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Comparison of bioconcentration factor of heavy metals between endemic fish and aquacultured fish in Maninjau Lake, West Sumatra, Indonesia

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Abstract. *Komala PS, Azhari RM, Hapsari FY, Edwin T, Ihsan T, Zulkarnaini, Harefa M. 2022. Comparison of bioconcentration factor of heavy metals between endemic fish and aquacultured fish in Maninjau Lake, West Sumatra, Indonesia. Biodiversitas 23: 4026-4032.* Fish have a high risk of accumulating metals and poses a risk of entering human bodies through the food chain. This study aims to analyze the concentration of lead (Pb), mercury (Hg), and cadmium (Cd) spatially and temporally as well as the Bioconcentration Factor (BCF) in endemic fish (*Rasbora argyrotaenia*) and aquacultured fish (*Oreochromis niloticus*) in Maninjau Lake and its relationship to environmental parameters (pH, DO and temperature). Sampling was conducted at domestic, hydropower, fish cage, and endemic fisheries. Spatial and temporal distribution using one-way ANOVA with 95% significance, while parameter correlation using linear regression. Almost all heavy metals in both fish samples exceeded the permissible level except in endemic fisheries sites. Metal concentrations in both fish species spatially showed a significant difference, while temporally showed no significant difference. *Rasbora argyrotaenia* showed a slightly higher BCF value than *O. niloticus*. The BCF values were low accumulative with order Pb>Hg>Cd in *R. argyrotaenia* and Pb>Cd>Hg for *O. niloticus*. There is a strong and positive correlation between temperature and the BCF value of both fish species for the three different metals. Monitoring fish by keeping metal content within acceptable limits is necessary. Further research on risk analysis of fish consumption in humans is recommended.

Keywords: Aquacultured cage, endemic fisheries, environmental parameters, *Oreochromis niloticus*, *Rasbora argyrotaenia*, toxicology

INTRODUCTION

Heavy metals are one of the primary pollutants in aquatic ecosystems that can harm biotic communities (Ali et al. 2019). Heavy metals are derived both from natural and human activities. Domestic and industrial waste, animal and human waste, agricultural runoff, transportation, and burning fossil fuels are the major pollutants entering the water body (Wong et al. 2016). Primary natural sources come from volcanic activity, geological weathering, and forest fires (Goher et al. 2014). A substantial amount of ash and pyroclastic material is produced from magnified volcanic eruptions, containing nutrients such as magnesium, calcium, nitrogen, phosphorus, potassium, sodium, etc., and toxic elements and metalloids, i.e., mercury, arsenic, etc. (Ma et al. 2019).

Maninjau Lake, one of the largest lakes in West Sumatra, Indonesia, has shown high levels of heavy metals. A previous study on heavy metals from 11 locations around the lake indicated 8 from 11 sites were placed in the medium pollution category (Komala et al. 2021). Heavy metals, including Cd, Pb, Hg, and Cu in the water column, exceeded the allowable levels at all sampling points. In aquatic systems, heavy metals Pb, Hg, and Cd are very toxic if they accumulate in the body of biota (Bhuyan and Bakar 2017). Marine animals, including fish, are exposed to metals for long periods. Bada fish *(Rasbora argyrotaenia*) is one of the endemic fish in Maninjau Lake. At the same time, Tilapia (*Oreochromis niloticus*) is a native species (Syandri and Yunus 2014) and is also cultivated in Maninjau Lake through aquaculture cages. Besides being preserved, these fish also have high economic value for consumption in local communities and outside the lake area. Even *O. niloticus* is distributed to other cities. In recent years, heavy metals found in *R. argyrotaenia* and Betutu fish (*Oxyeleotris marmorata)* in Maninjau Lake indicated that Fe metal in fish had passed the World Health Organization (WHO) standard (Syandri 2015). Some heavy metals such as Cd and Pb are found in mollusks often consumed as food by the locals, namely *Corbicula moltkiana*, *Melanoides*, and *Bivalvia violacea*, which have exceeded the established standards (Hariyadi et al. 2016). It indicated that heavy metals had polluted almost the entire lake area.

As one of the aquatic biota, fish is considered an indicator of water pollution. The ability of fish to accumulate metals is expressed by the Bioconcentration Factor (BCF) (Burkhard 2021). The accumulation of high heavy metals in fish organs can indicate water pollution (Mo 2016). Heavy metals such as mercury, lead, chromium, cadmium, and arsenic can be life-threatening if their concentration in fish exceeds acceptable limits (Mo 2016).

With the increased pollution in Maninjau Lake and natural volcanic-tectonic activity, fish can be exposed to different metals, usually more toxic than individual metals. Therefore, keeping the fish safe for human consumption and preserving endemic fish from extinction is crucial. The present study explains the distinction in heavy metal levels between endemic fish and cultured fish. This study also evaluates the correlation between heavy metals in lake waters and fish and their correlation to the Bioconcentration Factor (BCF) spatially and temporally.

MATERIALS AND METHODS

Study area

Maninjau Lake is one of the tropical lakes in Tanjung Raya Sub-district, Agam District, West Sumatra Province, Indonesia. Maninjau Lake is located at the coordinates of 0°17'07.04"S and 100°09'58.0"E with 461.5 masl. The lake has a water surface area of 999.5 acres, an average depth of 105 m, a water volume of 10,226,001,629.2 10,226,001,629.2 m^3, and a water retention time of 25.04 years (Syandri and Yunus 2014). Maninjau Lake has various functions, including a hydropower plant, tourism, endemic fisheries, and aquaculture cage nets.

Sampling

The study was carried out in February-May 2018 with three times the sampling frequency. Water sampling locations are determined based on the Indonesian National Standard for Surface Water Sampling Method (Badan Standardisasi Nasional 2008). Characteristic test samples were taken at 5 locations. For the bioconcentration test, samples were taken at four areas: inlet (near the domestic area) and based lake utilization sites (hydropower, fish cage, and endemic fisheries). The sampling location can be seen in Figure 1.

To get the sampling location, we used a boat with a capacity of 6 people. Water samples were taken to analyze heavy metals, temperature, DO and pH. Temperature, DO, and pH was measured directly at the sampling location using Lutron DO-5510 for DO and temperature and Lutron pH-201 for pH, while heavy metal samples were measured in the laboratory. Water samples for heavy metal testing were put into a 1 L volume bottle with 1.5 mL HNO_3 and closed tight so that air did not enter the bottle and placed in a cool box. Fish samples were taken with the help of anglers around the lake using nets.

The fish were then wrapped in aluminum foil and stored in a cool box filled with ice. The fish samples were taken to the Environmental Engineering Laboratory Universitas Andalas to analyze heavy metals concentrations.

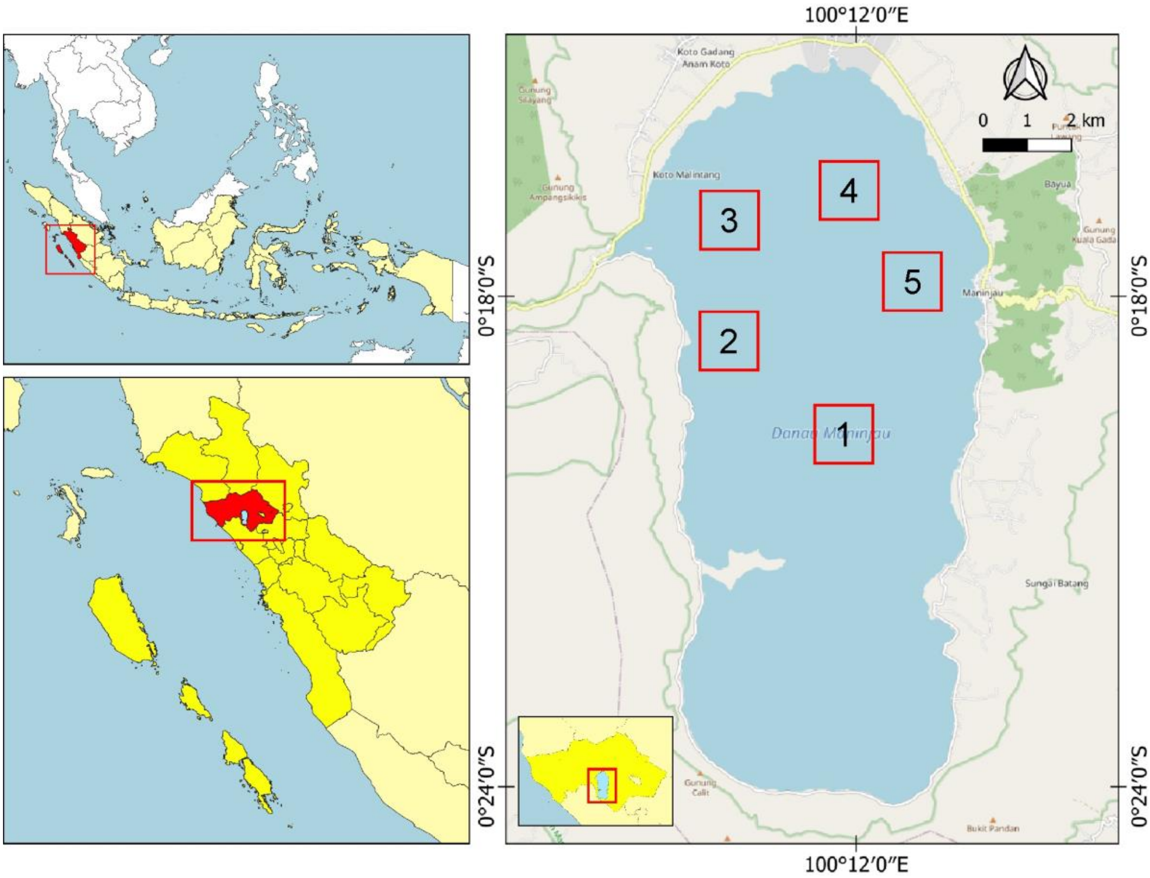

Figure 1. Map of the sampling location in Maninjau Lake of Tanjung Raya Sub-district, Agam District, West Sumatra Province, Indonesia. Notes: 1. Center of the Lake; 2. Dense Settlement; 3. Hydropower; 4. Fish cage; 5. Endemic Fisheries

Analysis procedures

The characteristic test of lake water was carried out to determine the quality of the lake water through several parameters, namely DO, pH, temperature, BOD_5, COD, oil and fat, TSS, TDS, Total Phosphate, Sulfate, Sulfide, Total Nitrogen, and heavy metals. Furthermore, in the primary analysis, the parameters measured were DO, pH, temperature, and heavy metals. The parameter analysis and sampling method refer to the Standard Methods for The Examination of Water and Wastewater (APHA 2017). The water analysis is then compared with the allowable limit set by Indonesian Government Regulation No. 22 of 2021 for Standard Quality for Water Use Class 2 (Pemerintah Republik Indonesia 2021).

The samples of *R. argyrotaenia* had an average weight of 3.50 g, while the average weight of *O. niloticus* was 71 g. Fish samples were cleaned with distilled water and dried using an oven at 80°C. A total of 1.0 grams of dry sample was then dissolved in 10 mL of concentrated nitric acid (HNO_3) in a beaker glass using a hot plate at a low temperature (40°C) for 1 hour and continued at a higher temperature, 140°C for ± 3 hours and then cooled. Distilled water was added into the beaker glass until the volume was 25 mL, then filtered into the sample bottle. The filtrate was analyzed using the ICP-9000 Shimadzu. The heavy metal concentration in fish was compared with the Maximum-Permissible-Level (MPL) of the Government Regulation of the National Agency of Drug and Food Control No. 5 of 2018 concerning the Maximum Limit of Heavy Metal Contamination for fish (BPOM 2018). A normality test is carried out to find out whether the data is normally distributed or not. Analysis of Variance (One-Way Anova) of SPSS 16.0 was used to determine spatial and temporal significant differences in Hg and Cd metals concentrations because the data were distributed normally. In contrast, we used Spearman Rho for Pb because the data was not normally distributed. Pearson correlation analysis is used for environmental parameters of pH, DO, and temperature since the data are normally distributed. The Bioconcentration Factor (BCF) value is calculated based on the ratio of metal concentrations in water and fish. The BCF value is used to show the magnitude of the ability to accumulate metals by organisms from environments exposed to heavy metals using equation 1.

$$BCF = \frac{\text{heavy metal concentration in fish} \left(\frac{mg}{kg}\right)}{\text{heavy metal concentration in water} \left(\frac{mg}{L}\right)} \qquad (1)$$

RESULTS AND DISCUSSION

Characteristics of Maninjau Lake

The water temperature of each sampling location ranged from 28.1-32.8°C. The lake water pH is predominantly alkaline at each sampling location, from 6.73 to 8.47. DO ranged from 6.8-7.7 mg/L, where the highest concentration was around the fish cage site, i.e., 7.7 mg/L, while the lowest was in the middle of the lake, 6.8 mg/L. Other water quality parameters included sulfides concentration ranging from 4-16 mg/L, BOD 21.87-47 mg/L, COD 35.2-74 mg/L, TSS 462-850 mg/L, nitrite 0.108-0.183 mg/L, total phosphate 3.033-4.826 mg/L and for metal parameters i.e., Cd with concentrations ranging from 0.05-0.099 mg/L, Cu 0.0003-0.046 mg/L, Hg 0.27-0.62 mg/L, Se 0.0180-0.322 mg/L, and Zn 0.29 to 0.354 mg/L.

Heavy metals in water

The concentration of Cd, Hg, and Pb metals in Maninjau Lake water in four locations can be seen in Figure 2. Average concentrations of heavy metal lead (Pb) have exceeded the quality standard, i.e., 0.03 mg/L (Pemerintah Republik Indonesia 2021). The concentrations recorded at domestic, 0.097±0.0008 mg/L, hydropower 0.088±0.0025 mg/L, fish cage 0.062±0.001 mg/L, and at endemic fisheries 0.043±0.0008 mg/L. The highest concentration of Pb is found in domestic locations. The measured Hg concentrations were 0.035±0.003 mg/L domestic, 0.319±0.0026 mg/L hydropower plant, 0.435±0.0036 mg/L fish cage, and 0.277±0.0043 mg/L endemic fisheries. The highest concentration is located in the fish cage. Hg metal concentration has also exceeded the quality standard Government Regulation No. 22 Tahun 2021 Class II concerning Water Quality Management and Water Pollution Control, 0.02 mg/L. The average Cd levels were 0.041±0.0014 mg/L in the settlement area, 0.043±0.0004 mg/L in the hydropower plant, 0.035±0.003 mg/L fish cage, and 0.041±0.0009 mg/L in the endemic fisheries sites. The highest concentration of Cd is found in the hydropower plant. This concentration has also exceeded the quality standard of government regulation No. 82 of 2001 class II concerning Water Quality Management and Water Pollution Control, namely 0.01 mg/L.

Heavy metals in *Rasbora argyrotaenia* and *Oreochromis niloticus*

Figure 3 shows the concentration of Pb metal in both fish. At the domestic and fish cage locations for *R. argyrotaenia* (0.281±0.053 mg/kg and 0.273±0.05 mg/kg) and *O. niloticus* (0.370±0.19 mg/kg and 0.320±0.19 mg/kg) have exceeded the maximum threshold of the government regulation for heavy metal contamination in processed food from fish (0.200 mg/kg).

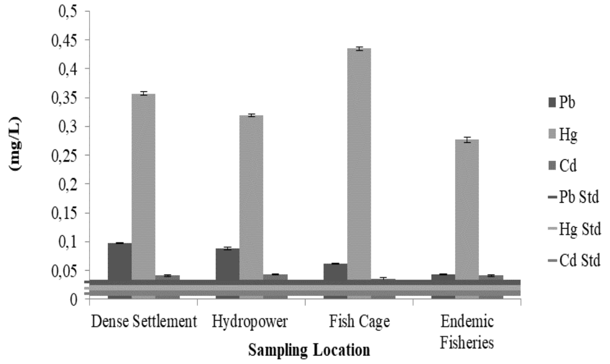

Figure 2. Heavy metals concentration in Maninjau Lake waters

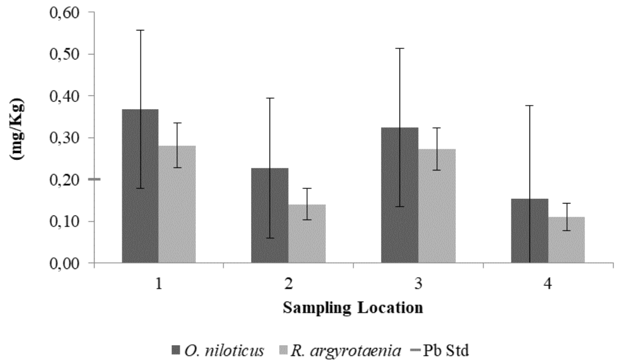

Figure 3. The concentration of Pb Metal in *Rasbora argyrotaenia* and *Oreochromis niloticus*. Note: 1. Dense Settlement; 2. Hydropower; 3. Fish Cage; 4. Endemic Fisheries. Pb Std: Standard of Pb in fish

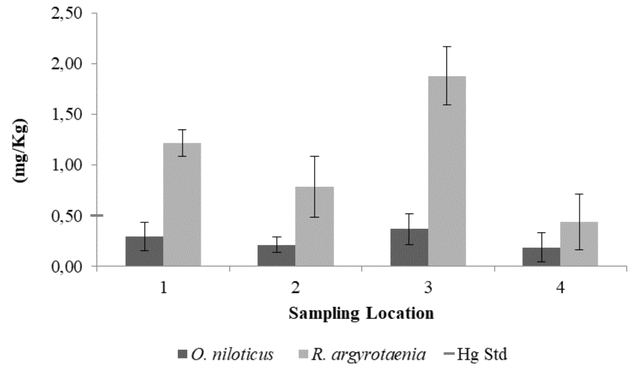

Figure 4. The concentration of Hg Metal in *Rasbora argyrotaenia* and *Oreochromis niloticus*. 1. Dense Settlement; 2. Hydropower; 3. Fish Cage; 4. Endemic Fisheries. Hg Std: Standard of Hg in Fish

Pb metal in *O. niloticus* in hydropower plants exceeds the permissible level (0.230±0.17 mg/kg), while *R. argyrotaenia* is below the limit (0.141±0.038 mg/kg). Meanwhile, the Pb level does not exceed the limit for both types of fish (<0.200 mg/kg) at endemic locations. Figure 4 shows the average concentration of Hg metal in *R. argyrotaenia* and *O. niloticus*. Hg concentration in *O. niloticus* does not pass the permissible level of heavy metals in processed food in fish. The concentration of Hg in *O. niloticus* ranged from 0.190±0.14 to 0.370±0.15 mg/kg (<0.50 mg/kg). Hg concentration in *R. argyrotaenia* has exceeded the maximum permissible level, except for *R. argyrotaenia* in endemic locations (0.439±0.274 mg/kg). Hg concentration in *R. argyrotaenia* exceeded the highest level ranging from 0.786±0.303-1.879±0.285 mg/kg.

The average Cd level in *O. niloticus* ranges from 0.10±0.12 to 0.15±0.10 mg/kg (Figure 5). It has exceeded the Regulation of the Food and Drug Supervisory Agency Number 5 of 2018 concerning the Maximum Limit of Heavy Metal Contamination in Food Processed fish (> 0.10 mg/kg) for all sampling locations. The average Cd level in *R. argyrotaenia* ranged from 0.054±0.07-0.144±0.096 mg/kg. The Cd metal concentration in *R. argyrotaenia* has not exceeded the limit except in the fish cage (0.144±0.096 mg/kg).

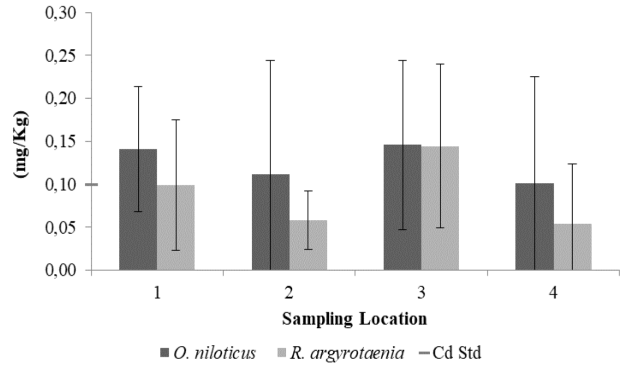

Figure 5. Concentration of Cd Metal in *Rasbora argyrotaenia* and *Oreochromis niloticus*. 1. Dense Settlement; 2. Hydropower; 3. Fish Cage; 4. Endemic Fisheries. Cd Std: Standard of Cd in fish

Spatial and temporal heavy metals concentration in waters and fish

The spatial and temporal heavy metal concentrations in *R. argyrotaenia* and *O. niloticus* were analyzed after the data normality was examined. Data normality showed that only Pb concentration in *R. argyrotaenia* was not distributed normally. Thus, the spatial and temporal data for Pb was analyzed using Spearman Rho, while the other parameters were examined using ANOVA. Statistical analysis was determined using the SPSS version 16.00 application. The data are presented in Table 1. Both concentrations of metals in *R. argyrotaenia* and *O. niloticus* showed no significant difference by the time of sampling, except for Pb concentration in *R. argyrotaenia*. In comparison, the spatial analysis showed that sampling locations affect the different concentrations of metals in both fish species, except for Pb concentration in *R. argyrotaenia*. The characteristics of metals and the nature of fish species may contribute to metal uptake (Yousif et al. 2021).

The spatial and temporal heavy metal concentrations in *R. argyrotaenia* and *O. niloticus* were analyzed by one-way ANOVA using the SPSS version 16.00 application, as can be seen in Table 1. The ANOVA test on Pb, Hg, and Cd metals in *R. argyrotaenia* and *O. niloticus* at different sampling times were $p>0.05$, meaning no significant difference. Meanwhile, the significance of metals Pb, Hg, and Cd in fish at various sampling locations was $p<0.05$.

Correlation of heavy metals in waters and fish

The correlation between Pb water and *R. argyrotaenia* 0.452 with a p-value of 0.548 indicates a positive, moderate and not significantly different relationship. A positive, strong, and not considerably different relationship occurred between Pb in water and *O. niloticus*, 0.648 and 0.352. The concentration of Hg in water on *R. argyrotaenia* and *O. niloticus* had the same positive relationship, with correlation values of 0.998 and 0.984 very strong and significantly different with p-values of 0.02 and 0.016. In contrast to the others, Cd has a very strong and strong but negative relationship, with a correlation value of -0.898 for *R. argyrotaenia* and -0.714 for *O. niloticus*, while the p-value shows no significant difference with 0.102 and 0.286.

Pb in water with *R. argyrotaenia* and *O. niloticus* has a weak positive correlation with r 0.2048-0.4527. Hg metal has a positive and strong correlation with the two fish 0.8078-0.9651. Meanwhile, the relationship of Cd metal with *R. argyrotaenia* was negative and very strong (-0.997), while with *O. niloticus*, it was moderately negative (-0.5294).

Bioconcentration Factor (BCF) in *Rasbora argyrotaenia* and *Oreochromis niloticus*

The value of the Bioconcentration Factor (BCF) is the ratio of metal concentrations in water and fish calculated by equation 1. The BCF values of lead (Pb), mercury (Hg), and cadmium (Cd) in *R. argyrotaenia* and *O. niloticus* can be seen in Table 2. BCF values in *R. argyrotaenia* are Hg> Cd> Pb, while Niloticus Pb> Cd> Hg ranges from 0.668-5.223 for *O. niloticus* and 1.317-4.319 for *R. argyrotaenia*.

Correlation of pH, DO, temperature and BCF in *Rasbora argyrotaenia* and *Oreochromis niloticus*

The correlation between DO and BCF of *R. argyrotaenia* for metal concentrations of Pb, Hg, and Cd, respectively, namely 0.045; 0.376; 0.24, indicates a very weak to a low positive relationship. While the correlation between pH and BCF values for Pb, Hg, and Cd, namely 0.564; 0.468; 0.495, indicates a moderately positive relationship. A moderate to a very strong positive relationship was obtained between temperature and BCF, namely 0.58; 0.93; 0.87.

For *O. niloticus*, the correlation between pH and BCF for Pb, Hg, and Cd metals was 0.566; 0.20; 0.62, indicating a low to a strong positive relationship. Meanwhile, the BCF correlation of these metals to DO, respectively, 0.026; 0.043; 0.29, has a very low, positive relationship. The temperature is moderately correlated to BCF for Pb, which is 0.551, a very strong correlation to BCF for Hg (0.90), and a strong correlation to BCF for Cd (0.779). Overall, the temperature showed a strong correlation between temperature and the BCF for both species than other physical parameters.

Table 1. The ANOVA of heavy metals in fish

Analysis	Heavy metals	*R. argyrotaenia (p-value)*	*O. niloticus (p-value)*
Temporal	Lead (Pb)	<0.05	0.105
Temporal	Mercury (Hg)	0.672	0.105
Temporal	Cadmium (Cd)	0.672	0.105
Spatial	Lead (Pb)	0.714	<0.05
Spatial	Mercury (Hg)	<0.05	<0.05
Spatial	Cadmium (Cd)	<0.05	<0.05

Table 2. BCF of heavy metals in fish

Sampling point	*O. niloticus*			*R. argyrotaenia*		
	BCF Pb	BCF Hg	BCF Cd	BCF Pb	BCF Hg	BCF Cd
Dense settlement	3.790	0.825	3.429	2.898	3.408	2.422
Hydropower	2.591	0.668	2.591	1.599	2.463	1.347
Fish cage	5.223	0.845	4.160	4.403	4.319	4.123
Endemic fisheries	3.581	0.679	2.454	2.553	1.584	1.317

Discussion

Maninjau Lake, located in the equator zone, has minimum air temperatures of 22.66°C and maximum averages of 31.27°C. The temperature measurement was conducted from morning until noon, close to the maximum temperature. The difference between these temperatures and the maximum temperature is around ±1-3ºC. These temperatures are somewhat higher than that of a tropical lake in Africa, Lake Nkuruba, i.e., 22.0 to 24.7°C. Tropical equatorial lakes are more susceptible to small temperature rises. In contrast, increasing surface temperature can increase vertical thermal stratification.

The water quality of Maninjau Lake, compared to the quality standards of Government Regulation (Pemerintah Republik Indonesia 2021), for TSS, nitrite, total phosphate, BOD, COD, and heavy metals Cd, Hg, exceeded the standard. It indicates that activities around the lake have polluted the lake water and caused some heavy metals, which have exceeded the limits permitted by regulations for the lake. Heavy metals might originate from natural and anthropogenic sources (George et al. 2013).

The source of Pb metal is estimated from waste from community activities due to dense settlements, tourism, and agricultural areas. The high concentration of Pb in lake water was caused by oil spills and speed boat fuel used for water transportation and recreational vehicles. The primary sources of Pb metal contamination derived from coal, fuel, and leaded gasoline discharged into the water (Li et al. 2019). Hg emissions originate from mining, industrial or wastewater, atmospheric deposits, and other natural sources that can increase Hg concentrations (Hu et al. 2017). Besides human activities, weathering of Hg- carrying minerals in the soil also contributes to the natural Hg level (Driscoll et al. 2013). Cd is usually found at a low concentration in the aquatic environment. However, the overuse of phosphate fertilizer and industrial use are the primary Cd input source (Ahmed et al. 2019).

The order of metal concentrations in water is Hg>Pb>Cd. The Pb, Hg, and Cd metal concentrations in the waters have different patterns. The highest Pb metals are found in domestic locations, Hg at the fish cage, and Cd at hydropower sites. In this hydropower area, there are tourist activities where boats take tourists around the lake. It shows that the heavy metal level in the waters varies depending on the activities around the sampling area.

Sediment can be a primary source of Pb contamination, which directly affects the deposition of metals in the body due to their feeding habitat (Jayaprakash et al. 2015). Pb is a neurotoxin that causes behavioral disturbances, decreases survival and growth in vertebrates, decreases learning ability and causes long-term chronic effects in children, and can be used as a bioindicator of lead contaminants in the environment (Rajeshkumar and Li 2018). Among the metals, Hg is the most toxic metal in our environment. One form of mercury considered toxic and harmful to humans is methyl mercury. Methyl mercury toxicity hampers protein synthesis, microtubule nuisance, and the increase of intracellular Ca^{2+} with disruption of neurotransmitter function (Jakob et al. 2015). Aquatic organisms, including fish, may uptake Cd in the free ionic form, whereas bioaccumulation in the food web may happen due to Cd contamination in lake waters. Cadmium can generate free radicals, which leads to the oxidation of nucleic acids and alteration of DNA repair mechanisms, membrane structure/function alterations, and energy metabolism inhibition. Cadmium compounds in fish or other seafood are generally very easily absorbed in the form of $CdCl_2$ (Omer et al. 2012). All heavy metals in fish below the maximum level are only in endemic fishery areas. However, Hg has passed the permissible level for *R. argyrotaenia* in domestic, fish cage, and hydropower plants.

On the other hand, Hg metal in *O. niloticus* did not exceed the allowable level in all sampling locations. Heavy metal levels vary among species depending on feeding habits, age, size, fish length, and habitat (Yousif et al. 2021). Besides, metal uptake from contaminated water and food may differ with ecological requirements, metabolic and contamination gradients of water, food, sediment, and other factors such as salinity, temperature, and interacting agents (Yi and Zhang 2012).

The difference in sampling locations significantly changed Pb, Hg, and Cd levels in the two fish. At the time of the research, there was no significant change in climate in terms of rainfall, so the concentration in the sampling site did not change significantly. The different sampling locations demonstrate that each area has specific characteristics representing its pollution levels. In addition, it also emphasizes that human activities significantly affect the contamination of nearby lake sites.

The level of Pb accumulation was lower in the two fish species than in the other two metals. Heavy metal Hg has the most consistent accumulation rate among the three heavy metals, with a positive, strong relationship. However, Cd metal had a strong and negative correlation in the smaller fish compared to the larger fish *O. niloticus*, even though the Cd concentration was the lowest among all metals in lake waters. The lowest Cd concentrations were also found in Taihu Lake, Beyşehir Lake, and Yenicağa Lake (Başyiğit and Tekin-özan 2013). From Başyiğit and Tekin-özan study in Karatas Lake was found that in small fish, heavy metal bioaccumulation tends to be higher. Meanwhile, the metal level in fish is influenced by heavy metal levels in the waters, which depend on the physicochemical parameters of the waters. Apart, size, feeding habits, and habitat also affect the level of metal accumulation in fish. *Rasbora argyrotaenia* with a range of 7.3-11.3 cm in length and 3.1-11.0 g in weight (Nasution et al. 2020), which is lower than *O. niloticus*, with a range of 6.70-22.00 cm length and 5.20-243.70 g weight (Samir et al. 2021).

BCF can be considered as a bioindicator in the area of environmental pollution status assessment. BCF may vary depending on the trophic level, food web structure, and an organism's life history (El-moselhy et al. 2019). The BCF of metals in fish is less than 100, which is low accumulative. Many studies have shown that the bioaccumulation of heavy metals in fish muscles is significantly associated with fish species. Although both types of fish are omnivores, *R. argyrotaenia* showed a slightly higher BCF value than *O. niloticus*, *R. argyrotaenia* is a smaller pelagic fish than *O. niloticus*. However, these results showed that heavy metals did not contaminate both fish species in the endemic areas. Further research may be worthwhile investigating the relationship between heavy metal levels in fish and fish intake patterns and determining the risk analysis of humans consuming them.

Environmental parameters pH, DO, and temperature negatively relates to BCF for all metals. One of them, pH, shows a negative relationship to BCF. High pH is toxic to fish (Wood 2001). However, a low pH also affects the growth rate (Watras et al. 1998). Other studies have also found a negative relationship between Dissolved Organic Carbon (DOC) and HCB accumulation (Teunen et al. 2021).

This study has shown that all heavy metals in lake waters exceed the maximum level in the order of Hg>Pb>Cd. All heavy metals in *R. argyrotaenia* and *O. niloticus* are still below the permissible level in endemic fisheries. In contrast, almost all heavy metals in both fish samples exceeded the maximum level in other sampling locations. The results of the temporal analysis showed that the metal concentrations in *R. argyrotaenia* and *O. niloticus* were not significantly different ($p>0.05$). However, they were spatially significant ($p<0.05$). However, the BCF values in fish are still relatively low. The bioaccumulation of heavy metals in *R. argyrotaenia* is higher than *O. niloticus*. Correlation results between environmental parameters (pH, temperature, and DO) show that temperature has a moderate to very strong relationship to the BCF value of all metals in both fish species. All human activities such as aquaculture, settlement, and tourism contribute to heavy metal levels in the waters and BCF values.

The accumulation of potentially toxic heavy metals in fish requires special attention, especially for commercial fish widely consumed in Maninjau Lake. In addition, endemic lake fish need to be preserved by maintaining their habitat. Therefore, monitoring fish by keeping the metal content within acceptable limits is advisable. Furthermore, intensive water and sediment quality monitoring, especially to identify early hazards to human health.

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