Health risk assessment of consuming mackerel scads (*Decapterus macarellus*) contaminated by mercury

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Abstract. Gold processing activities undertaken by the community lead to environmental pollution in Hulawa Village, Indonesia. This study aims to determine public health risks of consuming mackerel scads (*Decapterus macarellus*) that contain the heavy metal mercury (Hg) in the aforementioned village. An observational analysis design of environmental health risks was employed. There were 30 environmental samples from 3 different locations and 82 human samples based on certain criteria. Data was collected mainly by direct interviews with respondents and examinations of laboratory samples. The collected data were then analyzed by the Health Risk Assessment method using Microsoft Excel and SPSS programs. The results indicate that the highest Hg concentration in mackerel scads was at the 2nd location showing a risk quotient (RQ) value greater than 1 of mackerel scads consumption. As for the 1st and 3rd locations, the RQ values were less than 1. Accordingly, the consumption of mackerel scads at the 2nd location contributes to public health risks. It is expected that people can limit the amount and frequency of mackerel scads consumption and cultivate the fish properly to reduce Hg concentrations.
Key Words: AAS, gold mining risk assessment, mercury exposure.

Introduction. A high amount of mercury can harm one's health (WHO 2016), and its most significant pathway to human exposure is through fish consumption and dental amalgam (WHO 2016; Weinberg 2010; Saturday 2018). Mercury used to be applied in gold processing, known as the amalgamation step, to separate gold from rocks. Mercury usage in artisanal and small-scale gold mining (henceforth, ASGM) is not adequately managed and is directly released in the environment (mainly rivers) without treatments (Palapa & Maramis 2015). Thus, mercury can evaporate into the atmosphere, travel and accumulate worldwide. It also seeps in river aquatic systems, adulterating fish, being transformed into methylmercury and accumulating in marine organisms (Pandey et al 2012; Kimáková et al 2018; Tamele & Loureiro 2020). Gold mining activities contribute with mercury pollutants to the environment and affect aquatic habitats (Mallongi et al 2015).

ASGM plays a crucial role and has a searchable place in many developing countries (Veiga et al 2005). It is among the main contributors to mercury pollution in the environment (air, water and soil), before coal combustion (UNEP 2012). Mercury, as a heavy metal in gold mining activities, polluts the aquatic environment after being released (Amqam et al 2020). 1400 tonnes of mercury are applied widely in ASGM, in the amlgamation process (UNEP 2012; Arifin et al 2014a). In rural areas, artisanal mining has engaged many people, because it has low requirements, simple technology and does not need special competencies. It also gives the gold miner a higher salary than other conventional activities. However, the workers in gold mining are at risk of being exposed to chemical contamination, especially women and children. Gold mining is also related to environmental effects, mostly influenced by mercury (Funoh 2014). In Gorontalo, Indonesia, ASGM is available in each part of the province, excluding the city.

The average amount of mercury usage in Hulawa Village is 1 kg for processing 120 kg of rocks. In addition, approximately 30 kg of mercury per month or 360 kg per year are dumped into the wastewater flowing to the nearby river and are directly streamed to the sea (Utina & Katili 2014).

Heavy metal pollutants, including mercury, produced from ASGM activities are more likely to decrease the quality of the aquatic system, as well as influence the composition of aquatic species (Pandey & Madhuri 2014). Mackerel scads (*Decapterus macarellus)* are species that are regularly consumed and exported in Gorontalo (http://www.bkipm.kkp.go.i), and in Hulawa village. Nevertheless, this fish has been potentially contaminated by the mercury pollutant emerged from the ASGM wastewater. This research aims to identify mercury concentrations in mackerel scads.

Material and Method

Description of the study sites. Mercury contamination had been revealed in Hulawa village, along with the nearby river and sea. It was generated from the activities of the gold mining (Arifin et al 2014b, 2020; Mallongi et al 2014, 2015). This study was conducted in the waters of Sumalata Timur, Hulawa Village, Sumalata Timur District, North Gorontalo Regency, Indonesia. The sampling location was divided into three different stations (Figure 1). The nearby community could be exposed to mercury produced by ASGM activities (Arifin et al 2020).

Figure 1. Waters of Sumalata Timur; locations of mackerel scad (*Decapterus macarellus*) sampling.

Ethical statement. The present work had been assessed and approved by the Ethical Commission at the Health Polytechnic of Gorontalo with the registration number of LB.01.01/KEPK/48/2020.

Research samples. The samples in this research were divided into 2 (two) different groups. The first is the mackerel scad as an environmental data resource. The second is represented by the residents of Hulawa village, with the following criteria: (1) have been residing in the gold mining area of Hulawa Village for at least five years; (2) have been working for more than 15 years and consuming mackerel scads from Sumalata waters. The sample size was determined by using the formula below (Hidayat 2010):

$$n = \frac{\mathbf{N.\ Z_{\alpha}^2\ \ P.q}}{\mathbf{d^2\ (N-1) +\ Z_{\alpha}^2\ \ P.q}}$$

Where: n - sample size; P - proportion of population estimated (0.5); d - false tolerance (absolute) (0.05); Z_{α}^2 - number of curve depended by α (1.96); N - number of population units. The total population comprised 570 people; therefore, the sample size was 82 people.

Regarding fish, this study involved 30 mackerel scads collected from fishermen from three different locations in the waters of Sumalata Timur. Each location was marked with GPS. Fish were preserved in a coolbox and transported to the laboratory for mercury identification.

Mercury analysis. To identify the mercury level, all mackerel scads were brought to the certified laboratory of the Center for Fisheries Product Quality Supervision and Development in Bitung, South Sulawesi. This process relied on the Atomic Absorption Spectrophotometry (AAS) method and had been standardized by SNI-01-2354.6-2016. AAS is considered a highly-precise method to identify mercury in fish tissue on account of its sensitivity (Houserova et al 2006). Based on SNI-01-2354.6-2016, it is also possible to analyze samples with low concentrations. In the CV-AAS method, 1 g of fish muscle tissue was collected, then blended and stored in cooler. The Hg ions in the samples were determined through a hydride process by using a strong reducing agent ($SnCl_2$) so that it could transform mercury to neutral Hg (Hg^0) in gas type. Next, it was excited by the absorption of light produced in cathode Hg.

Age and length of stay. In this study, age refers to the respondents who have lived in Hulawa Village for at least 15 years. Age can influence the accumulation of heavy metals through the consumption of mackerel scads in the human body (U.S. Department of Health and Human Services 1999; Vieira et al 2013). Length of stay is the length of time the respondents have lived in Hulawa Village (at least five years) and it served as a criterion for selection. The length of stay defines the duration of heavy metal exposure in the neighborhood where the respondents live (U.S. Department of Health and Human Services 1999).

Health risk assessment. Human health risk assessment is the estimation of the human health exposure to chemicals due to pollution, either in this present day or in the future, in order to protect human beings from the negative effects of the particular hazardous material.

The exposure in this study refers to the Hg intake from mackerel scads consumed and absorbed by the respondents for one year. The risk quotient (RQ) requires the value of reference dose for Hg (RfD mg/kg/day). RQ is also calculated.

If RQ<1, there is no indication of adverse health effects due to consuming mackerel scads. Conversely, if RQ>1, there is a possibility of adverse health effects after eating the fish. The reference dose (RfD) for mercury (Hg) is 0.0001 mg/kg/day according to US EPA (2002).

The Environmental Health Risk Assessment method was employed in this research. The following formula identified the intake of mackerel scads (US EPA 2002).

$$I=(CxRxf_ExD_t)/W_bxT_{avg}$$

Where: I - intake (mg/kg/day); C - concentration of risk agent (mg kg^{-1}); R - rate of intake or consumption (kg day^{-1}); fE - frequency of annual exposure (day $year^{-1}$); Dt - duration of exposure (real time or projection, 30 years for residential default value); Wb - weight (kg); tavg - average time period (Dt x 365 days per year for non-carcinogenic substances, 70 years x 365 days per year for carcinogenic substances).

The risk rates were calculated with the following formula (US EPA 2002):

RQ=I (mg/kg/day)/RfD (mg/kg/day)

Where: I -intake; RfD - oral reference dose.

Health risk management was calculated with the following formulas:

1. To decrease pollutant:

C=(RfD x Wb x tavg)/(R x fE x Dt)

2. To decrease intake:

$R=(RfD \times W_b \times t_{avg})/(C \times f_E \times D_t)$

3. To calculate the time contact:

$D_t = (RfD \times W_b \times t_{avg})/(C \times R \times f_E)$

Where: C - concentration of risk agent (mg kg^{-1}); R - rate of intake or consumption (kg day^{-1}), fE - frequency of annual exposure (day $year^{-1}$); Wb - weight (kg), Dt - duration of exposure, year (real time or projection, 30 years for residential default value); tavg - average time period (Dt x 365 days per year for non-carcinogenic substances, 70 years x 365 days per year for carcinogenic substances); RfD - oral reference dose).

Results and Discussion. Table 1 presents the results of the AAS analysis of mercury in mackerel scads. Location 1 had 0.009 mg kg^{-1} of mercury, location 2 had 0.014 mg kg^{-1} of mercury, and location 3 had 0.07 mg kg^{-1} of mercury in mackerel scads. A previous research found the following mercury concentrations in some fish from Sulawesi Sea (the same location used in this research): *Lutjanus* sp. (0.3 mg kg^{-1}), *Ocyurus chrysurus* (0.5 mg kg^{-1}), and *Lutjanus sinagris* (0.7 mg kg^{-1}, being over the safety limit) (Arifin et al 2015). Another study of mercury within fish in Manado bay, Sulawesi, revealed that the concentration of mercury in *Holocentridae* sp. ranged from 0.1144 to 0.1151 ppm, in *Siganidae* it ranged from 0.0020 to 0.0034 ppm, in *Apogonidae* from 0.0461 to 0.050 ppm, and in *Nemipterus* from 0.0142-0.0144 ppm (Ronoko et al 2019); all these samples were collected in the northern part of the bay. Meanwhile, the samples obtained from the southern part of the bay had also contained mercury: *Holocentridae* sp. featured 0.1090 to 0.1104 ppm, *Siganidae* from 0.160 to 0.164 ppm, *Apogonidae* from 0.1280 to 0.1291 ppm, *Nemipterus* from 0.0522 to 0.0530 ppm, and *Priacanthus* sp. from 0.0194 to 0.0210 ppm (Ronoko et al 2019).

Table 1

AAS analysis of mackerel scads (*Decapterus macarellus*)

No	*Sample*	*Characteristics*	*Test result*	*Limit of quality standard*	*Test method*
1	Mackerel scads (location 1)	Chemical Test: Mercury max (mg kg^{-1})	0.187	1	SNI 01-2354.6-2006
2	Mackerel scads (location 2)		0.646		
3	Mackerel scads (location 3)		0.238		

Health risks of consuming mackerel scads from location 1. Respondent 07, weighing 68 kg has been consuming mackerel scads during the exposure duration (Dt) of 30 years for the lowest Hg concentration (C=0.000563 mg g^{-1}), the intake being 0.0000306 mg/kg/day. The RQ for residents who consume the fish with the lowest Hg concentration (0.000563 mg g^{-1}) for 30 years is 0.306 mg/kg/day. Respondent 26 has an intake during the exposure duration of 30 years for the highest Hg concentration (C=0.00057 mg g^{-1}) of 0.000162 mg/kg/day. The RQ for residents who consume mackerel scads with the highest Hg concentration (C=0.00057 mg g^{-1}) for 30 years is 1.621 mg/kg/day. The intake in the exposure duration of 30 years for the average Hg (C=0.000187 mg g^{-1}) is 0.0000532 mg/kg/day. The RQ for residents who consume mackerel scads for the average Hg concentration (C= 0.000187 mg g^{-1}) for 30 years is about 0.532 mg kg^{-1}. Since the RQ is lower than 1, the consumption of mackerel scads caught from location 1 does not need risk management.

Health risks of consuming mackerel scads from location 2. Respondent 07 with 68 kg of weight has been consuming mackerel scads during the exposure duration (Dt) of 30 years for the lowest Hg concentration (C=0.000641 mg g^{-1}), the intake being 0.0000348 mg/kg/day. The RQ for residents who consume the fish with the lowest Hg concentration (0.000563 mg g^{-1}) for 30 years is 0.348 mg/kg/day. The intake of respondent 26 during the exposure duration of 30 years for the highest Hg concentration (C=0.000658 mg g^{-1}) is about 0.000187 mg/kg/day. The RQ for residents who consume the fish with the highest Hg concentration (C=0.000658 mg g^{-1}) for 30 years is about 1.187 mg/kg/day. The intake in the exposure duration of 30 years for the average Hg concentration (C=0.000646 mg g^{-1}) is 1.837 mg/kg/day. The RQ for residents who consume mackerel scads for the average Hg concentration (C=0.000658 mg g-^{1}) for 30 years is about 1.187 mg kg^{-1}. Since RQ>1, the consumption of mackerel scads caught from location 2 should be continued with risk management.

Health risks of consuming mackerel scads from location 3. Respondent 23 with 66 kg of weight has been consuming mackerel scads during the exposure duration (Dt) of 30 years for the lowest Hg concentration (C=0.000223 mg g^{-1}), with the intake being 0.0000146 mg/kg/day. The RQ for residents who consume the fish with the lowest Hg concentration (0.000233 mg g^{-1}) for 30 years is 0.146 mg/kg/day. Respondent 24 with 56 kilograms of weight has an intake in the exposure duration of 30 years for the highest Hg concentration (C= 0.000245 mg g^{-1}) of 0.000154 mg/kg/day. The RQ for residents who consume mackerel scads with the highest Hg concentration (C=0.000245 mg g^{-1}) for 30 years is 0.154 mg/kg/day. The intake in the exposure duration of 30 years for the average Hg concentration (C=0.000238 mg g^{-1}) is 0.0000628 mg/kg/day. The RQ for residents who consume the above mentioned fish for the average Hg concentration (C=0.000238 mg g^{-1}) for 30 years is 0.628 mg kg^{-1}. Since RQ<1, the consumption of mackerel scads from location 3 does not need risk management.

The distribution of respondents based on age, sex, education, length of stay, and disease in Hulawa Village. Table 2 shows that the present work involved 82 respondents (44 females and 38 males) who live around the ASGM of Hulawa Village. 21 respondents (25.6%) are under 30 years old, 45 respondents (54.9%) are 30 to 50 years old, and 16 respondents (19.5%) are over 50 years old. Based on the length of stay, 40 respondents (48.8%) have lived for 5 to 25 years, 30 respondents (36.6%) have stayed for 26 to 50 years, and 12 respondents (14.6%) have lived over 50 years in the area. In terms of diseases, 28 respondents (34.1%) had influenza, 21 respondents (25.7%) suffered from muscle aches, 32 respondents (39%) had a cough, and one respondent (1.2%) experiences rheumatism.

Table 2
The distribution of respondents based on age, sex, education, length of stay, and disease in Hulawa Village, Indonesia

Variable	*Category*	*Total*	*Percentage*
Age	<30 Years Old	21	25.6
	30-50 Years Old	45	54.9
	>50 Years Old	16	19.5
Sex	Female	44	54.0
	Male	38	46.0
Education	Not graduated from primary school	47	57.3
	Primary School	19	27.2
	Junior High School	4	4.9
	Senior High School	5	6.1
	University	7	8.5
Length of stay	5-25 Years	40	48.8
	26-50 Years	30	36.6
	>50 Years	12	14.6
Disease	Influenza	28	34.1
	Muscle ache	21	25.7
	Asthma	-	-
	Rheumatism	1	1.2
	Cough	32	39.0
	Diarrhea	-	-

Intake rate of mackerel scads consumption. Table 3 points out that the highest intake rate of mackerel scads is 100 g day^{-1} and the lowest one is 50 g day^{-1}. It was discovered that 12 respondents consume 50 g day^{-1} of fish, and 70 respondents have 100 g day^{-1}.

Table 3
Intake rate of mackerel scads (*Decapterus macarellus*)

Mackerel scads consumed (g day^{-1})	*Number of Respondents*	*Percentage*
50	12	14.6
100	70	85.4
Total	82	100.0

The average distribution of mercury in mackerel scads. The average intake rate of mackerel scads is 92.68 g day^{-1}, with the highest rate of 100 g day^{-1} and the lowest rate of 50 g day^{-1}.

The average exposure of respondents who consume mackerel scads. The average exposure of the respondents who consume mackerel scads is at 113.68 days year^{-1}. The highest exposure is 180 days per year and the lowest one is 76 days per year.

The average weight of respondents who consume mackerel scads. The average weight of respondents who consume mackerel scads is 57.57 kg. The highest weight is 83 kg, and the lowest one is 38 kg.

Intake of mercury contaminated mackerel scads consumption the duration of 30 years of residents in Hulawa Village. Respondents consume mackerel scads averaging 0.0489 mg/kg/day, with the minimum and maximum values of 0.0489 mg/kg/day and 0.256 mg/kg/day, respectively (Table 4).

Table 4

Intake of mackerel scads contaminated by mercury (mg kg^{-1}) with the duration of 30 years of the residents in Hulawa Village

Sample	*Min*	*Max*	*Mean*	*Median*	*SD*
Fish from location 1	0.000010	0.000053	0.00002675	0.0000254	0.0000101
Fish from location 2	0.000035	0.000184	0.00009242	0.0008784	0.0000348
Fish from location 3	0.000013	0.000068	0.00003405	0.0000323	0.0000128

Risk quotient (RQ) of mercury contaminated mackerel scads consumption with the duration of 30 years of residents in Hulawa Village. The average RQ of consuming mackerel scads from location 1 is 0.267, with minimum and maximum values of 0.101 and 0.532, respectively. In contrast, the average RQ of the consumption of the fish caught from location 2 reaches 0.924, with the minimum value of 0.351 and the maximum value of 0.183. The average RQ of mackerel scads consumption from location 3 is 0.34, with the minimum value of 0.129 and the maximum value of 0.67 (Table 5).

Table 5

Risk quotient (RQ) of mackerel scads contaminated by mercury with the duration of 30 years of residents in Hulawa Village

Sample	*Min*	*Max*	*Mean*	*Median*	*SD*
Fish from location 1	0.101712	0.532034	0.26752375	0.25428082	0.100999822
Fish from location 2	0.351370	0.1837935	0.92417295	0.87842466	0.348908477
Fish from location 3	0.129452	0.677134	0.34048477	0.32363014	0.128545228

Estimation of average risk level of Hg contaminated mackerel scads consumption, average intake rate, average body weight, and average amount for the respondents. The analysis results presented in Table 6 regarding respondents who consume mackerel scads can estimate possible risks for the heavy metal (Hg) in Hulawa Village.

Table 6

Estimation of average risk level of mercury contaminated mackerel scads, average intake rate, average body weight, and average amount for the respondents

Sample		*Wb*	*R*	*Fe*	*RQ of Hg with exposure duration*					
					5	*10*	*15*	*20*	*25*	*30*
Fish from location 1	Mean	57.57	27.44	112.62	0.045835	0.09167	0.13751	0.18334	0.22918	0.275
	Median	58	25	90	0.033125	0.06625	0.09937	0.1325	0.16562	0.1987
	Min	38	15	76	0.025616	0.05123	0.07685	0.10247	0.12808	0.1537
	Max	83	50	180	0.09259	0.18518	0.27777	0.37036	0.46295	0.5555
Fish from location 2	Mean	57.57	27.44	112.62	0.15834	0.31668	0.47502	0.63336	0.7917	0.95
	Median	58	25	90	0.114431	0.22886	0.34329	0.45772	0.57215	0.6866
	Min	38	15	76	0.088493	0.17699	0.26548	0.35397	0.44247	0.531
	Max	83	50	180	0.319855	0.63971	0.95956	1.27942	1.59927	1.9191
Fish from location 3	Mean	57.57	27.44	112.62	0.058336	0.11667	0.17501	0.23334	0.29168	0.35
	Median	58	25	90	0.042159	0.08432	0.12648	0.16863	0.21079	0.253
	Min	38	15	76	0.032603	0.06521	0.09781	0.13041	0.16301	0.1956
	Max	83	50	180	0.117841	0.23568	0.35352	0.47136	0.58921	0.707

Note: Wb - weight (kg); R - intake rate; fE - frequency of annual exposure (day $year^{-1}$); RQ - risk quotient.

The lowest body weight is 38 kg with an average concentration level of 0.646 mg g^{-1}, an intake rate of 15 g day^{-1} for 76 days per year, and with a RQ value of consuming mackerel scads of 0.531 mg/kg/day. The highest body weight is 83 kg with a concentration level of 0.563 mg g^{-1}, an intake rate of 50 g day^{-1} for 180 days per year, and with the RQ value of 1.9191 mg/kg/day in terms of the exposure duration.

Risk management of mackerel scads consumption. Table 7 represents that the minimum and maximum values (C min = 0.000641 mg/kg and C max = 0.000658) and average concentration of mercury (C average = 0.646) are within the range of safe concentrations for consuming mackerel scads in Hulawa Village The average body weight of respondents who consumed mackerel scads from location 2 is 57.57 kg, and the exposure duration in 30 years is 0.00068 mg/kg/day. Thus, the Hg concentration of mackerel scads is reduced to 0.00068 mg/kg/day in order to get a safe concentration for consumption with an exposure duration of 30 years. Therefore, the mackerel scads are safe for consumption in an amount of 27.44 g day^{-1} for 112.62 days per year in 30 years (exposure duration) by a person weighing 57.57 kg or over, and if the Hg level in the fish is not more than 0.00068 mg/gr/day.

Table 7

Risk management for the safe concentration of mackerel scads consumption (average WB, average R, and average fE)

Sample	*Wb*	*R*	*Fe*	*RfD*	*The safest concentration to every exposure duration*					
					5	*10*	*15*	*20*	*25*	*30*
Mackerel scads collected from location 2	57.57	27.44	112.62	0.0001	0.00408	0.00204	0.00136	0.00102	0.00082	0.00068

Note: Wb - weight (kg); R - rate of intake; RQ - risk quotient; fE - frequency of annual exposure (day $year^{-1}$); RfD - oral reference dose.

Risk management for intake rate (minimum C, average fE, average Wb). Table 8 shows the consumption rate of mackerel scads containing heavy metal (Hg) in Hulawa Village for an average body weight of 57.57 kg, so that the exposure duration to mackerel scads in 30 years is 29.099 g day^{-1}. Based on the risk level of the respondents with a body weight of 65 kg consuming 27.44 g day^{-1} of mackerel scads for 113.68 days per year with an RQ value of 1.837 mg/kg/day (RQ>1), it can be said that this poses a risk to their health. For this reason, it is essential to make risk management efforts in order to prevent health problems (RfD of Hg = 0.0001 mg/kg/day). Risk management for mackerel scads consumption can be completed by reducing the intake rate. Accordingly, mackerel scads with an average concentration of 0.000646 mg g^{-1} Hg will be safe to be consumed by someone weighing 57.57 kg or over for 113.68 days per year for 30 years, if the daily intake rate is lower than 29.0991335 mg/g/day.

Risk management for intake exposure duration (minimum and maximum C, average R, average Wb). It can be seen in Table 9 that the average Hg concentration for risk management for the duration of exposure to the safe intake of mackerel scads does not exceed 0.0315 mg/g/day.

Table 8

Risk management for intake rate

Sample	*Wb*	*R*	*Fe*	*C (Min)*	*RfD*	*The safest concentration (C) to every exposure duration (Dt)*					
						5	*10*	*15*	*20*	*25*	*30*
Mackerel scads	57.57	27.44	112.62	0.000641	0.0001	174.5948	87.297401	58.198267	43.6487	34.91896	29.0991335
Sample				*C (Max)*							
Mackerel scads	57.57	27.44	112.62	0.000658	0.0001	170.24055	85.120276	56.74685	42.560138	34.04811	28.3734252
Sample				*C (Average)*							
Mackerel scads	57.57	27.44	112.62	0.646	0.0001	0.1732975	0.0866488	0.0577658	0.0433244	0.0346595	0.02888292

Note: Wb - weight (kg); R - rate of intake; QR - risk quotient; fE - frequency of annual exposure (day year^{-1}); RfD - oral reference dose; Dt - duration of exposure, year (real time or projection, 30 years for residential default value).

Table 9

Risk management for intake exposure duration

Heavy metal	*Sample*	*Wb*	*R*	*Fe*	*C (Min)*	*RfD*	*Safe Dt*
Hg	Mackerel scads	57.57	27.44	112.62	0.000641	0.0001	31.81392148
					C (Max)		
		57. 57	27.44	112.62	0.000658	0.0001	31.0205086
					C (Average)		
		57.57	27.44	112.62	0.646	0.0001	0.031577533

Note: Wb - weight (kg); R - rate of intake or consumption; RQ - risk quotient; fE - frequency of annual exposure (day year^{-1}); RfD - oral reference dose; Dt - duration of exposure, year (real time or projection, 30 years for residential default value).

The concentrations of mercury in fish from each location vary. Mackerel scads caught from the first (0.009 mg kg^{-1}) and third location (0.007 mg kg^{-1}) have a lower level of mercury than the second location (0.014 mg kg^{-1}). Mackerel scads from the second location have the highest mercury concentration because the location is linear with the river outlet. Locations 1 and 3 are far from the outlet, making the mercury concentration lower than location 2. Mercury concentration in fish can be influenced by temperature, source of contamination, and ASGM operation time (Sunardi et al 2017). Other factors that influence accumulation are the age of fish, the amount of mercury pollutant, climate change and others (Houserova et al 2006).

The amount of exposure will affect the mercury intake within the body and the rate of risk agent consumption, e.g., mercury. The ones who consume mackerel scads containing mercury have a greater risk than those who do not eat it throughout the year because the intake of mercury is also higher (U.S. Department of Health and Human Services 1999; Vieira et al 2013; Rice et al 2014; Kimáková et al 2018; Vasanthi et al 2019; Amqam et al 2020; Diaz et al 2020).

The measure of the intake rate of mackerel scads consumed at location 2 of Sumalata Timur's waters will strongly influence the measure of the mercury amount within the human body. In the present study, a greater intake rate (or amount of consumption) will increase the amount of mercury that gets in the body (U.S. Department of Health and Human Services 1999; Rice et al 2014; Kimáková et al 2018; Vasanthi et al 2019; Amqam et al 2020; Diaz et al 2020).

Exposure duration represents the length of time of the respondent contact with the mercury (Hg) from mackerel scads. Continuous consumption of mackerel scads containing mercury will lead to mercury accumulation in the community of Hulawa Village. It is an accumulation of chemicals in the human body that in a certain period will cause adverse effects on health. Chronic mercury poisoning occurs over a very long time, and it can, at first, be tolerated by the body. However, since the ingestion takes place continuously, the body will at one point no longer be able to tolerate the toxicant. Exposure to low levels of mercury will lead to chronic cases of mercury poisoning (Cizdziel et al 2002; Jezierska & Witeska 2006; Pandey et al 2012; US EPA 2013; Rice et al 2014; Morcillo et al 2017; USGS 2018; Huseen & Mohammed 2019). The toxic effect of metals relates to the level and duration of exposure. Generally, a higher metal content with a longer exposure time will increase the toxic effect of the metal. For instance, mercury in a single large dose can induce gastrointestinal disorders (Morcillo et al 2017; Mallongi et al 2017; Huseen & Mohammed 2019; Tamele & Loureiro 2020). In the risk analysis, it is theoretically shown that a higher body weight decreases the mercury risk (US EPA 2002).

The risk level is determined by the amount of mercury within the human body. Mercury intake is affected by several factors: concentration of chemicals in food, body weight, exposure duration, intake rate, and amount of exposure (Mallongi et al 2015; WHO 2016; Mandeng et al 2019; Amqam et al 2020). In this study, the RQ value higher than 1 indicates a greater probability of health adverse effects.

Conclusions. The lowest intake of fish is less than 25 g per day for 15 respondents. The highest intake was between 21-25 g of mackerel scad per day, in the case of 39 respondents. The lowest exposure period by fish consumption is 91-114 days per year, in the case of 8 respondents, while the highest was 70 to 90 days per year for 42 respondents. When the risk quotient value is higher than 1, there is potential harm to human health; in this study, the RQ was higher than 1 in some cases. Health risk management is required to be applied because of the high heavy metal exposure probability. It could be recommended to decrease the consumption of mackerel scads from East Sumalata waters.

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