, and banana. Non-carcinogenic risk quotients (RQ) of cyanide, arsenic, fluoride, chromium, mercury, and nitrite were 86.02, 41.33, 26.34, 3.37, and 1.85, respectively, indicating that the likelihood of adverse health effects from exposure to these contaminants is high. Exposures to manganese, iron, copper, zinc, aluminum, cadmium, selenium, and nitrate resulted in $RQ < 1$, meaning that these minerals were of less health concern. Meanwhile, excess cancer risk (ECR) of arsenic in drinking water, vegetables, cassava, banana, and fish were $2.69E-4$, $2.19E-3$, $1.06E-4$, $8.85E-5$, and $6.6E-3$, respectively, which all of them are unacceptable. Cyanide, arsenic, fluoride, chromium, mercury, and nitrite were the top six risky non-carcinogenic minerals, whereas fish was the main exposure medium responsible for high unacceptable ECR of arsenic. Health risks of other minerals could not be estimated since they have no quantitative toxicity values. High level of contaminant is not necessarily resulted in high health risk, because chronic intake depends also on parameters other than concentration such as contact time rate and consumption rate.

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Peer-review under responsibility of the Scientific & Review committee of ITMAR-2014.

Keywords: Artisanal Gold Mining, Excess Cancer Risk, Pongkor, Mineral, Risk Quotient

Introduction

Indonesia has ubiquitous mineral deposits across the country where gold, silver, and copper have been exploited since decades by either modern or artisanal minings. Modern gold and copper mining in Batu Hijau, southwestern Sumbawa, and modern and artisanal small-scale gold mining (ASGM) in Buyat-Ratatotok, North Sulawesi, are examples of intensive mineral exploitation. Metal abundance and its environmental pollution and

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health consequences in these mining sites have been reported in many publications (Blackwood & Edinger, 2007; Clode, Proffett, Mitchell, & Munajat, 1999; Lasut, Yasuda, Edinger, & Pangemanan, 2010; Limbong, Kumampung, Rimper, Arai, & Miyazaki, 2003; Welker, 2009).

In the gold mining, metals and metalloids are released to the environment during crushing, milling, amalgamation or cyanidation, carbon leaching and stripping, electro winning, and casting processes of ores to produce mineral concentrate. In the environment, the metals and metalloids undergo chemical, biological, and physical changes leading to pollution in soil, groundwater, surface water, aquatic biota, and food crops. In ASGM site, metal contamination is also derived from chemicals used for mineral extraction such as mercury from amalgamation for gold extraction. In modern (industrial) mining, cyanide is used for gold extraction.

People living in the gold mining sites may expose to metals, metalloids, and nonmetals as well as anionic contaminants through ingestion of drinking water and foods, inhalation of dust and gases, and skin absorption during bathing, swimming, or contact with dust and soil. Drinking water is primary medium for chronic intake of metals and metalloids with relative contribution to all environmental media up to as 80% (US-EPA, 1990). In this typical setting, the metals and metalloids may spread out in soil, groundwater, surface water, grown foods (i.e. vegetable, grain, fruits), and aquatic biota (e.g. fish, catfish, eel, snail).

Gunung Pongkor in Bogor Regency, West Java, is one of typical mineral-rich area in Indonesia. It has high gold-silver deposit of about 1.3 million oz that can be mined until 2019 (PT Aneka Tambang, 2012). PT Aneka Tambang Tbk, a state-owned mining company known as Antam, has exploited gold in 14,940-acre concession area (including community residences) since 1992. Soon it attracted artisanal miners (better known as gurandil in local language) from remote areas to exploit gold illegally using mercury amalgamation. There are thousands of gurandils in Gunung Pongkor with the peak number of 7,000 gurandils in 1998 (Irawan, Mumbunan, & Ardianto, 2005). Due to artisanal mining, surface water and groundwater in Gunung Pongkor contained high level of metals (such as cadmium, chromium, copper, lead, zinc, and mercury) and metalloid (such as arsenic), which are not only originated from natural mineral rocks but also from amalgamation of ores (Tim Konservasi Pongkor, 2006).

Gold and silver deposit in Gunung Pongkor is an adularia-sericite epithermal type that are rich in manganese oxides and limonite and very poor in sulphides, with average gold and silver concentrations of 16.4 g/tonne and 171.2 g/tonne, respectively (Milesi et al., 1999). Gunung Pongkor has three main gold veins at Ciguha Utama, Kubang Cicau, and Ciurug. At Ciguha Utama and Kubang Cicau, Antam uses conventional cut and fill stoping mining method with hydraulic tailings placement. At Ciurug, a mechanised cut and fill method with hydraulic jumbo drill and load haul dump is used. Using cyanidation for gold extraction, Antam produces 1,500 to 2,000 kg (48,226 to 64,301 toz) gold annually (Antam, 2012).

There are increasing public concerns about adverse health effects from multipathways exposure to toxic minerals in ASGM site in Gunung Pongkor. In Nangung Sub-District of Gunung Pongkor, approximately 75,000 residential population are at risk from exposure to toxic metals, metalloids, and nonmetals. In addition to man-added minerals for

amalgamation and cyanidation, the occurrence of contaminants in environmental media is also multiplied during mechanical and chemical processes of gold ores.

Exposure to toxic minerals in ASGM site potentially leads to mineral overload-related diseases. However, previous studies in Gunung Pongkor mostly focused on geological surveys and mineral analysis (Basuki, Aditya Sumanagara, & Sinambela, 1994; Tim Konservasi Pongkor, 2006; Warmada, Lehmann, & Simandjuntak, 2003; Yasuda et al., 2011). So far, public health issues associated with gold mining contamination have not been addressed. For this reason, the present study aimed at estimating health risks from exposure to particular biological metals, metalloids, nonmetals, and anionic contaminants in drinking water and foods. Employing environmental health risk assessment design, the estimated quantitative health risks were used to formulate management options to manage the likelihood of adverse health effects over lifetime.

Materials and Methods

Study Design

The present study employed environmental health risk assessment design as described elsewhere (ATSDR, 2005; National Research Council, 1983; WHO, 2009). It consists of four iterative steps: (i) hazard identification, (ii) exposure assessment, (iii) dose-response assessment, and (iv) risk characterization. Mathematical equations or models to quantify health risk estimates are available in many guidelines and standard textbooks (Aral, 2010; ATSDR, 2005; Kolluru, 1996; Louvar & Louvar, 1998; Robson & Toscano, 2007; WHO, 2009). Fifteen trace transition essential and beneficial metals, heavy metals, metalloids, and anions in drinking water and heavy metals in foods were selected as mineral contaminants. Selection of minerals was based on physiological importance (essentiality and /or toxicity) and ubiquitous distribution in exposure media.

Population and Samples

Human population was adult residents who have resided no less than 5 consecutive years in the selected villages at Ring-1 of the ASGM site in Nanggung Sub-District of Gunung Pongkor, Bogor. A total of 200 respondents were drawn randomly from Mala-sari, Bantar Karet, and Cisarua villages using sampling methods as described elsewhere (Lwanga & Lemeshaw, 1997). The respondents were surveyed for anthropometric exposure factors and measured for their body weight and activity pattern (exposure frequency and duration). At the same time, a total of 200 drinking water samples and 19 local (grown, cultivated, caught) food samples were collected for minerals analyses.

Site Description and Demography

The gold-silver mining site of Gunung (mount) Pongkor is located in Nanggung Sub-District of Bogor Regency, West Java Province. Gold-silver deposit in Gunung Pongkor is located at upstream of Cikaniki, Ciguha, and Cisarua rivers. These rivers are used by local residents for daily purposes such as bathing, swimming, washing, toilet, and even boiled for drinking. The rivers are combined at downstream and flow to Cisadane River in Tangerang Regency, Province of Banten. Cikanika is the main river into which most tailing from ASGM flows.

Gunung Pongkor gold-silver mine is situated in 112-km² area, about 80 km south of Jakarta. Administratively, Gunung Pongkor belongs to three sub-districts of Nanggung (70%), Leuwiliang (20%), and Cigugur (10%), covering forests, agriculture fields, and residences from 106031° to 106036° Longitude 6035° to 6042° Latitude with elevation ranging from about 400 to 900 meter above sea level. Most ASGMs are located in Nanggung Sub-District. Present study selected three from 11 villages in Nanggung Sub-District as study location: Malasari, Bantar Karet, and Cisarua, with population (all ages) of 7,609; 8,469; and 8,469; respectively. These villages are located at Ring-1 (the closest site to Antam) where most artisanal miners operate their gold mining.

Sampling and Analysis

The present study selected 15 minerals as typical contaminants that commonly found in the gold mining sites: (i) trace essential and beneficial transition metals (chromium, manganese, iron, copper, zinc, aluminum), (ii) heavy metals (cadmium, mercury, lead), (iii) metalloids (arsenic, selenium), and (iv) anionic species (cyanide, fluoride, nitrite, nitrate). All these minerals were analyzed in drinking water. In foods, only arsenic, cadmium, mercury, and lead were analyzed.

Drinking water and foods samples were collected and analyzed from 28 June to 18 July 2012 by accredited Jakarta Health Laboratory (Balai Besar Laboratorium Kesehatan Jakarta). Analytical methods of Indonesian National Standards (SNI) were used for mineral analysis using AAS and GC-MS techniques. Data on anthropometric exposure factors and activity pattern of respondents were collected from 25 September to 10 October 2012. Ethical clearance for anthropometry survey was obtained from Ethical Committee of Health Research and Development Agency, Ministry of Health, Jakarta.

Hazard Identification

The primary hazard of concerns were toxic minerals (mercury, cyanide, arsenic, cadmium), trace elements (chromium, manganese, iron, copper, zinc, aluminum, selenium), and anionic minerals (fluoride, cyanide, nitrite, nitrate). Trace transition metals are of particular importance because at certain levels they are both essential or beneficial and potentially toxic. At specific lower concentration, some metals are cofactor of enzymes, whereas at higher levels they exhibit toxicity through ligation or chelation mechanism with nucleophilic sites of organic molecules such as amino acids, enzymes, hormones, and vitamins (Taylor & William, 1995). Toxicity of mercury, cyanide, arsenic, and cadmium is reported in epidemiology studies, while their essentialities are commonly studied on dietary aspect (Serra-Majem et al., 2009).

Many studies reported that renal function impairment is associated with chronic exposure to chromium (Wang et al., 2011), arsenic and cadmium (Hong, Jin, & Zhang, 2004; Ikeda, Fukui, Ohashi, Sakuragi, & Moriguchi, 2011; Ikeda, Ohashi, Fukui, Sakuragi, & Moriguchi, 2011; Kawada, Koyama, & Suzuki, 1989; Thomas, Hodgson, Nieuwenhuijsen, & Jarup, 2009), mercury (Tian, Guro, Gao, Lu, & Li, 2009), and lead (Barregdrd et al., 1999). Renal dysfunction is indicated by the increase of the enzyme activity of N-acetyl- β -glucosaminidase (NAG) in urine (Horak, Hopfer, & Sunderman, 1981; Kawada et al., 1989; Noto et al., 1983; Price, 1992).

Arsenic has been well known as both non-carcinogen and carcinogen. Consuming drinking water containing arsenic more than 0.022 mg/L may develop hyperpigmentation, keratosis, vascular complications, blackfoot disease, and skin cancer over lifetime (IRIS, 1998). Both organic and inorganic arsenic are naturally toxic, but inorganic is more toxic than the organic species (Lim, Yeo, Clement, Roh, & Lee, 2007). Of the inorganic species, As³⁺ is the most abundance in drinking water and is more toxic than the As⁵⁺ (Muhammada, Shah, & Khan, 2010). The As³⁺ species has been classified as Type A human carcinogen that affects human organs including dermal, gastrointestinal, hepatic, neurological, and respiratory systems (ATSDR, 2007).

Mercury toxicity has been more appreciated than arsenic as it is associated with Minamata disease. In general, long term oral exposure to mercury results in systemic and cancer effects including nervous system disorder, endocrine disruption, renal impairment, liver midzonal necrosis, tremors, muscle fasciculation, myoclonus, elevated leukocyte count, stomatitis, increased blood pressure, immunological and lymphoreticular disorders, reproductive and developmental effects, genotoxic effect, and leukemia (ATSDR, 1999). Nervous system disorder and cancer are the most well known long term effects.

Transition metals such as copper, zinc, chromium, cobalt, and manganese are found drinking water. At normal concentration, these metals do not exhibit serious adverse health effects. Exposure to those essential metals in drinking water is of dietary concern since their concentrations are normally low (US-EPA, 1990).

Exposure Assessment

Exposures to trace essential transition metals, heavy metals, metalloids, and anions were assessed in residential setting. It quantified chronic exposure to these contaminants from drinking water and foods. Exposures to minerals from other exposure media and routes (inhalation and skin absorption) were excluded. Ingestion of drinking water and foods were quantified using deterministic (single point estimate) approach. As such, chronic daily dose (CDI) of non-carcinogen minerals and lifetime average daily dose (LADD) of carcinogenic mineral were estimated using central tendency values of intake variables. CDI and LADD of individual contaminant were calculated according to Eq. (1):

$$\text{LADD or CDI} = \frac{C \times R \times f_E \times D_E}{W_B \times t_{\text{avg}}} \quad (1)$$

where LADD is lifetime average daily dose of carcinogen and CDI is chronic (life span) daily intake of non-carcinogen, both in mg/kg/day; C is environmental concentration of mineral in mg/L for drinking water and mg/kg for foods; R is consumption rate in L/day for drinking water and g/day for foods; f_E is exposure frequency in day/year; D_E is life span or lifetime exposure duration in year; W_B is body weight in kg; and t_{avg} is averaging time of chronic exposure i.e. life span D_E / 365 day/year for non-carcinogen or lifetime (i.e. life expectancy) D_E / 365 day/year for carcinogen.

Dose-Response Assessment

Quantitative toxicity of the selected contaminants was obtained from peer-reviewed IRIS database (<http://www.epa.gov/iris>). Of 15 contaminants, only 11 have oral reference dose (RfD). Of these minerals, only arsenic has cancer slope factor (CSF). The RfD (mg/kg/day) of the 11 minerals is: Cd = 0.0005; Cr = 0.003; MeHg = 0.0001; Mn = 0.14; Zn = 0.3; As = 0.0003; Se = 0.005; CN[□] = 0.02; F[□] = 0.06; NO₂[□] = 0.1; NO₃[□] = 1.6. Iron, as essential element, has RfD of 0.7 mg/kg/day, a provisional value to prevent both deficiency and toxicity (US-PPRTV, 2006). CSF of arsenic is 1.5 (mg/kg/day)[□]1.

Risk Characterization

Health risks were categorized into non-cancer and cancer risks. Non-cancer health risk is expressed as risk quotient (RQ), better known as hazard index (HI) according to US EPA, calculated by dividing CDI by RfD. Cancer health risk was expressed as probabilistic excess cancer risk (ECR), calculated by multiplying LADD by CSF.

For non-carcinogens, health risks are considered to exist and require control measures if $RQ > 1$. For carcinogens, health risks are considered to exist and required to manage if lifetime $ECR > E-6$ or $ECR > E-4$. $ECR > E-6$ is applied for population greater than one million, while $ECR > E-4$ is applied for population smaller than one million. Exponential values of $E-4$ (10^{-4} or 1/10,000) and $E-6$ (10^{-6} or 1/100,000) indicate the number of individuals in specified population who anticipated to develop cancer over lifetime. These values are considered as acceptable lifetime carcinogenic risks for general population (US-EPA, 2005).

Results

Statistical summary of the data on environmental concentration of trace essential trans-ition metals, heavy metals, metalloids, and anionic contaminants is summarized in Table 1, while toxic mineral in foods is presented in Table 2. In these tables, con-centration of methylmercury (MeHg) was calculated as 83% using total mercury to MeHg biomagnificat-ion ratio (Hajeb, Jinap, & Ahmad, 2010).

Table 1:

Statistical summary of concentration (mg/L, except unitless for pH) of selected trace essential trans-ition metals, heavy metals, metalloids, anionic contaminants, and relevant parameters in drinking water (n = 200) in artisanal gold mining site of Gunung Pongkor, Bogor.

Contaminant	Standard ^a	Range	Median	Mean ± SD	Fold to standard
Chromium	0.05 ^b	0.00 – 0.90	0.20	0.29 ± 0.237	5.8
Manganese	0.4	0.02 – 0.74	0.03	0.07 ± 0.109	0.17
Iron	0.3	0.01 – 0.76	0.02	0.07 ± 0.105	0.23
Copper	2	0.002 – 0.779	0.280	0.053 ± 0.1054	0.03
Zinc	3	0.04 – 0.23	0.09	0.10 ± 0.062	0.03
Aluminum	0.2	0.001 – 0.500	0.170	0.208 ±	1.05

				0.1674	
Cadmium	0.003	0.001 – 0.011	0.0012	0.0022 ± 0.0029	0.73
Mercury, MeHg	0.001 ^c	0.00008 – 0.00082	0.00012	0.00025 ± 0.00028	0.25
Lead, Pb	0.01	0.002 – 0.30	0.004	0.005 ± 0.0052	0.5
Arsenic, inorg	0.01	0.002 – 0.090	0.010	0.012 ± 0.0106	1.2
Selenium, Se	0.01	0.002 – 0.03	0.002	0.005 ± 0.0074	0.2
Cyanide	0.07	6.2 – 126	49.6	49.34 ± 22.981	700
Fluoride	1.5 ^d	6.60 – 146.0	34.5	45.33 ± 31.406	30
Nitrite	3	0.64 – 31.20	4.89	5.30 ± 3.556	1.8
Nitrate	50	6.60 – 146.0	34.5	45.33 ± 31.406	0.91
pH	6.5 – 8.5	5.6 – 8,3	6.8	6.74 ± 0.470	–
TDS ^e	500	6.60 – 146,0	34.5	45.33 ± 31.406	0.09

^aIndonesian Ministry of Health Regulation (*Peraturan Menteri Kesehatan*, Permenkes) No. 492/Per/ Menkes/IV/2010, unless otherwise stated. ^bAs total chromium. ^cAs total mercury. ^dUS-EPA set enforceable maximum contaminant level at 4 mg/L for health protection and non-enforceable guideline of 2 mg/L for unwanted cosmetic and aesthetic effects (US-EPA, 2013). ^eTotal dissolved solid.

Table 2:

Mean concentration (mg/kg) of arsenic, cadmium, lead, and methyl-mercury in local (grown, cultivated, caught) foods (n = 19) in artisanal gold mining site, Gunung Pongkor, Bogor

Food item	As	Cd	Pb	MeHg
Rice/grain	2.27	ND	0.43	0.18
Vegetables ^a	1.66	ND	0.47	ND
Cassava	2.71	ND	0.8	ND
Banana	1.41	ND	0.75	ND
Fish ^b	2.71	0.03	ND	ND

^aIncluding leafy and fruity vegetables. ^bIncluding catfish and eel. ND = not detected (below detection limit).

Data on anthropometric exposure factors and activity pattern are summarized in Table 3. In this table, default values for intake (consumption) rates for drinking water and foods

(rice, vegetables, cassava, banana, and fish) were applied, since local data on daily consumption of drinking water and foods in the present study were incomplete.

Table 3:

Summarized data on anthropometric exposure factors, activity pattern, and consumption rate for intake estimation of trace essential transition metals, heavy metals, metalloids, and anionic contaminants in drinking water and foods in artisanal gold mining site, Gunung Pongkor, Bogor

Input variables	Assign value	Source
Body weight	55 kg	Present survey (2012)
Exposure frequency	350 day/year	Present study survey (2012)
Exposure duration	30 years	US-EPA (US-EPA, 1997)
life span	70 years	US-EPA (US-EPA, 1997)
lifetime		US-EPA (US-EPA, 1997)
Consumption rate	2 L/day	US-EPA default (US-EPA, 1997)
Drinking water	86	US-EPA default (US-EPA, 1997)
Rice	g/day	National Survey, 2009-2013
Vegetables	134	National Survey, 2009-2013
Cassava	g/day	National Survey, 2009-2013
Banana	3.5	National Survey, 2009-2013
Fish	g/day	National Survey, 2009-2013
	5.6	National Survey, 2009-2013
	g/day	National Survey, 2009-2013
	93	National Survey, 2009-2013
	g/day	National Survey, 2009-2013

Table 1, Table 2, and Table 3 were used to calculate central tendency CDI and LADD of mineral contaminants from drinking water and foods ingestion. RQ of all contaminants in drinking water and foods are presented Table 4, while ECR of arsenic are presented in Table 5.

Table 4:

Risk quotient (RQ) (unitless) from exposure to selected trace transition metals, heavy metals, metalloids, and anionic contaminants in drinking water and foods among residents in artisanal gold mining site of Gunung Pongkor, Bogor

Risk agent	Drinking	Rice	Vegetables	Cassava	Banana	Fish	$RQ_{combine}$
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t	water						
Cr ⁶⁺	3.37	NQ	NQ	NQ	NQ	NQ	3.37
Mn	0.02	NQ	NQ	NQ	NQ	NQ	0.02
Fe	0.03	NQ	NQ	NQ	NQ	NQ	0.03
Zn	0.01	NQ	NQ	NQ	NQ	NQ	0.01
Cd	0.15	ND	ND	ND	ND	0.0 97	0.25
Me	0.09	2.7	ND	ND	ND	ND	2.79
Hg		0					
As	1.39	11. 35	12.93	0.55	0.46	14. 65	41.33
Se	0.04	NQ	NQ	NQ	NQ	NQ	0.04
CN ⁻	86.02	NQ	NQ	NQ	NQ	NQ	86.02
F ⁻	26.34	NQ	NQ	NQ	NQ	NQ	26.34
NO ₂	1.85	NQ	NQ	NQ	NQ	NQ	1.85
-							
NO ₃	0.99	NQ	NQ	NQ	NQ	NQ	0.99
-							

ND = the occurrence of this contaminant was not detected (<detection limit). NQ = these contaminants were not quantified (measured).

Table 5:

Lifetime excess cancer risk (ECR, unit/lerss) from exposure to arsenic in drinking water and foods among residents in artisanal gold mining site of Gunung Pongkor, Bogor

Media	Exponential	Per Population No.
Drinking water	2.69E-4	1/3,717
Rice	2.19E-3	1/457
Vegetables	2.49E-3	1/402
Cassava	1.06E-4	1/9,434
Banana	8.85E-5	1/11,299
Fish	6.60E-3	1/151

Discussion

Mineral Contaminants

Table 1 show that mean concentrations of 10 out of 15 drinking water contaminants comply with the existing drinking water standard of Peraturan Menteri Kesehatan (Minister of Health Regulation) No. 492/Menkes/Per/IV/2010 (herein after referred to as Permenkes 492/2010), while concentration of chromium, mercury, arsenic, cyanide, fluoride, and nitrite exceeds the standard. These contaminants in drinking water had not been investigated previously, so the seasonal or temporal variation of mineral concentration cannot be evaluated. Compared to Permenkes 492/2010, concentration of contaminants ranges from 0.03 to 700 folds their standards with the following order: cyanide (700)>fluoride (30)>chromium (5.8)>nitrite (1.8)>arsenic (1.2)>aluminum (1.05)>nitrate (0.91)>cadmium (0.73)>lead (0.5)>mercury (0.25)>iron (0.23)> selenium (0.2)>manganese (0.17)>copper and zinc (0.03). Accordingly, there are top five critical contaminants in drinking water i.e. cyanide, fluoride, chromium, nitrite, and arsenic. Mercury is not in priority as it only at 10th position. This figure is different from health risk estimates order where mercury is in the 5th position after chromium (see Health Risk Estimates below).

Since all the selected contaminants were detected in drinking water samples with detection rate ranging from 4.5% (cyanide and zinc) to 90.5% (chromium), the minerals of either naturally occurring or man-added in ASGM site has spread out in the ASGM site. However, as shown in Table 2, of four minerals analyzed only arsenic was detected in all foods. It suggests that water is primary exposure medium for mineral distribution among environmental media.

There are only few studies in gold mining sites of Gunung Pongkor investigating the occurrence of particular minerals. For example, in Cikaniki River, into which the artisanal gold extraction tailings were mostly disposed, concentration of manganese, aluminum, lead, and mercury was below the river water quality standard of Government Regulation (Peraturan Pemerintah, PP) No. 82/2001 (Yasuda et al., 2011). But, mercury in Cikaniki River sediment was detected at 0.83 to 1.07 mg/kg which was close to Indonesian sediment standard. In paddy samples, 0.08 mg/kg mercury was detected which was 44% lower than the present level of 0.18 mg/kg methyl-mercury (about 36% lower than 0.22 mg/kg total mercury).

Low level of mercury is inconsistent with commonly found in many ASGMs such as in Colombia (Marrugo-Negrete, Benitez, & Olivero-Verbel, 2008), Ghana (Nartey, Klake, Hayford, Doamekpor, & Appoh, 2011), Brazil (Cesar, Egler, Polivanov, Castilhos, & Rodrigues, 2011), Burkina Faso (Africa) (Tomicic, Vernez, Belem, & Berode, 2011), and in many parts of Indonesia. For example, in Central Kalimantan where about 43,000 small-scale gold miners operated, no less than 65.3 tonnes of mercury was used in 2008 only (Stapper, 2006). It was modelled that about 19.4 tonnes of mercury flows to main river system (Barito, Katingan, Kapuas, Kahayan, Sampit, Arut, Seruyan) annually. Even though, earlier study in Gunung Pongkor reported that mercury level in surface water was 1.7 mg/L (Tim Konservasi Pongkor, 2006). This level was 170% of the current standard of 0.01 mg/L (PP

82/2001). Surprisingly, in 2007 mercury level in Cikaniki River was only 0.00012 to 0.00022 mg/L (Yasuda et al., 2011), far lower the 2006 level.

Mercury and cyanide are assumed to be mostly man-added minerals. In industrial (modern) gold mining, cyanidation is used instead of amalgamation for gold extraction. In Gunung Pongkor, current concentration of cyanide in drinking water (49.34 ± 22.981 mg/L, Table 1) was extremely high, about 700 folds existing standard of 0.07 mg/L (Permenkes 492/2010). On the other hand, concentration of arsenic, mercury, chromium, and nitrite was only 1.2, 0.25, 5.8, and 1.8 folds its standard. This concentration profile is different with the corresponding health risk estimates as a result of consumption pattern (see Health Risk Estimates below).

The occurrence of high level cyanide in gold mining site was reported in Ghana (Obiri, Dodoo, Okai-sam, & Essumang, 2006). Cyanide concentration in Bogo River water at Ghana Bogoso Gold Limited has contributed to very high non-carcinogenic risk (RQ of 230 from drinking water ingestion and 43 from dermal contact). This means that the probability of impacted residents (consumers) experiencing possible health problems such as headache, breathing difficulties, weakness, and reduced haemoglobin levels was very high. But, in groundwater at gold mining site in Oman, cyanide was undetected (Abdalla, Suliman, Al-ajmi, Al-hosni, & Rollinson, 2010).

Cyanide may associate with other nitrogen species including nitrite, nitrate, and ammonia. Since currently nitrite level in drinking water exceeds its standard by 1.8 folds, cyanide transformation into less toxic nitrogen species may occur in water and soil and groundwater. It is well known that nitrite is an intermediate in the cyanide or thiocyanate biodegradation into nitrate involving several microbe species (see Management Options below). Due to high level of cyanide, nitrite in drinking water might be not only of natural origin but also generate from microbial degradation.

Cyanide might play as complexing (chelating) agent for transition and heavy metals resulting in coordination compounds (Abdalla et al., 2010). These compounds are pH-sensitive, where at basic pH they precipitate as hydroxide that might be indicated by low level of total dissolved solid and electrical conductivity. In fact, the pH of drinking water in Gunung Pongkor was acidic (6.74 ± 0.470 , Table 1). At this pH, metals become more soluble and cyanide may volatilize into hydrocyanic acid (HCN) gas. This transformation might be intensified during rainy season as rain water is normally acidic. It is therefore dilemma in gold extraction where on one hand the cyanidation can eliminate mercury hazard, but on the other hand it creates more solubility of toxic metals in water and HCN production in ambient air.

Similar to cyanide, the occurrence of fluoride in Gunung Pongkor has not been reported previously, might be because it was not considered as typical mineral in gold mining site. Rather, this anionic mineral is natural contaminant in drinking water which

concentration is commonly below its standard. Current fluoride concentration exceeding its standard by 30 folds is unusual and never been found anywhere.

High level of fluoride in drinking water might be associated with volcano activity (Mazziotti-tagliani et al., 2012), since Gunung Pongkor is nearby Gunung Salak, an active volcano in Bogor. In Dogubeya-zit and Caldi-ran areas which located around young Tendurek Volcano in eastern Turkey, fluoride level in natural waters ranged from 2.5 to 12.5 mg/L. It was hypothesized that fluoride might deposit on the surface of minerals, transported by fumaroles or escaped from devitrified lavas, and finally trans-formed in high pH environment into dissolved species at the foothills of the Tendurek Volcano. At area closed to Pliocene lake containing amorphous microscopic fluorite in south-midwest of Turkey, fluoride level in ground-water was 0.7 to 2.0 mg/L (Oruc, 2008). This finding suggests that volcano nearby Gunung Pongkor might be responsible for high level of fluoride in drinking water. In fact, gold-silver deposit in Gunung Pongkor is similar to that of Tendurek Volcano, that is, Pliocene supergene-enriched epithermal gold-silver-manganese type, a low-sulfidation epithermal type located close to the internal rim of a volcano-tectonic depression (caldera) (Basuki et al., 1994). Unfortunately, fluoride was intentionally not quantified in other exposure media that human might contact to.

Similar to fluoride, the occurrence of chromium in drinking water in Gunung Pongkor has not been reported previously. Chromium in trivalent species [(Cr(III))] is essential, but in hexavalent state [Cr(VI)] is toxic. Cr(III) is essential in glucose and lipid metabolism, while Cr(VI) is known as human carcinogen by inhalation. So far, there is no study on exclusive exposure to Cr(III), while its role in mixture with Cr(VI) is unknown (US-EPA, 1998). In the present study, chromium was determined as total chromium.

Unlike other minerals, arsenic was detected in drinking water and in all foods, although its detection rate in drinking water was only 4.5%. It indicates that arsenic is a natural mineral in the gold mining site, although the occurrence of this metalloid in drinking water and foods in Gunung Pongkor has not been reported previously. In Buyat village in Manado at closed proximity to finished Minahasa gold mining site, arsenic level in groundwater (used for drinking water by local community) was 0.04 to 0.1 mg/L, four to 10 folds Permenkes 492/2010 standard of 0.1 mg/L (BTKLPPM-Manado, 2005). Compared to this level, by mineral level Gunung Pongkor could be considered as non-endemic area of arsenic.

Since arsenic was detected in drinking water and all foods, Table 4 can be used to derive relative contribution source (RCS) of individual medium to the total media for arsenic intake. For example, RCS of drinking water is $1.39/41.33 = 3.36\%$. Therefore, RCS of drinking water, rice, vegetable, cassava, banana, and fish is 3.36%, 27.46%, 31.28%, 1.33%, 1.11%, and 35.45%, respectively. US-EPA assumes that the highest RCS of drinking water for metal contaminant ingestion is 80% (US-EPA, 1990). The RCS is important parameter

for management formulation as demonstrated later (see Proposed Management Option below).

Similar to fluoride, arsenic also might be associated with volcano activity. For example, concentration of arsenic in mud of volcanoes in south-western Taiwan was up to 0.12 mg/L (C.-C. Liu et al., 2012). The area is located at arc-continent collision belt in the Western Pacific between the Philippine Sea plate and the Eurasian Continental plate. Meanwhile, in the groundwater of Cimino-Vico volcanic area in central Italy, concentration of arsenic was as much 0.195 mg/L (Angelone, Cremisini, Piscopo, Proposito, & Spaziani, 2009). This location is close to areas of volcano-tectonic structures of potassic series in Cimino and high-potassium series in Vico complexes in the Roman Province. This finding suggests that arsenic and fluoride are likely to be found at high level in the vicinity of volcanic area such as Gunung Pongkor.

Aluminum in drinking water is of the lowest concern as its concentration is only 1.05 fold its standard. Previously, aluminum concentration in Cikaniki River was 0.14 to 0.16 mg/L (Yasuda et al., 2011), slightly lower than the current mean level of 0.208 ± 0.167 mg/L. Aluminum is a natural contaminant of drinking water and its concentration is normally below the standard of 1.5 mg/L of Permenkes 492/2010.

Health Risk Estimates

Table 1 and Table 2 show that mineral contaminants of concern in Gunung Pongkor are cyanide, arsenic, fluoride, chromium, mercury, and nitrite that contributed to high values of RQs from drinking water and foods (Table 4). By health risk estimates, the risk order is cyanide>arsenic>fluoride>chromium>mercury>nitrite. Essential microminerals (manganese, iron, zinc, selenium) are of less concern since its $RQ < 1$. Cadmium also has $RQ < 1$, although this mineral was detected in drinking water and fish. Nitrate is in borderline with RQ approaching 1.

More remarkable risks are shown in Table 5 where all the exposure media contributed to unacceptable carcinogenic risks of arsenic. Among exposure media, fish ingestion resulted in highest carcinogenic risks of 1/151, meaning that there will be one person among 151 who will develop cancer over lifetime. Since by convention the highest acceptable carcinogenic risk is 1/10,000 (US-EPA, 2005), carcinogenic risk from exposure to arsenic in Gunung Pongkor is extremely high. Overall, the carcinogenic risk order in foods is fish>vegetables>rice>drinking water>cassava> banana.

For non-carcinogenic risk, cyanide is the most critical mineral in drinking water (Table 4). However, its level in foods is unknown. Among the raw foods analyzed, cassava (singkong, ubi kayu, sampeu, or dangdeur in local language) is important for its cyanide content. Recent study reported that total hydrocyanic acid (HCN) in ready-to-eat cassava

chip was 13 to 165 mg/kg dry weight (Miles et al., 2011). In 2008, Australia New Zealand Food Standards Code set HCN level in cassava at 10 mg/kg. Unfortunately, cyanide level in local cassava grown in Gunung Pongkor was not quantified. Therefore, current total RQ of cyanide in the present study might be under estimate, since cassava is often consumed as snack food for carbohydrate source. In addition, cyanide may also present in different food crops and edible animals.

Arsenic in drinking water and foods is of special concern for its non-carcinogenic and carcinogenic toxicities. For non-carcinogenic risk, combined RQ from drinking water and foods is in the second top six minerals (Table 4), although by concentration arsenic is in the lowest rank of the five top minerals (see Mineral Contaminants above). For carcinogenic risk, all foods have unacceptable risk ($ECR > 10,000$). For this reason, arsenic should be placed in the first rank of the six risky minerals. Because there are still lot of food items that were not analyzed for arsenic content, current health risks of both non-carcinogenic and carcinogenic effects might be under estimate. In the present study, raw foods were selected arbitrarily rather than systematically due to limited food frequency data. In fact, Sundanese (native west Java) people can prepare about 50 food varieties for meals and snacks from fruits and vegetables (Suriawiria, 2009).

Ingestion of fluoride in drinking water resulted in RQ at third rank of the top six risky minerals (Table 4), although by concentration it was in the second to cyanide. This finding was unpredicted as so far no studies reported critical level of fluoride in the gold mining sites. High RQ value from exposure to fluoride in drinking water indicates that the probability of consumers experiencing adverse health effects of fluoride toxicity is very high. Chronic consumption of drinking water containing fluoride greater 4 mg/L may result in bone disease including pain and bone tenderness in adult and mottled teeth in children (US-EPA, 2013).

Fluoride is not essential but is beneficial to protect tooth decay if it ingested no more than 4 mg/day (US-EPA, 2010). Current fluoride standard of 1.5 for drinking water (Permenkes 492/2010) is lower than the US EPA secondary standard of 2 mg/L. This value is intended to protect moderate dental fluorosis (discoloration of the tooth enamel) (US-EPA, 2010). Therefore, fluoride level in drinking water is critical for its deficiency and toxicity dose.

Non-carcinogenic risk from exposure to chromium in drinking water was in the fourth position of the six top risks (Table 4). As the $RQ > 1$, the exposed residents are likely to be chronically experiencing nephrotoxicity, liver damage, kidney failure, and dermatitis (US-EPA, 1998). The present study used oral RfD of Cr(VI) for health risk estimate because oral RfD of total chromium is not available. In addition, excess cancer risk was also not estimated since concentration of chromium in ambient air was not determined. So, it is uncertain whether current health risk from chromium exposure is under estimate or over estimate.

Surprisingly, non-carcinogenic health risk from exposure to mercury is far lower than that of cyanide, arsenic, and fluoride. As mercury was extensively used by artisanal miners, it was previously predicted that this heavy metals would be predominant. However, health risk from mercury exposure is in the fifth rank of the six top risks. It has good agreement with previous study where total mercury level ranged from 0.00012 to 0.00022 mg/L in Cikaniki River water and 0.08 to 0.63 mg/kg in paddy, although the total mercury concentration in Cikaniki River sediment (0.83 to 1.07 mg/kg) closed to Indonesian standard (Yasuda et al., 2011). This finding raises question whether the artisanal miners used cyanidation rather amalgamation for gold extraction, or Antam cyanidation has impacted outside its mining site. In the present study, this issue was not addressed. It is inconclusive whether artisanal miners have stopped using amalgamation.

Management Options

Health risk estimates (Table 4 and Table 5) clearly show that cyanide, arsenic, fluoride, mercury, chromium, and nitrite are the top six contaminants that should be controlled properly. Of these, cyanide and arsenic are of primary concerns for some reasons as discussed above. In general, risk management to prevent the likelihood of adverse health effects from exposure to toxic agent could be by (i) reducing contaminant level, (ii) reducing contact rate (i.e. exposure frequency and duration), and (iii) combining (i) and (ii) in realistic manner. The management options below are proposed to be implemented by local community.

At this time, there are chemical, physical, and biological processes to detoxify cyanide that have been used in commercial application. The processes include SO₂/air (INCO process), copper catalyzed hydrogen peroxide, Caro's acid, alkaline breakdown chlorination, iron precipitation, granular activated carbon, cyanide recovery, and natural attenuation (Akcil & Mudder, 2003). Meanwhile, microbial destruction has been applied since many decades based on natural processes by bacteria which use cyanide as source of carbon and nitrogen for their life.

Recently, a simpler chemical process has been tried using hypochlorite to oxidize cyanide (Khodadad, Teimoury, Abdolahi, & Samiee, 2008). High level of cyanide of as much 270 mg/L in gold mining wastewater was successfully oxidized to cyanate (CNO⁻) by sodium hypochlorite (NaOCl) or calcium hypochlorite (Ca(OCl)₂) over a pH range of 6 to 13 and temperatures 25 to 50 °C. Cyanide was completely removed at higher temperature (up to 65 °C) and pH of 12.3 where cyanate further degraded to ammonia and carbon dioxide. This redox technique could be appropriate to current problem of cyanide in Gunung Pongkor, since NaOCl and Ca(OCl)₂ are commonly used for drinking water disinfection. However, this technique should be applied with caution. Although detoxification can be carried out at lower pH, high pH (>7) condition is recommended to prevent HCN formation and evaporation. Ca(OCl)₂ instead of NaOCl could be appropriate as it can adjust water to higher pH.

This removal technique could be applied in community level. For a pilot scale, a detoxification tank or pond with sufficient volume to supply drinking water to a Rukun Tetangga (neighbour households unit consisting of 40 to 60 households) is required. Simple direct-reading instruments to measure pH, temperature, suspended solid, dissolved metals, cyanide and metal concentrations, and $\text{Ca}(\text{OCl})_2$ doses should be provided. For safety reason, the removal process should be operated by well-trained technicians under government authority or professional supervision. Therefore, further study is required to construct proper design and process that can be operated with affordable cost to local people.

In addition to traditional chemical processes, cyanide in drinking water and wastewaters can be removed by microbial destruction in both aerobic and anaerobic condition. In aerobic condition, nitrogen cyanide is firstly converted to bicarbonate and ammonia. Ammonia is then converted to nitrite which finally oxidized to nitrate. This process can use many microorganisms such as *Actinomyces*, *Alcaligenes*, *Arthrobacter*, *Bacillus*, *Micrococcus*, *Neisseria*, *Paracoccus*, *Pseudomonas*, and *Thio-bacillus* genera (Akcil & Mudder, 2003).

This process could be applied at community level. Some *Pseudomonas* species, which can completely convert cyanide into nitrate, have been used in commercial application to detoxify gold mining wastes, but *Bacillus subtilis* and *Pseudomonas stutzeri* are the most tolerable bacteria against high level cyanide (Nwokoro & Dibua, 2014). *Bacillus subtilis* and *Pseudomonas stutzeri* degraded soil cyanide in 10 days from 218 mg/kg to 72 mg/kg (66.9% reduction) and from 218 mg/kg to 61 mg/kg (72% reduction), respectively. Reduction rate was higher (88.5%) when *Bacillus subtilis* and *Pseudomonas stutzeri* were mixed. *Bacillus subtilis* and *Pseudomonas stutzeri* were isolated from cassava processing site.

However, successful biological degradation of cyanide depends on the requirement of bacteria growth. Particular conditions such as pH, temperature, oxygen level, microbial population, minerals, and time, in addition to nutrient requirement such phosphorus, should be properly controlled (Akcil & Mudder, 2003). Again, direct reading instruments to measure such parameters are required. Biotechnological treatment of cyanide is more affordable in operating cost, but its process is usually longer than that of chemical processes.

Unlike cyanide, arsenic is difficult to degrade into less toxic species, partly because this metalloid has different oxidation state (-3, 0, +3, +5) with different physicochemical properties. As such, the appropriate method to reduce arsenic toxicity is immobilization of its bioavailable species (Kruger, Bertin, Heipieper, & Arsène-ploetze, 2013). There are technologies for arsenic removal from drinking water such as coagulation, precipitation, ion-exchange, reverse osmosis, electro-dialysis, and adsorption. Of these, adsorption technique has been widely used.

Recently, iron-modified bamboo charcoal (BC-Fe) was used as adsorbent for arsenic removal from aqueous systems (Liu, Ao, Xiong, Xiao, & Liu, 2012). To prepare BC-Fe material, iron was impregnated by soaking it in a ferric salt solution. Using this adsorbent of

63 to 125 μm in size, 19.8 mg As^{3+} can be adsorbed in one g BC-Fe charcoal from water at pH 3 to 4 in 30 hours. Unlike iron oxide powder, this modified bamboo charcoal can be easily separated from water by filtration. Iron oxide is the best adsorbent for arsenic, but if not soaked in charcoal its fine powder is difficult to separate from water.

Although granular material such as sand, cement, zeolite, cellulose, and sponge can be used to impregnate iron, activated charcoal is preferable for its high surface area. However, activated charcoal is expensive. Bamboo charcoal is less expensive than activated charcoal. It can be prepared by thermal decomposition of bamboo tree. As bamboo trees are available and accessible in rural area, adsorption technique for arsenic removal using modified bamboo charcoal could be applied in community scale. To eliminate arsenic hazard after adsorption, arsenic-containing BC-Fe charcoal can be immobilized by encapsulating it in concrete (Chintalapati, Davis, Hansen, Sorensen, & Dixon, 2009). However, laboratory and pilot scales are required to find out optimal condition for BC-Fe preparation and activation and arsenic removal efficiency and effectiveness from drinking water.

High arsenic level in drinking water may also be treated by biological process. In water and soil some microorganisms can convert arsenic to less toxic species. Different microorganism has different detoxification modes, but all microorganisms have resistant mechanisms against arsenic toxicity through active extrusion, extracellular precipitation, chelation or ligation, intracellular sequestration, electron transfer, methylation of inorganic species, and demethylation of organic species. These mechanisms govern bioavailability of arsenic in water and sediment (Kruger et al., 2013).

Until now, biodegradation of arsenic has not been used in commercial application for industrial wastes remediation. Understanding towards bio-detoxification mechanism is in progress and being reviewed (Kruger et al., 2013). Studies on arsenic biodegradation are mostly concentrated on identification of arsenic-resistant bacteria and physicochemical condition of the bacteria for maximum arsenic removal. For example, in West Bengal, India, 64 arsenic-resistant bacteria have been isolated including *Agrobacterium* or *Rhizobium*, *Ochrobactrum*, and *Achromobacter* genera (Sarkar, Kazy, & Sar, 2013). These bacteria produced enzymes such as arsenite oxidase and phosphatase. In the presence of these enzymes, the bacteria use As^{3+} [As(III)] as electron donor to gain energy heterotrophically and thus oxidized As^{3+} to less toxic As^{5+} [As(V)] species.

In Dhulikhel, Nepal, the influence of iron and manganese towards the ability of *Staphylococcus aureus*, *Bacillus subtilis*, *Klebsiella oxytoca*, and *Escherichia coli* to detoxify As^{3+} was investigated (Shrestha, Lama, Joshi, & Sillanpää, 2008). Of these microbes, *S. aureus* was the best arsenic remover which completely removed As^{3+} in 48-hour culture with and without Fe and Mn supplementation. Addition of Fe and Mn salts increased removal efficiency of all microbes. In *S. aureus* culture, addition of Fe and Mn salts increased arsenic removal efficiency by 32% in 24 hours.

Other example of biodegradation method for arsenic removal is co-precipitation of As(III) and As(V) with Fe(III) and sulfate in water and sediment. In Carnoulès mine in France, iron-oxidizing microbes (e.g. *Acidithiobacillus ferrooxidans*, *Alicyclobacillus ferrooxydans*, *Ferrimicrobium*, or *Gallionella*) and arsenic-oxidizing microbes (e.g. *Thiomonas* sp.) were identified in pale-yellow As(V)-Fe(III) hydroxysulfate sediment (Bruneel et al., 2011). The authors suggests that those bacteria are responsible for changing the ratio of the oxidized to the reduced forms of iron, arsenic, and sulphur leading to formation of Fe(III)-As(V) hydroxysulfate co-precipitates.

In addition to technological control measures as described above, health risks from multi pathways exposure to mineral contaminants can be managed by fostering safe intake. This control measure can be implemented at individual level. That is, individuals in the community are encouraged to control their daily intakes in such a way that the intakes are not exceeded the reference toxicity levels. To do so, contribution of every exposure medium to overall exposure media should be known. For the present study, only safe intake from exposure to arsenic can be formulated.

Safe intake for non-carcinogenic and carcinogenic health risks can be derived from Eq. (1). According to this equation, there are two parameters that can be controlled i.e. (i) consumption rate and (ii) contact time rate (exposure frequency and exposure duration). To define safe consumption rate, Eq. (1) is rearranged to Eq. (2):

$$R = \frac{CDI \times W_B \times t_{avg}}{C \times f_E \times D_E} \quad (2)$$

Safe consumption can be achieved if CDI is equal to or less than RfD. CDI of each exposure medium is computed according its RCS. For example, RCS of fish is 34.45% (see Mineral Contaminants above). Therefore, allocated CDI of fish to arsenic intake is 34.45% of the RfD, that is, 0.00010335 mg/kg/day. Other assumption is constant exposure frequency of 350 day/year. Using this value and other parameter values from Table 1, Table 2, and Table 3, the safe consumption rate for fish is:

$$R_{As-Fish} = \frac{0.00010335 \frac{\text{mg}}{\text{kg} \times \text{day}} \times 55 \text{ kg} \times 30 \text{ year} \times 365 \frac{\text{day}}{\text{year}}}{2.71 \frac{\text{mg}}{\text{kg}} \times 350 \frac{\text{day}}{\text{year}} \times 30 \text{ year}} = 21.9 \text{ g/day}$$

The safe fish consumption rate of 21.9 g/day is about 23% of current rate (Table 3). Safe consumption rate of other exposure media is calculated using allocated CDI according to each RCS. Overall, simultaneous scenario for safe consumption rates of drinking water and foods is summarized in Table 6.

Table 6:

Summary of safe simultaneous consumption scenario for arsenic intakes based on allocated chronic daily intake (CDI), assuming constant exposure frequency of 350 years/day over 30-year exposure duration

Exposure media	Current rate	Allocated safe CDI (mg/kg/day)	Calculated safe rate	Reduction rate (%)
Drinking water	2 L/day	0.00001008	0.41 L/day	79.5
Rice	86 g/day	0.0000822	2.08 g/day	97.6
Vegetables	134 g/day	0.00009387	3.24 g/day	97.6
Cassava	3.5 g/day	0.0000039	0.08 g/day	97.7
Banana	5.6 g/day	0.0000033	0.13 g/day	97.7
Fish	93 g/day	0.00010335	2.19 g/day	97.7

Safe consumption scenario as presented in Table 6 is impossible to be implemented. The calculated values for safe consumption rate are extremely small with reduction rate of almost 100%. Similarly, scenario for safe exposure frequency and exposure duration cannot be implemented since the reduction rates are extremely high (data not shown). Therefore, in Gunung Pongkor the likelihood of adverse effects of arsenic should be managed by applying appropriate removal technologies.

In conclusion, non-carcinogenic health risk from exposure to cyanide is much higher than those from arsenic, fluoride, chromium, mercury, and nitrite. Surprisingly, health risk from exposure to mercury is far lower than arsenic and fluoride, slightly lower than chromium, but a little bit higher than nitrite. Arsenic was detected in drinking water and all foods attributing to very high unacceptable ECR. Iron, manganese, cadmium, zinc, selenium, and nitrate are not risky as each $RQ < 1$. Higher level of contaminant is not necessarily resulted in higher health risk, because chronic intake depends also on parameters other than concentration such as contact time rate and consumption rate. High level of fluoride and arsenic in drinking water might be associated with volcanic activity as Gunung Pongkor is closed to Gunung Salak volcano. Some simple technologies including oxidation of cyanide by hypochlorite, biodegradation of cyanide by particular cyanide-resistant bacteria, and adsorption of arsenic by modified bamboo charcoal might be appropriate for detoxification measure at community level. Further studies are recommended to understand biogeocycle contamination mechanism of cyanide and fluoride, to investigate distribution of toxic mineral in foods, and to design laboratory and pilot scales for cyanide and arsenic removal.

Acknowledgment

The authors wish to thank Health Research and Development Agency (Litbangkes) of the Ministry of Health for fully financial support, Health Office of Bogor Regency for

facilitating administrative arrangement, and Puskesmas (primary health center) of Nanggung Sub-District for facilitating field data collection.

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