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Potential Health Risks From Mercury (Hg) Exposure Through Rice Consumption In The Sijunjung Gold Mining Area, West Sumatera

Potensi Risiko Kesehatan Akibat Pajanan Merkuri (Hg) Melalui Konsumsi Beras di Kawasan Pertambangan Emas Sijunjung, Sumatera Barat

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ABSTRACT

Accumulation of mercury (Hg) in food crops can pose serious health risks to humans. In Indonesia, the population may be exposed to mercury through rice consumption, a staple food cultivated in areas surrounding gold mining sites. This study aimed to estimate the health risk associated with mercury exposure through rice consumption among communities living near gold mining areas in Sijunjung Regency, West Sumatra, Indonesia. The study was conducted in artisanal and small-scale gold mining (ASGM) areas using a public health risk assessment approach, determining the risk quotient (RQ) by comparing estimated daily intake (EDI) with the reference dose (RfD) to evaluate real-time and lifetime risk levels. Rice (n = 6) and water (n = 6) samples were collected from paddy fields located near the mining areas, along with one market rice sample (n = 1) as a comparison. A total of 103 adult respondents were included in this study. Data were collected through structured interviews using a standardized questionnaire that assessed consumption habits and lifestyle patterns, including body weight. The results showed that the mean total mercury (T-Hg) concentration in rice from ASGM areas ranged from 0.0087 to 0.01 mg/kg. Exposure assessment indicated that the community was exposed to mercury at levels of 0.053 to 0.23 µg/kg/day through rice consumption. The risk quotient (RQ) values indicated a relatively low risk level based on the analyzed rice consumption pathway. In conclusion, mercury intake from rice consumption in communities around gold mining areas in Sijunjung Regency remains within a tolerable daily intake level. However, potential exposure through other pathways, such as inhalation and consumption of other food sources, warrants further investigation.

Keywords: ASGM, gold mining, health risk, mercury, rice, food safety

ABSTRAK

Akumulasi merkuri (Hg) pada tanaman pangan dapat menimbulkan dampak serius terhadap kesehatan manusia. Di Indonesia, masyarakat berpotensi terpapar merkuri melalui konsumsi beras sebagai makanan pokok yang dibudidayakan di sekitar kawasan pertambangan emas. Penelitian ini bertujuan untuk mengestimasi risiko efek kesehatan akibat pajanan merkuri melalui konsumsi beras pada masyarakat yang tinggal di sekitar kawasan pertambangan emas di Kabupaten Sijunjung, Sumatera Barat, Indonesia. Penelitian ini dilakukan di wilayah pertambangan emas skala kecil dan tradisional (artisanal and small-scale gold mining/ASGM) dengan pendekatan analisis risiko kesehatan masyarakat melalui penentuan nilai risk quotient (RQ) berdasarkan perbandingan estimasi asupan dengan reference dose (RfD) untuk menilai tingkat risiko secara real time dan seumur hidup. Sampel beras (n=6) dan air (n=6) dikumpulkan dari lahan sawah di sekitar area pertambangan emas, serta satu sampel beras pasar (n=1) sebagai pembanding. Sebanyak 103 responden dewasa dilibatkan dalam penelitian ini, dengan pengumpulan data melalui wawancara menggunakan kuesioner standar terkait kebiasaan konsumsi dan pola hidup, termasuk pengukuran berat badan responden. Hasil penelitian

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menunjukkan bahwa rata-rata konsentrasi T-Hg pada beras dari kawasan ASGM berkisar sebesar 0,02 mg/kg. Estimasi pajanan menunjukkan bahwa masyarakat terpapar merkuri sebesar 0,06 µg/kg/hari (real time) dan 0,03 µg/kg/hari (seumur hidup) melalui konsumsi beras, dengan rata-rata konsumsi beras sebesar 292 gram per hari. Nilai risk quotient (RQ) < 1 menunjukkan tingkat risiko yang relatif rendah berdasarkan parameter konsumsi beras yang dianalisis. Dengan demikian, asupan merkuri melalui konsumsi beras di sekitar kawasan pertambangan emas di Kabupaten Sijunjung, Sumatera Barat, masih berada pada tingkat yang dapat ditoleransi untuk konsumsi harian. Namun demikian, pajanan merkuri melalui jalur lain, seperti inhalasi dan konsumsi jenis pangan lainnya, masih perlu diteliti lebih lanjut.

Kata Kunci : ASGM, Pertambangan emas, Risiko kesehatan, Merkuri, Beras

INTRODUCTION

Mercury (Hg), especially in the form of methylmercury (MeHg), is the most toxic form to human health[1–3]. Mercury is easily absorbed into the bloodstream and can cause serious health problems such as neurological disorders, damage to the cardiovascular system, and negative effects on the reproductive and immune systems. The spread of mercury occurs through air, water, and the food chain, so it can cover a large area [4,5]. Since the Minamata disease case in Japan, the impact of mercury on health has become a global concern, especially in areas vulnerable to mercury pollution, such as artisanal gold mining areas [6,7].

Artisanal gold mining is a small-scale gold mining activity carried out by local communities using simple methods, which, although it provides employment for more than two million people and contributes to the local economy, the use of mercury in the process creates significant environmental pollution and health risks for miners [8–11]. The gold refining process in gold mining often involves the use of mercury as an amalgam, which can pollute the environment because mercury waste is often discharged into waterways. The waste can accumulate in rice plants around the mining area through irrigation sources, potentially exposing people who consume rice from these fields to mercury. PER accounts for 37% of total global mercury emissions, with an estimated release of about 4,100 tons of mercury per year [1,11].

People's Gold Mining (PER) is a major source of mercury emissions in Indonesia, particularly in Sumatra, Kalimantan, and Papua. These mercury emissions have the potential to pollute surrounding ecosystems and agricultural land. Studies have shown that rice grown on mercury-contaminated land can absorb mercury at a higher rate than other crops, endangering the health of people who consume the rice [1,11,13,14]. Indonesians, as one of the largest rice consumers in the world, may be an at-risk population in terms of the health effects of mercury exposure in rice. However, risk assessment and estimation of public health effects of mercury exposure through rice consumption in Indonesia is still very limited.

The presence of artisanal gold mining (PER) in Indonesia is a major source of mercury exposure, especially in agricultural areas that are prone to soil and irrigation water contamination. Research shows that 88% of stunted toddlers in small-scale gold mining areas had urinary mercury levels exceeding the safe threshold of 7 µg/L, and 99% of children aged 25-59 months also showed similar mercury levels [15]. Environmentally, ASGM's activities contribute significantly to atmospheric mercury pollution. Concentrations of mercury around the gold refining site reach 14,000 ng/m³, and the soil mercury content reaches 8.9 mg/kg. In addition, a study in Sekotong, Indonesia, recorded soil mercury levels of 0.3089 ppm, with mercury adsorption influenced by soil texture and composition [18].

Mercury exposure is also a risk to the agricultural sector, where plants can absorb mercury and introduce it into the food chain [19,20]. Although some studies suggest that the health risks of consuming mercury-contaminated crops may be low, long-term effects remain a concern [19,21]. Disturbances to agricultural ecosystems can lead to the degradation of soil and water quality, which are essential for sustainable agriculture [22,23].

The potential bioaccumulation of mercury in the food chain demands continuous monitoring and research to protect public health and ecosystem sustainability.

The presence of artisanal gold mining in Sijunjung Regency, West Sumatra, is one of the areas with the largest artisanal gold mining activities in West Sumatra. Several previous studies have shown indications of mercury pollution in river water in this region, but no study has specifically examined mercury content in rice consumed by local communities. Therefore, this study was conducted to analyze the public health risks associated with mercury exposure in the artisanal gold mining area of Sijunjung Regency through rice consumption. This research is expected to identify indicators of exposure, provide an initial assessment of potential health risks, and serve as a basis for mitigation measures to protect the community from the negative impacts of mercury exposure.

METHODS

This study used a quantitative approach with the Environmental Health Risk Assessment (EHRA) method. The EHRA method estimates health risks from exposure to certain chemicals in the environment by measuring intakes from various pathways. This study measured mercury (Hg) intake in the community around artisanal gold mining in Sijunjung Regency, West Sumatra, through rice consumption. A total of 103 adult respondents were included in this study. Data were collected through interviews using a standardized questionnaire assessing consumption habits and activity patterns, including body weight measurement.

Rice samples were collected from rice fields around artisanal gold mining, totaling 7 samples (6 from local rice fields and 1 from the market as a comparison). The rice taken was white rice that had been peeled and put into a plastic zip. In addition, 6 samples of paddy field water were taken to assess indicators of pollution using a 1-liter PP bottle containing nitric acid (HNO_3). Total mercury (T-Hg) was measured in rice and paddy field water samples using the cold vapor atomic absorption spectrophotometry (CV-AAS) method conducted by the Laboratory of the Padang Industrial Standardization and Services Center [24]. Rice samples were dried at 40°C for 2 days in an oven dryer to reduce moisture content, after which the rice was pulverized by pounding and sieved through a 150-micron sieve[25,26]. Rice flour is then deconstructed with HNO_3 and H_2SO_4 at 100°C heating, and the addition of H_2O_2 as an oxidizing agent [27,28]. Measurement of total mercury concentration was carried out at a wavelength of 253.7 nm using a mercury analyzer with the CV-AAS technique [29,30]. Water samples were treated at 100 ml with the same procedure [31,32]. To ensure test results quality, the test was repeated 3 times (triplicate), and standard mercury test materials were used.

Intake was calculated by modifying the probable daily intake formula for mercury (WHO, 1990) and exposure assessment (US EPA, 1992). The intake is the product of concentration (C = μg/kg), consumption rate (R = grams/day), frequency (f = days/year), and duration of exposure (Dt = years), divided by the product of body weight (Wb = kg) and average exposure time for non-carcinogenic exposure (Tavg = 30 x 365 days), shown in formula 1:

$$Intake = (C \times R \times f \times Dt)/(Wb \times Tavg) \quad .. (1)$$

Intake is measured in two conditions: real-time and lifetime. Real-time intakes are measured using data on actual exposure patterns in the community, collected through questionnaires, while lifetime intakes are measured using estimated values when exposure occurs over a lifetime.

The risk quotient (RQ) was calculated by comparing the intake value with the reference dose (RfD) (formula 2). The reference dose (RfD) of mercury was derived from the WHO provisional tolerable weekly intake (PTWI) of 4 μg/kg/week or 0.57 μg/kg/day. RQ value which greater than 1 is considered not safe.

$$RQ = Intake/ RfD \ldots\ldots\ldots\ldots.. (2)$$

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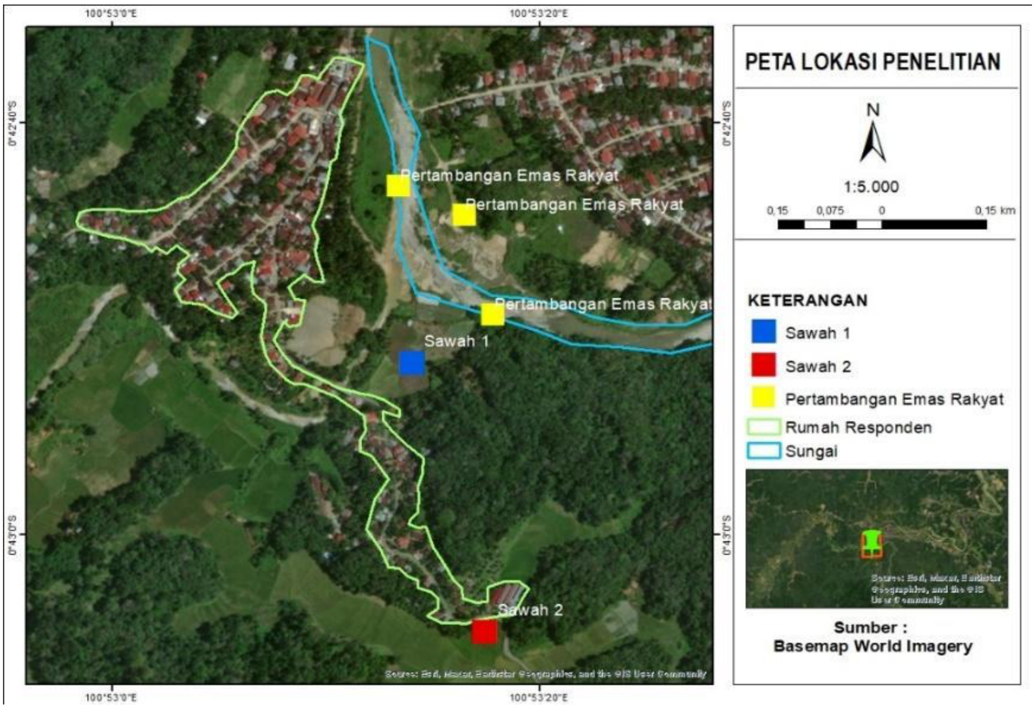

Figure 1. Research Location

RESULTS

In this study, the frequency distribution of respondents' characteristics is presented in Table 1. According to the table, 23 male respondents (22.3%) and 80 female respondents (77.7%) were included. Most respondents had a high school education (50 individuals; 48.5%), followed by elementary school (24 individuals; 23.3%), junior high school (20 individuals; 19.4%), and college education (9 individuals; 8.7%). Regarding occupation, the largest proportion of respondents were housewives (56 individuals; 54.4%), followed by self-employed workers (21 individuals; 20.4%) and farmers (18 individuals; 17.5%). A smaller proportion consisted of industrial laborers (2 individuals; 1.9%), students (2 individuals; 1.9%), and honorary employees (2 individuals; 1.9%), while drivers and civil servants each accounted for 1 individual (1%).

Table 1. Frequency Distribution of Respondents by Gender, Education, and Occupation (n=103)

No	Characteristics of Respondents	Frequency	Percentage (%)
1.	Gender		
	1. Male	23	22,3
	2. Female	80	77,7
2.	Last education		
	1. Elementary School	24	23,3
	2. Junior High School	20	19,4
	3. High School	50	48,5
	4. College	9	8,7
3.	Occupation		
	1. Industrial Worker	2	1,9
	2. Farmer	18	17,5
	3. Self-employee	21	20,4
	4. Housewife	56	54,4
	5. Driver	1	1
	6. Government employee	2	1,9
	7. Student	2	1,9
	8. Temporary employee	1	1

No	Characteristics of Respondents	Frequency	Percentage (%)
4	Age		
	1. 17 - 25 (Teenager)	10	9,7
	2. 26 – 45 (Adult)	42	40,8
	3. 46 – 75 (Elderly)	51	49,5

Anthropometric characteristics and community activity patterns were measured using questionnaires and scales in 150 communities. Measurements were carried out by direct interviews with the community so that data on age, weight, and length of residence were obtained. Then univariate analysis of anthropometric characteristics and community activity patterns with the results in table 2.

Table 2. Anthropometric Characteristics and Consumption Patterns

No	Characteristics	Mean	Med	Mode	Min	Max	SD
1	Age (year)	45,46	45	30	17	75	14,761
2	Body Weight (kg) / Wb	54,79	54	45	29	97	10,374
3	Exposure Duration (years) / (Dt)	37,34	40	40	2	75	20,235
4	Consumption Rate (R) (gram)	292,23	300	300	50	600	126,560
5	Exposure Frequency (days/year)/ (fE)	350	350	350	350	350	350

Based on Table 2, the community's average age was 45.46 years, with the youngest respondent aged 17 and the oldest aged 75. The average body weight was 54.79 kg, ranging from 29 kg to 97 kg. On average, respondents had lived in Nagari Muaro Bodi for 37.34 years, with a minimum duration of 2 years and a maximum of 75 years.

The average rice intake rate among the Muaro Bodi community was 292.23 g/day, with the lowest intake recorded at 50 g/day and the highest at 600 g/day. The exposure frequency at the study site was 350 days/year, consistent with the default value recommended in the ARKL guidelines. This assumption accounts for periods when residents are away from their homes, such as visiting relatives or traveling, and therefore do not continuously consume locally sourced food or water. Based on direct interviews using questionnaires conducted with 103 respondents, data were obtained on potential health symptoms associated with mercury exposure from rice consumption in paddy fields surrounding the Sijunjung gold mining area.

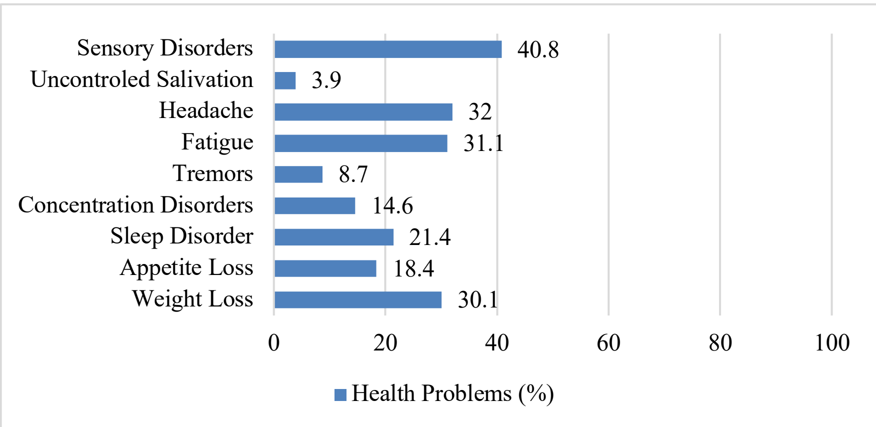

Figure 2. Health Problems among Respondents

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Figure 2 illustrates the symptoms experienced by respondents, including sensory disorders reported by 42 individuals (40.8%), followed by frequent headaches in 33 individuals (32%), easy fatigue in 32 respondents (31.1%), weight loss in 31 respondents (30.1%), sleep disturbances in 22 individuals (21.4%), impaired health conditions in 21 individuals (20.4%), decreased appetite in 19 individuals (18.4%), concentration disorders in 15 individuals (14.6%), tremors without an apparent cause in 9 individuals (8.7%), and excessive uncontrolled salivation in 4 individuals (3.9%).

Mercury Concentration in Rice

Rice was collected directly from rice fields in the Sijunjung Artisanal and Small Scale Gold Mining Area. The results of T-Hg concentration in rice are shown in Table 3. It shows that the concentration of mercury (Hg) in rice samples was still below the quality standard in accordance with the Indonesian National Standard (SNI) in 2009 & the regulation of the Head of the Indonesian Food and Drug Administration. The rice concentrations ranging from 0.0087 to 0.01 mg/kg.

Table 3. Mercury Concentrations in Rice

Code	Sampling Point	Mercury (Hg) (mg/kg)
B1	Rice Field 1	0.0087
B2	Rice Field 1	0.009
B3	Rice Field 2	0.01
B4	Rice Field 2	0.01
B5	Rice Field 2	0.01
B6	Rice Field 2	0.0087
B7	Local Market	0.0087

Mercury Concentration in Rice Field Water

Rice field water was obtained through direct collection of irrigation water from rice fields in the Sijunjung PER Area. The results are shown in Figure 3. Figure 3 shows that the concentration of mercury (Hg) in rice field water in Sijunjung Regency exceeds the predetermined quality standard of 5.5 µg/las, in set forth in Government Regulation Number 22 of 2021 concerning procedures for environmental protection and management. The quality standard limit for rice field water for mercury parameters is 5 µg/l.

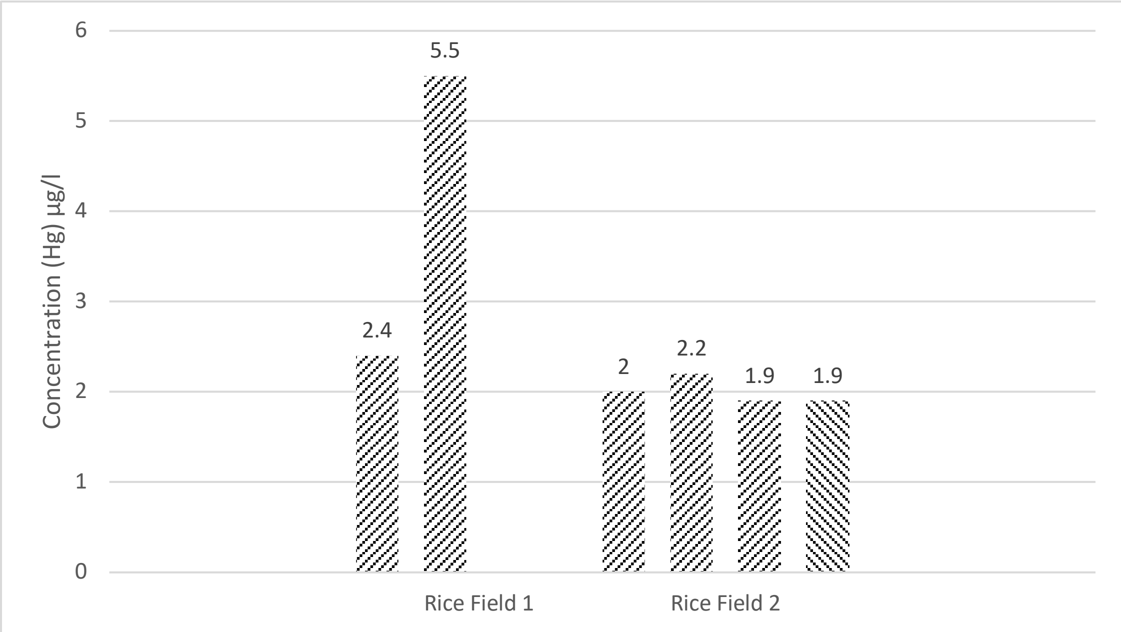

Figure 3. Mercury Concentration in Rice Field Water

Environmental Health Risk Analysis (EHRA)

The estimated mercury intake from rice consumption based on rice samples is presented in Table 4. The results indicate that residents living around the Sijunjung ASGM area were exposed to mercury through rice consumption, with intake levels ranging from 0.053 to 0.061 µg/kg/day. These intake values were calculated based on the average of exposure pattern values as shown in Table 5. The risk quotient (RQ) values ranged from 0.093 to 0.106 across all sampling points. Although slight variations were observed among locations, all RQ values remained below 1, indicating that the exposure to mercury through rice consumption at these sites is within acceptable risk levels.

Table 4. Intake value based on rice samples

No	Sampling Points	Hg Concentration (mg/kg)	*Intake* (µg/kg/hari)	*RQ*
1	Rice Field 1 (B1)	0,0087	0.053	0.093
2	Rice Field 1 (B2)	0,009	0.055	0.096
3	Rice Field 2 (B3)	0,01	0.061	0.106
4	Rice Field 2 (B4)	0,01	0.061	0.106
5	Rice Field 2 (B5)	0,01	0.061	0.106
6	Rice Field 2 (B6)	0,0087	0.053	0.093
7	Local Market (B7)	0,0087	0.053	0.093

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Table 5. Exposure Pattern Value

Variable	Value
C	8.7 to 10 µg/kg/day
R	0.292 kg/day
Dt	37.34 years
Fe	350 years
Wb	54.79 kg
*T*avg	365 day/year x 30 years (Non carsinogenic)
RfD	0.57 µg/kg/day

Table 5 shows that the average rice consumption rate of the community is 0.292 kg/day, which is slightly higher than the average rice intake rate of the Indonesian population per capita (0.222 kg/day). The average length of stay of the Muaro Bodi community is 37.34 years, exceeding the default value of 30 years based on EPA assumptions. The exposure frequency is 350 days/year, while the average body weight of the Muaro Bodi population is 54.79 kg. For non-carcinogenic exposure assessment, the averaging time used follows the default value of 365 days/year × 30 years.

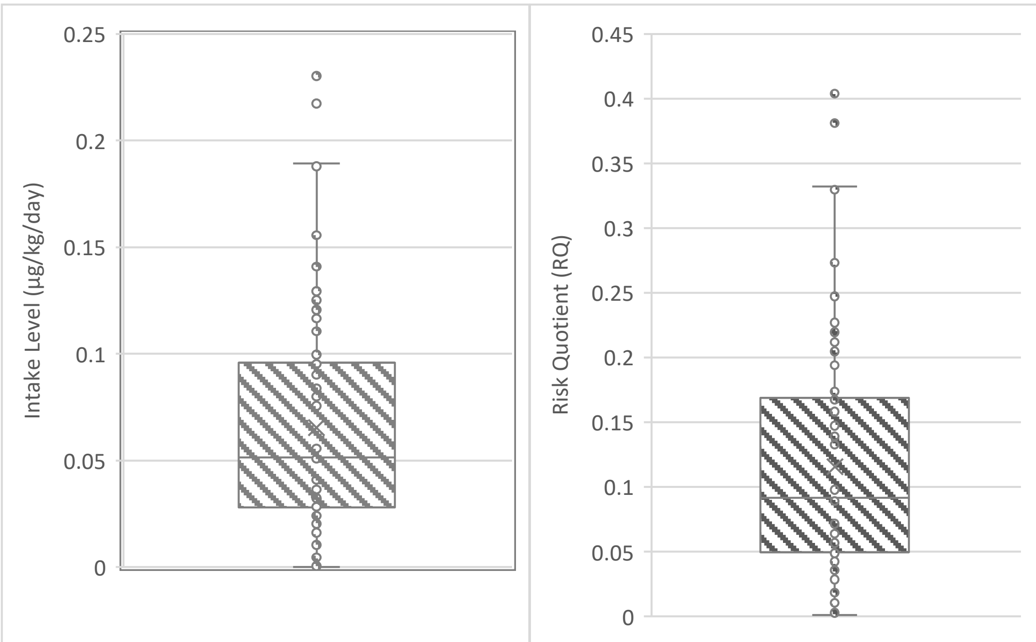

Figure 4. Distribution of Realtime Mercury Intake Level and Risk Quotient (RQ)

Figure 4 shows the distribution of realtime mercury intake and risk quotient (RQ) values among the Sijunjung ASGM community (n = 103). The results were calculated based on activity pattern values presented in Table 2. The intake values ranged from 0.0005 to 0.23 µg/kg/day, with a mean of 0.067 µg/kg/day. The standard deviation of 0.049 suggests moderate variability in individual intake levels. Similarly, the RQ values ranged from 0.0008 to 0.403, with a mean of 0.115. Despite the observed variability, all RQ values remained below the threshold of 1, indicating that mercury exposure through rice consumption among the studied population is within acceptable limits

DISCUSSION

The results of the study on rice and paddy field water in the PER area of Sijunjung Regency revealed that one water sample exceeded the established quality standard (5 µg/L), while the majority of samples remained below this threshold. This finding indicates a potential for mercury (Hg) contamination in the paddy field environment, although it does not appear to be the dominant pollutant. The total mercury (T-Hg) concentration in rice samples suggested that the rice is currently within the acceptable consumption limits set by the Indonesian National Standard (SNI) and the Indonesian Food and Drug Administration (BPOM)[33–37].

The presence of mercury in paddy field water indicates ongoing environmental contamination, most likely associated with artisanal and small-scale gold mining activities in the surrounding area. In addition, secondary inputs of mercury may originate from amalgam processing in residential areas, where inadequate waste management allows mercury to enter surface water systems and subsequently be transported into irrigation networks. Although mercury was not detected in rice samples above analytical limits, the existence of environmental contamination suggests a potential exposure pathway that warrants continued monitoring and further investigation [33–37].

Hg intake through rice consumption showed relatively small values compared to similar studies in West Java [1]. The low value of mercury intake from rice consumption also implies a low risk (RQ<1), indicating that the rice consumed is still has a potential risk with the current consumption pattern of the community. However, in this study, intake sources from other routes have not been assessed such as drinking water, air, and other types of foodstuffs. Some studies recommend that fish can be a potential source of mercury exposure in humans.

Mercury in river sediments can be distributed to downstream areas through currents, so mercury concentrations in rice fields connected to rivers are highly dependent on hydrological conditions, irrigation patterns and distance from the source of pollution [36]. In addition, the study revealed that the mobility of mercury in soil and irrigation water is influenced by the physicochemical conditions of the environment, such as pH, temperature, and the presence of organic matter. Under certain conditions, mercury tends to be trapped in sediment particles rather than dissolved in water, which may explain the low contamination of rice [38].

The presence of mercury in agricultural ecosystems is mainly influenced by water pollution sources and complex interactions with other environmental components, such as soil type and mercury speciation [39]. Other studies have also revealed that some rice varieties have genetic tolerance to heavy metals, including mercury, which can inhibit accumulation in grains despite high exposure in the growing environment [40]. This shows that genetic factors also play a role in determining mercury levels in crop yields, so rice varieties with low mercury accumulation can be an alternative in mitigating the impact of pollution.

The environmental impacts of mercury contamination are not only limited to aquatic and agricultural ecosystems, but can also increase health risks for people who depend on these resources. Mercury in irrigation water can undergo transformation into methylmercury, a more toxic form that easily accumulates in the food chain [41]. Therefore, regular monitoring of water quality and agricultural products in the affected areas is a must [7]. In addition, the implementation of effective mitigation strategies, such as phytoremediation techniques and more sustainable water resource management, needs to be considered to reduce the impact of heavy metal pollution [42].

Although research results show that the health risks of consuming mercury-exposed rice are low, long-term exposure is still a cause for concern. Mercury is known as a neurotoxin that can cause central nervous system disorders, such as tremors, motor disorders, and sensory disturbances, especially if it accumulates in the body. The results also indicated that tremors and sensory disturbances were more common among women and those aged 26-45 years, which may be due to the higher intake rate of rice compared to other groups. Previous studies have also shown that productive age groups with high levels of rice consumption are more susceptible to the toxic effects of mercury, as this substance can accumulate in the body and potentially damage the The presence of mercury in rice that is still below the detection limit should still be a concern, given the potential for cumulative exposure through the

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environment. Mercury found in rice paddy water can move through the food chain and cause wider impacts if not addressed immediately. Mitigation efforts, such as the closure of artisanal gold mines, have shown positive impacts in reducing the risk of mercury contamination. However, water quality monitoring and mine waste management must continue to prevent rising mercury levels that could endanger public health.

This study emphasizes the importance of sustainable environmental management to prevent mercury contamination from impacting long-term public health. Public education on the dangers of mercury and the implementation of environmentally friendly mining practices are important steps in reducing negative health impacts. With the right environmental management policies in place, health risks from mercury exposure can be minimized, allowing the sustainability of food production and the welfare of communities in affected areas to be maintained.

CONCLUSION

This study revealed that the average mercury concentration in rice remains below the quality standard. Mercury exposure through rice consumption was estimated to be below the risk threshold. However, this does not indicate the absence of risk, particularly under long-term exposure conditions. The presence of mercury contamination in paddy field water indicates environmental contamination and suggests a potential pathway for mercury transfer into the food chain. Therefore, these findings reflect a potential risk condition and highlight the need for further assessment of mercury exposure through multiple pathways, including other dietary sources such as fish.

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