

An Assessment of Heavy Metals Pollution in the Waters and Sediments of Lake Maninjau, Indonesia

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An Assessment of Heavy Metals Pollution in the Waters and Sediments of Lake Maninjau, Indonesia

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Abstract. This research performs an analysis of heavy metals in the waters and sediments of Lake Maninjau and the resultant pollution index value. The research was carried out in 11 locations, e.g., floating net cages, endemic fisheries, near settlements, hydropower plants, and seven rivers at the lake's inlet and outlet at a depth of 0-1.5 metres. Determining the pollution index was conducted based on heavy metals and environmental parameters. Aside from Zn, the concentration of Cd, Hg, Pb, Cu in the waters in all locations exceeded the quality standard. The metal in sediments in all areas exceeded the quality standard of contaminated soil. Concentrations of heavy metals in sediment are higher than that of heavy metals in water. 8 of 11 sampling locations were in the medium polluted category, with the fish cage location having the highest pollution index (PI) value. Anthropogenic activities such as aquaculture, water transportation, and settlements around the lake have an effect on the waters and sediments of the lake, characterised by heavy metal contamination. The lake's quality must be continuously monitored, and wastewater management improved from activities around the lake to control heavy metal contamination. Further evaluation is required of the heavy metals contamination originating from anthropogenic activities and natural sources.

1. Introduction

One lake which has a crucial role in supporting the surrounding community's development and economy is Lake Maninjau in West Sumatra. Various activities have recently severely polluted the lake and have degraded water quality and sediment. Three main activities are performed in Lake Maninjau: hydropower plants, freshwater aquaculture centers, and tourism destinations [1]. Other activities on the lake include agriculture, human settlements, and water transportation; these are thought to have contributed to the deterioration of water quality and sediment due to the presence of heavy metals. Both human and natural activities from urban and industrial activities are the primary sources of heavy metals entering the aquatic environment, these include forest fires, continental weathering, and volcanic activity [2].

At a high level, heavy metal content can cause harm to organisms which live in lakes; as a result there is a high likelihood of them entering the food chain and being consumed by humans [3]. This material is distributed partly in aqueous phases, is partially adsorbed on suspended materials, and accumulates in the lake sediment [4]. Sediments are considered as the sink and source for heavy metals discharged into the environment [5]. How much these metals are released from the sediments into the water body depends on microbial activity, hardness, alkalinity, ionic strength, pH, and Eh [6]. Therefore, estimating the level of heavy metal pollution in the aquatic environment is determined by analyzing



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water, sediment, and marine organisms [7]. Water pollution levels can be determined through an environmental quality index. This study aims to obtain an overview of heavy metal concentrations of Cd, Hg, Pb, Cu, Zn in the waters and sediments of Lake Maninjau. The results from the heavy metal analysis were used to determine the pollution index in the waters of Lake Maninjau and assess the pollution in the waters and sediments due to heavy metals.

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2. Materials and Method

Study Area

Lake Maninjau is situated in West Sumatra Province, has a surface area of 99.5 km² with a catchment area of 24,800 ha, and a maximum depth of ± 165 m. Lake Maninjau is surrounded by nine villages, with Maninjau being the capital city. Lake Maninjau primarily serves as a hydroelectric power plant (PLTA), with power generated by 64 MW to supply electricity to West Sumatra [8]. The lake has also been developed as a center of aquaculture and tourism. This area is a volcano-tectonic depression area, with similarities to Lake Toba but smaller in size. The height of the Maninjau caldera wall is 1200-1400 meters above sea level or 459 meters from the lake's surface, with a maximum depth of 157 meters. The average monthly rainfall is 325.8 mm, and the average maximum temperature of Lake Maninjau is 31.27 °C, while the average minimum is 22.66 °C. 95.20% is the average level of humidity, with wind speeds around Lake Maninjau averaging 23.5 km/hr. 88 rivers, large and small, flow into the lake. The lake outlet flows into Batang Antokan and empties into the Indian Ocean. Various resident activities occur on the edge of the lake, for example, settlements, hotels, agriculture, and livestock, which are all sources of pollutants entering lake waters.

Sampling and Parameters Analysis

Sampling was conducted 3 times from February-May 2018 over a period of 2 weeks. The sampling site was decided on the basis of the Indonesian National Standard [9], as shown in figure 1. Eleven locations were determined by considering how the lakes are used and the site closest to the source of the pollutants, i.e., dense settlements, endemic fisheries, fish cages, hydropower, inlets (Batang Kularian, Batang Maransi, Jembatan Ampang, Batang Kurambit, Batang Asam, Bandar Ligin River) and the outlet (Batang Antokan River) of the lake. A vertical water sampler on the boat was used to obtain water samples. The water sampling procedure adhered to government regulation standards [9]. The water samples were directly measured for temperature and DO using Lutron DO-5510 and pH with HI 9813-5 pH-meter. 1.5 ml of concentrated HNO₃ was added to the water samples for metal analysis and then placed into the cool box. Sediment samples were obtained from the same location as the water samples. The sampling procedure used the sediment sampling guide and methodologies [10]. Analysis of the water samples was performed and then compared to the "Government Regulations of the Republic of Indonesia Number 82 (2001) Class 2" [11]. In comparison, heavy metals in sediment analysis referred to the "Government Regulation about Total Concentration for Determination of Management of Soil Contaminated by Hazardous and Toxic Waste" [12]. Identification of heavy metals in water and sediment was measured using "Inductively Coupled Plasma Shimadzu, ICPE-9000", which is referred to as "Standard Methods for the Examination of Water and Wastewater" [13].

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Pollution Index

The pollution indices were used for determining the water quality of Lake Maninjau based on environmental parameters (temperature, DO, pH) and heavy metal. These indices were calculated by using equation 1 based on the "Decree of the State Minister for the Environment Regarding Guidelines for Determining Water Quality Status" [14]. This value shows the water contamination level as a result of heavy metal and environmental parameters based on the "Government Regulation for Surface-Water Class 2" standard.

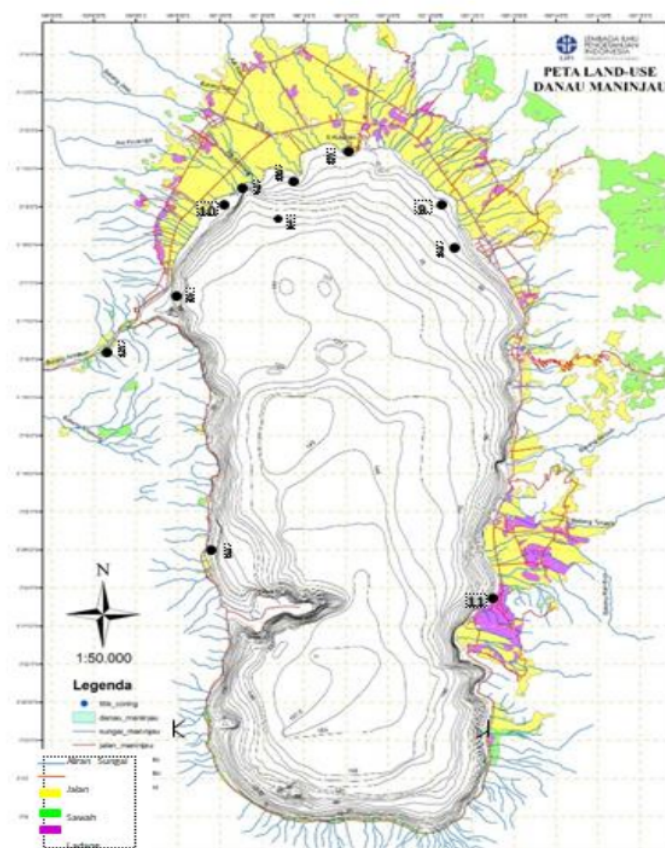


Figure 1. Map of Sampling Location. 1. Fish Cage, 2. Endemic Fisheries, 3. Dense Settlement, 4. Hydropower, 5. Batang Antokan River, 6. Batang Kularian River, 7. Jembatan Ampang River, 8. Batang Asam River, 9. Batang Maransi River, 10. Batang Kurambit River, 11. Bandar Ligin River

$$PI_j = m \sqrt{\frac{\left(\frac{c_i}{L_{ij}}\right)^2_M + \left(\frac{c_i}{L_{ij}}\right)^2_R}{2}} \dots \dots \dots (1)$$

Where:

²¹ ²³ = water quality concentration parameters listed in the water designation standard (j). Ci denotes water quality concentration parameters (i) of the water sample at the sampling locations. The calculated pollution index value is then categorised: $0 \leq PI_j \leq 1,0$ is baseline level, $1,0 < PI_j \leq 5,0$ lightly polluted, $5,0 < PI_j \leq 10$ moderately polluted, $PI_j > 10$ heavily polluted.

3. Results and discussion

3.1. Environmental Parameters

The pH of Lake Maninjau and the rivers entering and leaving the lake has a pH value of 7.17-9.4. The pH originating from the rivers is lower than the lake waters and ranges between 7.24 and 8.37. Lake and river water temperatures range between 27.17°C and 31.47°C. DO ranges from 5.23 to 9.9. The pH value of DO originating from rivers is lower, i.e., 5.23 - 7.7, while in lake waters, DO is higher, i.e., 8.8 to 9.9. This lower DO concentration exhibited incoming contaminants that originate in anthropogenic sources transported via river flow. High pH and DO levels also indicate a high level of primary production of algae blooms from the surroundings [15]. The green color evidences this in the lake waters.

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3.2. Heavy Metal Concentration in water and sediments

Figure 2a and figure 2b show heavy metal concentrations in waters and sediments. The Cd, Hg, Pb, and Cu metals concentrations have exceeded the quality standard in almost all sampling locations in the waters. In contrast, the metal concentrations in sediments have not exceeded the quality standard except for Hg.

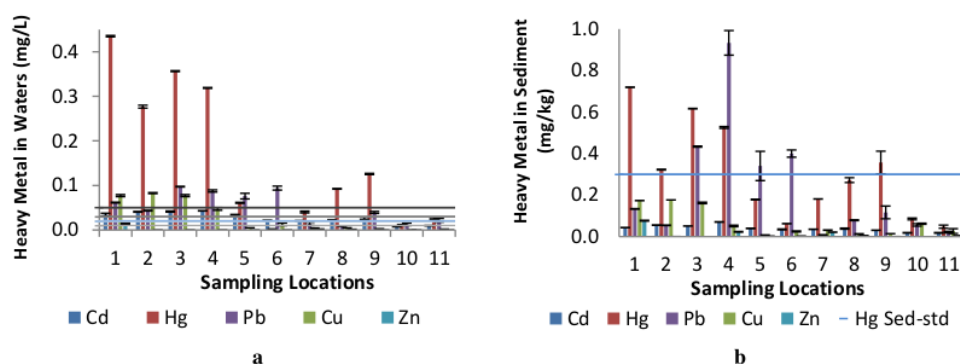


Figure 2. Heavy Metal Concentrations a. in water b. in sediment, sampling locations: 1. Fish Cage, 2. Endemic Fisheries, 3. Dense Settlement, 4. Hydropower, 5. Batang Antokan River, 6. Batang Kularian River, 7. Jembatan Ampang River, 8. Batang Asam River, 9. Batang Maransi River, 10. Batang Kurambit River, 11. Bandar Ligin River.

Aside from Zn, the Hg, Pb, Cd, and Cu lake water concentrations exceeded the quality standard in every sampling location, in decreasing order of $Hg > Pb > Cd > Cu$. Concentrations of Hg metal ranged between 0.002 and 0.435 mg/L, with the highest concentrations at the location of the fish cage. The cage area is the centre of dense fish farming activity, where there are also medium density settlements and traditional markets. The primary sources of Hg contamination are mining activities, industrial activities, wastewater, atmospheric deposits, etc. [16]. Aside from anthropogenic sources, weathering of Hg-carrying minerals in the soil also adds to natural Hg input [16]. The metal concentration in the lakeshore area is higher than the middle of the lake. Various activities around the lake and the vicinity of the contaminants increase the high concentrations of heavy metals. Apart from Hg, Pb, Cd, and Cu metals were not detected in the middle of the lake, exceeding the quality standard. Hg metal in the middle of the lake indicates that the Hg metal concentration is evenly distributed in the waters of Lake Maninjau. Pb concentrations in lake waters range between 0.0005-0.0973 mg/L, with the lowest concentration at the Bandar Ligin river and the highest concentration near residential areas. The high lake water concentration of Pb has resulted from oil and speedboat fuel spills. The primary source of Pb metal pollution stems from coal, fuels, and leaded gasoline being released into the water [17]. Metal concentrations entering the lake from the river flow are also dominated by Hg and Pb metals. Consequently, metal concentration in lake waters is higher than the metal concentration in river waters. The highest metal concentration comes from the Batang Maransi River, which is located in Nagari Bayur. There are hotels, markets, agriculture, and settlements of moderate density along the river, which contribute to heavy metals in the river and water sediments.

Heavy metal concentrations are usually higher in sediments than in water. Based on the contaminated soil standard, Hg metal concentration is excessive in all sampling locations, with concentrations ranging from 0.048-0.720 mg/Kg. This shows that Hg metal contamination is evenly spread in both the waters and sediments throughout the waters of Lake Maninjau. High heavy metal levels in sediment are frequently ascribed to anthropogenic influences instead of sediment being naturally enriched by geological weathering [2]. Hg metal content is higher in comparison to previous studies, namely 0.0005-

0.0591 mg/kg [18]. The high concentration of metals in sediments results from heavy metals combining with organic materials into metal complexes. Most remain relatively stable in the sediment [19].

3.3. Coefficient correlation of heavy metals in waters and sediments

The correlation of heavy metals in sediment and waters is shown in table 1. The association of heavy metals Cd, Hg, Pb, Cu, and Zn in both mediums ranges between 0.8767-0.9761, which indicates that there is a strong relationship between them. However, variation across components depends on an element's chemical form or speciation. These components include mobility, transportation, and partitioning of metals and metalloids in the environment (e.g., sediment, soil, water, air) [6]. Heavy metals change and partition into various physicochemical forms and phases [6]. Metal in the particulate phase can be absorbed into the water column or precipitate into the sediment.

Conversely, metal can also be released from the deposit into the water column by resuspension [17]. Heavy metals are unable to be removed from the water and therefore accumulate in sediments. Heavy metals can be distributed in sediments as the exchange-, organic matter- or residual-bound species [20].

Table 1 Correlation of Heavy Metals in Waters and Sediments.

No.	Heavy metals	Coefficient of Determination (R ²)	Correlation Coefficient (r)
1.	Cadmium (Cd)	0,8910	0,9439
2.	Mercury (Hg)	0,9155	0,9568
3.	Lead (Pb)	0,7686	0,8767
4.	Copper (Cu)	0,9528	0,9761
5.	Zinc (Zn)	0,8991	0,9482

3.4. Pollution Index

The Pollution Index (PI) is used for determining pollution levels relative to the parameters of allowable water quality. Figure 3 shows the PI value distribution in every sample location. The PI values ranged from 2.66-9.32 and met the moderate and light-polluted categories based on the Regulation of State Minister for the Environment. The Batang Antokan River, the Ampang Bridge River, the Batang Asam River, and the Batang Maransi River are included in the moderate polluted category with a PI 5.0 to 10. Contrastingly, the other three rivers remain in the lightly polluted category with a PI < 5.0. A higher PI value is a result of many polluting activities occurring around the Maninjau river and lake. The increase in metal concentration results from anthropogenic activities such as agricultural waste, household waste, and aquaculture activities [21]. Lake Maninjau is almost in the same pollution category as Lake Tempe in South Sulawesi. The Tempe Lake pollution index value is included in the medium polluted category in the range of 5.45-6.65 [22]. Lake Tempe's primary water source is several local rivers that are subject to many human activities, including transportation, bathing, washing, farming, etc. Similar to Lake Maninjau, the highest pollution source comes from aquaculture, water transportation, and settlements.

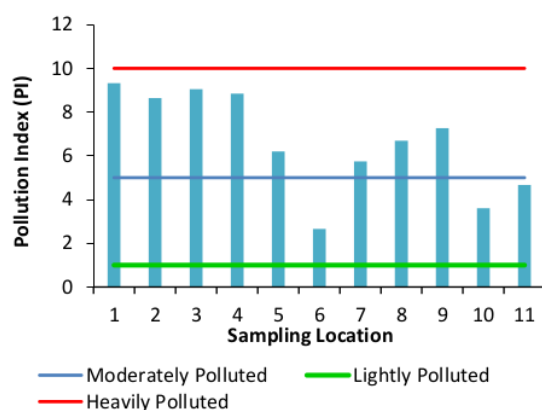


Figure 3. Pollution Index Distribution sampling locations: 1. Fish Cage, 2. Endemic Fisheries, 3. Dense Settlement, 4. Hydropower, 5. Batang Antokan River, 6. Batang Kularian River, 7. Jembatan Ampang River, 8. Batang Asam River, 9. Batang Maransi River, 10. Batang Kurambit River, 11. Bandar Ligin River.

4. Conclusion

Cd, Hg, Pb, Cu concentrations in the waters in every sampling location exceeded the "Government Regulation of Class 2" standards, apart from Zn. However, only heavy metal Hg in sediment exceeds the quality standard in all sampling locations. This significant correlation between heavy metals and sediments indicates mutual interaction. The pollution index is based on environmental parameters (temperature, DO, pH) and heavy metals from 8 of 11 sampling locations, which were in the medium polluted category, which indicates that the entire lake area is contaminated, particularly by heavy metals. The lake's activity, primarily from aquaculture, water transportation, and settlements, has affected the water and sediment quality of the lake. Therefore, it is necessary to continuously monitor the quality of the lake and improve wastewater management of the activities occurring around the lake to control heavy metal contamination.

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References

- [1] Komala P S, Nur A and Nazhifa I 2019 Distribution of organic contamination based on depth stratification in Maninjau Lake, Indonesia *IOP Conf. Ser. Mater. Sci. Eng.* **602** 9–16
- [2] Goher M E, Farhat H I, Abdo M H and Salem S G 2014 Metal pollution assessment in the surface sediment of Lake Nasser, Egypt *Egypt. J. Aquat. Res.* **40** 213–24
- [3] Monroy M, Maceda-Veiga A and de Sostoa A 2014 Metal concentration in water, sediment and four fish species from Lake Titicaca reveals a large-scale environmental concern *Sci. Total Environ.* **487** 233–44
- [4] Pintilie S, Brânză L, Bețianu C, Pavel L V, Ungureanu F and Gavrilăscu M 2007 Modelling and simulation of heavy metals transport in water and sediments *Environ. Eng. Manag. J.* **6** 153–61
- [5] Yin H, Gao Y and Fan C 2011 Distribution, sources and ecological risk assessment of heavy metals in surface sediments from Lake Taihu, China *Environ. Res. Lett.* **6**

- [6] Azeez P A, Anjan Kumar Prusty B and Jagadeesh E P 2006 Chemical speciation of metals in environment, its relevancy to ecotoxicological studies and the need for biosensor development *J. Food, Agric. Environ.* **4** 235–9
- [7] El Nemr A, Khaled A, Moneer A A and El Sikaily A 2012 Risk probability due to heavy metals in bivalve from Egyptian Mediterranean coast *Egypt. J. Aquat. Res.* **38** 67–75
- [8] Raya Consult 2016 *Detail Desain Pemanfaatan Pengembangan Danau Maninjau Provinsi Sumatera Barat* (Padang)
- [9] Badan Standardisasi Nasional 2008 SNI 6989.57:2008 Mengenai Air dan Air Limbah-Bagian 57:Metode Pengambilan Contoh Air Permukaan.
- [10] Ohio Environmental Protection Agency 2001 *Sediment Sampling Guide and Methodologies* (Columbus, Ohio)
- [11] Peraturan Pemerintah Republik Indonesia Nomor 82 2001 *Tentang Pengelolaan Kualitas Air dan Pengendalian Pencemaran Air*
- [12] Peraturan Pemerintah Republik Indonesia 2014 *Pengelolaan Limbah Bahan Berbahaya dan Beracun* (Indonesia)
- [13] APHA 2005 *Standard methods for the examination of water and wastewater* (Washington, D. C.: APHA-AWWA-WEF)
- [14] Keputusan Menteri Negara Lingkungan Hidup 2003 *Keputusan Menteri Negara Lingkungan Hidup Nomor 115 Tentang Pedoman Penentuan Status Mutu Air*
- [15] Komala P S, Primasari B and Ayunin Q 2020 The Influence of the Physicochemical Parameters on the Ortho Phosphate and Total Phosphate Concentrations of Maninjau Lake *J. Phys. Conf. Ser.* **1625**
- [16] Driscoll C T, Mason R P, Chan H M, Jacob D J and Pirrone N 2013 Mercury as a global pollutant: Sources, pathways, and effects *Environ. Sci. Technol.* **47** 4967–83
- [17] Hu J, Zhou S, Wu P and Qu K 2017 Assessment of the distribution, bioavailability and ecological risks of heavy metals in the lake water and surface sediments of the Caohai plateau wetland, China *PLoS One* **12** 1–15
- [18] Syawal M S, Wardiatno Y and Hariyadi S 2016 Pengaruh Aktivitas Antropogenik Terhadap Kualitas Air , Sedimen dan Moluska di Danau Maninjau Sumatera Barat *Jurnal Biologi Tropis*, Januari 2016: Volume 16 (1):1-14 ISSN: 1411-9587 **16** 1–14
- [19] Ying X and Lu J L 2010 Study on form distribution and correlation of heavy metals in the sediment of urban water *2010 4th Int. Conf. Bioinforma. Biomed. Eng. iCBBE 2010* 1–4
- [20] Kamaruzzaman Y, M.A. Z and Akbar J 2020 A review on the accumulation of heavy metals in coastal sediment of Peninsular Malaysia *Ecofeminism Clim. Chang.* **1** 21–35
- [21] Syandri H 2015 Heavy Metals in Maninjau Lake , Indonesia : water column , sediment and biota **3** 273–8
- [22] Yani A, Amin M, Rohman F, Suarsini E and Haerunnisa 2019 Water quality and pollution index of lake tempe in south Sulawesi, Indonesia *Pollut. Res.* **38** 568–74

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