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Research Article
Health Risk Analysis of Lead Exposure from Fish Consumption among Communities along Youtefa Gulf, Jayapura

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Abstract
Background: Human life is threatened by environmental hazards due to toxic contamination with lead. According to some studies, the waters and biota of Youtefa Gulf near Jayapura city have been polluted by lead. **Objective:** This study aimed to analyze the health risks caused by lead exposure from consuming fish and the non-carcinogenic risk of consuming fish for the citizens of Youtefa Gulf. The study used observational research with a risk analysis approach (Risk Quotient (RQ)). **Methodology:** The study population included fish and people living along Youtefa Gulf in Jayapura, with a sample composed of 75 people and fish collected from 12 stations. Samples were collected by purposive sampling. **Results:** The results showed that the concentrations of Pb in the fish from the12 stations was an average of 2.46 mg kg^{-1}, a level considered to indicate pollution because it is above the 0.3 mg kg^{-1} threshold defined by ISO 7387 in the year 2009. Out of the 75 respondents, 66 respondents (88%) were found to have an RQ>1, which is considered to indicate high risk of lead exposure because it is greater than 1. From the results, the average RQ from the 75 respondents who consumed fish was 6.03. Based on this very high RQ value, the risk for these individuals needs to be controlled. **Conclusion:** It is recommended that the Youtefa Gulf community reduce its exposure to lead by decreasing the amount of fish consumed and decreasing the duration of daily lead exposure to diminish the health effects caused by exposure to lead-contaminated fish.

Key words: Risk analysis, pollution, lead, risk quotient, lead

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Generally, coastal areas are susceptible to contamination due to management errors, as these areas serve as locations for the disposal for all types of mainland waste[1]. Improving development in Indonesia is essential for producing economic and social benefits, but it also carries the risk of pollution[2]. Marine pollution involves a change in the marine environment, including estuaries, that leads to negative consequences that could harm living marine resources, pose danger to human health, disrupt activities at sea (including fisheries and frequently used marine areas), decrease ocean water quality and degrade the usefulness and benefits of the ocean[3].

One heavy metal that often causes pollution is lead. Lead is a non-essential heavy metal. This heavy metal is widely used for industrial activities, such as in batteries and as an additive for vehicle fuel[4]. The main reason lead is such a dangerous pollutant is because it cannot be destroyed (non-degradable) by living organisms and therefore it accumulates in the environment, especially in bottom waters, forming complex compounds with organic and inorganic materials through combination and adsorption. Biota that live in water polluted by heavy metals can accumulate the heavy metals in body tissues[5]. According to Athena[6], if water or sediments contain heavy metals, the heavy metals will easily bind to protein molecules present in marine life, including those in the muscle tissues of fish (Bureau of Nutritional Sciences, Food Directorate of Health Products and Food Branch Canada, 2007)[6].

The impact of waste disposal in the form of heavy metals causes disruptions in aquatic life. Youtefa Gulf cannot be separated from the problem of heavy metal pollution because one half of Jayapura City empties into the Gulf. In 2004, a survey by Management Agency of Regional Environmental Impact in Jayapura observed that, among the parameters of water quality in Youtefa Gulf, lead contamination had reached[7] 0.03 mg L^{-1}.

Research by Priyanto *et al.*[8] in Waduk Cirata, West Java, also found that heavy metal contamination (Hg, Pb, Cu and Cd) had occurred in the waters at some stations and the concentrations of the heavy metals had already exceeded the permitted limits. Furthermore, the concentration of heavy metals in marine biota (fish) after the study was higher than the content of heavy metals in the water. This is presumably because the heavy metals in the water accumulated in the bodies of the fish[8]. Additionally, research by Sabuti and Mohamed[9] in Malaysia found that the radioactivity produced by the combustion operations of the Sultan Salahuddin Abdul Aziz coal-fired power plant (SSAAPP) was positively associated with higher concentrations of lead in the air[9].

Heavy metal exposure (e.g., lead) in animals and humans can result inacute, sub-acute, chronic and sub-chronic effects. Chronic toxicity occurs when chemicals accumulate in biological systems (absorption exceeds bio-transformation and excretion), when chemical exposure produces permanent toxic effects, biological systems cannot recover from damage during intervals between exposure, or when exposure is continuous; indeed, both sufficient time and nutrient intake are required to release chemicals[10,3].

Based on the facts above, human life is currently threatened by environmental hazards caused by toxic contamination with Pb. There are several studies that were conducted in Indonesia related to environmental pollution, such as research conducted by Jalius[11] in Banten Gulf, Amriani *et al.*[12] in the Kendari Gulf of Lubis *et al.*[13] and Manalu[14] in the Tallo Makassar River. However, these previous studies did not conduct a risk analysis of lead exposure. This study attempted to determine the health risks caused by lead exposure and whether these risks can be controlled without stopping the activity that is the source of the risk. Thus, to address these issues, it is necessary to analyze the associated environmental health risks.

MATERIALS AND METHODS

This study used observational research with a risk analysis approach. The process of risk calculation or estimation in the research sample (risk quotient) was completed using measurements of exposure to lead for each enrolled individual or intake rate, calculations of lead concentrations in fish and assessments of the anthropometric characteristics (weight and the rate of consumption) of the individuals.

The study population included fish and people living along Youtefa Gulf. Samples were taken from this population using purposive sampling. To identify the sample, the researchers set the following inclusion criteria:

- Willing to be a respondent
- Lived along Youtefa Gulf for more than 2 years

The researchers set the following exclusion criteria:

- Not willing to be a respondent
- Lived along Youtefa Gulf for less than 2 years

The following equation was used in this study:

- Large sample:

$$N = \frac{Z1-\alpha 1/2^2\left[P1(1-P1)+P2(1-P2)\right]}{d^2}$$

Where:

P1	=	No. of anemia cases/total population (1058/242.267)×100 = 0.436 per 100 inhabitants
P2	=	Total population of cases/total population (241209/242.267)×100 = 99.56 per 100 inhabitants
d^2	=	3%
Z 1-α 1/22	=	1.96

So:

$$N = \frac{1.96^2\left[(P1(1-P1)+P2(1-P2)\right]}{0.03^2}$$

$$= \frac{3.84\left[(0.0043)(1-0.0043)+0.9956(1-0.9956)\right]}{0.009}$$

$$= \frac{3.84[(0.00428)+(0.00428)]}{0.009}$$

= 36.5 = 37, so the samples taken are n1+n2 = 37+37 = 74

The determination of the lead concentrations in the fish samples was conducted at the Laboratory of Regional Health in Jakarta using an inductively coupled plasma spectrometer (ICP-Thermo IRIS Intrepid II).

Concentrations of lead in fish: The lead concentrations measured in the fish collected from the 12 stations in Youtefa Gulf are listed in Table 1. The Pb concentrations in the fish ranged from 0.16-5.75 mg L^{-1} (Table 1), with an average value of 2.46 mg kg^{-1}. Referring to ISO 7387, EPA[15] the bulanak fish from the 12 sampling stations were considered polluted with Pb, as their Pb levels exceeded the 0.3 mg kg^{-1} cut-off defined by this standard.

Risk analysis: Risk analysis was conducted by first identifying the risk of lead exposure by interviewing the respondents about their intake of the risk agent. "Intake" in this study was defined as fish consumption. Then, the anthropometric characteristics of the respondents, such as weight, height and patterns and frequency of fish consumption, were collected.

The next step of the risk analysis was to calculate the exposure concentration by analyzing the sources that led to the presence of lead in the fish from Youtefa Gulf, the health risks caused by exposure to the risk agent were identified by the associated non-carcinogenic effects (Table 2).

Table 1: Leadconcentrations in the fish sampled from the 12 stations in Youtefa Gulf

Stations	Location of the sample	Fish size (cm)	Concentration of Pb (mg kg^{-1})	ISO (mg kg^{-1})	Conclusion
1	02°58'81.6"LS 140°70'75.3"BT	P = 29 L = 7	1.91	0.3	Polluted
2	02°59'15.4"LS 140°70'60.9"BT	P = 26 L = 6.5	2.84	0.3	Polluted
3	02°59'31.6"LS 140°70'21.5"BT	P = 32 L = 6	1.47	0.3	Polluted
4	02°59'96.7"LS 140°71'20.4"BT	P = 33 L = 5	2.47	0.3	Polluted
5	02°61'23.0"LS 140°70'57.3"BT	P = 26 L = 6	3.32	0.3	Polluted
6	02°58'81.6"LS 140°71'86.4"BT	P = 22 L = 5	1.52	0.3	Polluted
7	02°262'79.1"LS 140°72'15.7"BT	P = 26 L = 6	3.07	0.3	Polluted
8	02°60'81.9"LS 140°71'20.8"BT	P = 20 L = 5	0.95	0.3	Polluted
9	02°62'81.2"LS 140°72'22.3"BT	P = 20 L = 5	0.16	0.3	Safe
10	02°61'83.7"LS 140°72'0.17"BT	P = 20 L = 5	3.86	0.3	Polluted
11	02°61'97.5"LS 140°72'21.7"BT	P = 21 L = 5	2.22	0.3	Polluted
12	02°62'54.4"LS 140°702'51.7"BT	P = 22 L = 5	5.75	0.3	Polluted
Total			29.54		
Average			2.46	0.3	Polluted

Source: Primary data, 2014

Table 2: Non-carcinogenic risk analysis associated with fish consumption in 15 respondents from Youtefa Gulf in 2014

Name	Wb	tE (h day^{-1})	Dt (year)	fE (day year^{-1})	C (mg kg^{-1})	R (kg day^{-1})	I (m kg^{-1} day^{-1})	RQ
LS	86	4	61	350	2.47	0.1	0.0223	5.59
FR	57	1	45	350	2.47	0.05	0.0031	0.77
MA	52	2	16	350	2.47	0.1	0.0048	1.21
DB	74	1	49	350	2.47	0.1	0.0052	1.30
YB	24	2	69	350	2.47	0.05	0.0226	5.67
YU	78	12	51	350	3.86	0.05	0.0484	12.10
KA	64	4	52	350	3.86	0.05	0.0200	5.01
SA	52	5	33	350	2.84	0.1	0.0288	7.20
JRi	66	1	50	350	2.84	0.1	0.0068	1.71
MC	64	2	43	350	2.84	0.05	0.0060	1.52
MR	42	2	25	350	2.84	0.05	0.0054	1.35
EP	46	6	72	350	2.84	0.15	0.1278	31.96
MK	71	6	33	350	2.84	0.15	0.0379	9.49
RI	55	6	59	350	2.84	0.15	0.0876	21.91
SE	85	1	40	350	2.84	0.15	0.0064	1.60

Source: Primary data, 2014

The initial step in calculating the RQ was to calculate the Intake rate of respondent 1 (LS) for non-carcinogenic effects with the following equation:

$$I = \frac{C \times R \times Te \times Fe \times Dt}{Wb \times t\ avg}$$

Where:

I = Intake, 0.0223 mg kg^{-1} day^{-1}
C = Concentration risk agent, 2.47 mg kg^{-1} for fish
R = Rate of intake or consumption, 0.1 kg day^{-1} for food
Te = Time exposure, 4 h day^{-1}
Fe = Frequency of exposure, 350 days year^{-1}
Dt = Duration of exposure, year (actual time, 6 years for protection, 30 years resident default value)
Wb = Body weight, 86 kg
t avg = Average time period (Dt = 30)×365 days year^{-1} for non-carcinogenic substances, 70 years×365 days year^{-1} for carcinogenic substances):

$$I = \frac{2.47 \times 0.1 \times 4 \times 350 \times 61}{86 \times (30 \times 365)}$$

$$I = \frac{21093.8}{941.700} = 0.0223$$

RQ = Risk quotient

Interpretation: The lead intake rate in the respondents with 86 kg average body weight who consumed bulanak fish with level of lead at 2.47 mg kg^{-1} day^{-1} for 350 days year^{-1} with a 61 year exposure duration was 0.0223 mg kg^{-1} day^{-1}.

After the intake rate was calculated, the next step was to calculate the health risk characteristics, expressed as the risk quotient (RQ, risk level) for the effects of non-carcinogenic risk[16-20] as well as carcinogenic risk, measured as Excess Cancer Risk (ECR)[15]. The RQ was calculated by dividing the intake of then on carcinogenic (Ink) risk agent by the RFD or RFC according to the following equation:

$$RQ = \frac{I_{nk}}{RfD\ or\ RfC}$$

Where:

I_{nk} = 0.0223
RFD = 0.004

$$\text{Non carcinogenic RQ} = \frac{0.0223}{0.004} = 5.59$$

Interpretation: The RQ of the Youtefa Gulf population (average body weight 86 kg) who consumed bulanak fish contaminated with lead at a rate of 2.47 mg kg^{-1} day^{-1} with a 61 year exposure duration is 5.59, which is considered to indicate a high risk of lead contamination because it is greater than 1.

RESULTS AND DISCUSSION

Concentrations of lead in fish: From the results of the lead concentration analysis in bulanak fish, out of the 12 fish taken from the 12 stations, 11 bulanak fish from 11 stations were categorized as polluted. Only one location produced a fish not categorized as polluted, which is station 9. This is because station 9 is located very far from human activity, while the other stations are closer to human activity, so the concentrations of lead are higher. According to research conducted by Julius Wake in the waters of Ancol Jakarta Bay in 2008, the Pb concentration in Silver tripod fish (*Triacanthus nieuhofii*) also exceeded the maximum limit of heavy metal contamination in food according to the Ministry of Health of Indonesia[21], therefore, the fish in that location are not safe for human consumption[22].

The above results are consistent with research conducted by Ozuni *et al.*[23] in Albania, in which it was found that fish consumed by Albanian people were often caught from waters polluted with lead. In Enkelada's research examining the species *Mullus barbatus*, an average Pb concentration of 0.21 mg kg^{-1} was found, while 0.11 mg kg^{-1} was the average Pb concentration in *Merlucius merlucius*. In this study, it appeared that there were differences among the measured Pb concentrations of each species and the differences were significant among the species. The Pb was not detectable in the species *Dicentrarchus labrax*, unlike the presence of lead in the species *Mullus barbatus* and *Merlucius merlucius*. There was a significant relationship between fish size and Pb concentration, in which larger sized fish species had higher lead concentrations[23]. The results of this study are also in agreement with the study conducted by Chen *et al.*[24] in Maine Gulf, Denmark, in which concentrations of Hg in marine biota exceeded the maximum threshold and variations in these Hg concentrations were associated with the contamination of sediments. It was concluded that the variations in Hg concentrations in marine life at some stations were likely associated with biogeochemical and ecological factors[24].

A similar pattern was observed by Bogoriani[25], who found accumulations of Pb and Cr in the bodies of tilapia. According to Bogoriani[25], accumulation of the heavy metals Pb and Cr occurs because the concentrations of heavy metals that are absorbed by the body are greater than the concentrations that are excreted from the body. Accumulation of these metals can occur from the consumption of food, the absorption of contaminated water or from the ingestion of contaminated water; therefore, higher metal concentrations were found in samples from estuary waters near the Badung River in Bali. According to this study, these metals can biomagnify in consumers through the food chain and humans will be exposed if they consume contaminated organisms[25].

Based on these observations in the field and the sample measurements from different station locations, the lead concentrations in the fish from the 12 stations in Youtefa Gulf also varied. These variations are highly influenced by biogeochemical and ecological factors in Youtefa Gulf, where the concentrations of lead in the water vary with location, which would certainly by reflected in the concentrations of lead in marine life.

One of the dangers of heavy metal exposure is that it causes DNA damage in fish. Research conducted by Senthamilselvan *et al.*[26] in India found that heavy metals (Cd and Hg) can damage DNA in blood cells of fish. Apparently, the hematological characteristics of various cultivated fish species show different profiles. In fish exposed to cadmium and mercury, hemoglobin levels were lower (3.96) than in fish that were not exposed to these heavy metals[26] (6.13). Therefore, it is clear that fish contaminated with lead are not only directly harmful to human health but also cause indirect effects that can harm humans, as lead contamination renders some locations unsuitable for fishing and also reduces fishing yields.

Risk analysis: According to the EPA, risk analysis is the characterization of hazards with the potential to affect human health and harm the environment. According to ML Richardson[27], risk analysis is a decision-making process used to address problems based on the probabilities of various events occurring. In the analysis of risk, a problem must first be defined and the associated risk estimated, then, the risk is evaluated in addition to factors that might influence decisions on what actions to take to assess, monitor and mitigate risk.

In this study, risk analysis was conducted to evaluate lead contamination in the waters, fish and shellfish of Youtefa Gulf due to the release of hazardous materials into the gulf. The aim was to assess past, present and future impacts on public health, especially in those living along the gulf. The results of our risk analysis are expected to help develop health suggestions and recommendations for the local government to mitigate negative health effects for the people living along Youtefa Gulf.

In evaluating a population from Youtefa Gulf with an average body weight of 86 kg and a rate of consumption of lead-contaminated bulanak fish of 2.47 mg kg^{-1} day^{-1} with a 61 year exposure duration, we calculated an RQ of 1.85, which is considered to indicate a high risk of exposure because it is greater than 1. From the results of this study, the average RQ for the 75 respondents was 6.03. Additionally, the average RQ of the fish was greater than 1, indicating that people living in Youtefa Gulf who consume fish at the above rate are at risk from the effects of lead exposure.

The results showed that, out of the 75 respondents, 66 (88%) had an RQ greater than 1, which is very high and indicates that the RQ for this population needs to be controlled. Therefore, risk management strategies need to be implemented to minimize the Risk Quotient (RQ) by altering the values of the exposure factors included in the formula used to measure intake rate. In other words, changes to the lead concentration in the environment, the amount of fish consumed and the duration of lead exposure per day must occur for this population.

An epidemiological survey to identify the symptoms or diseases that occur as a result of lead exposure should be conducted and more targeted surveillance and exposure durations should be calculated to obtain information regarding the length of time since the risk began. These measures should better control the risk of exposure. Therefore, Eq. 1 was rearranged and I_{nk} was substituted with RFD to create the following equation:

$$Dt = \frac{RfD \times Wb \times t\,avg(year)}{C \times R \times f_e}$$

Resulting in:

$$Dt = \frac{0.004 \text{ mg kg}^{-1} \text{ day}^{-1} \times 55 \text{ kg} \times 365 \text{ day year}^{-1} \times 30 \text{ years}}{3.48 \text{ mg kg}^{-1} \times 0.1 \times 350 \text{ day year}^{-1}}$$

$$= \frac{2409}{121.8} = 19$$

This value indicates that the toxic effects of lead are expected to be present in adults that weigh 55 kg and have been consuming lead-containing fish (at a concentration of 3.48 mg kg^{-1}) at a rate of 0.1 kg fish day^{-1} for 350 days $year^{-1}$ for 19.7 years. Thus, future epidemiological surveys should target those who have livedin the Youtefa Gulffor 19.7 years or more, as they are most likely to have a maximum Pb concentration of 3.48 mg kg^{-1}.

CONCLUSION AND SUGGESTIONS

- The non-carcinogenic Risk Quotient (RQ) for consuming fish was greater than 1,which indicated a high risk of exposure for the community in the Youtefa Gulf
- In total, 66 (88%) of the 75 respondents had an RQ>1 and were considered at high risk of exposure because an RQ greater than 1 is considered an unacceptable risk. The average RQ value from consuming fish for the 75 respondents was calculated as 6.03
- Further study on the impact of lead pollution in communities along Youtefa Gulf with a larger sample is needed
- An ongoing analysis about the environmental quality of Youtefa Gulf is necessary
- There should be regular monitoring and surveillance evaluation on the targets that have been achieved, as well as a review of the laws and regulations that are in place in accordance with the actual water quality conditions in Youtefa Gulf to avoid causing additional harm to the users of marine resources in Youtefa Gulf

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