LIMNOTEK Perairan Darat Tropis di Indonesia
transforming into ***Journal Limnology and Water Resources***
p-ISSN: 0854-8390 e-ISSN: 2549-8029
https://ejournal.brin.go.id/limnotek

Mercury Dynamics in Mining-Adjacent Ecosystems: Risk Assessment of Lake Lais, Central Kalimantan, Indonesia

Rosana Elvince*) and Budhi Ardhani

Study Program of Aquatic Resource Management, Department of Fisheries, Faculty of Agriculture, University of Palangka Raya, Central Kalimantan, Indonesia

*) Corresponding author's e-mail: rosana@fish.upr.ac.id

Received: 15 October 2024; Accepted: 26 April 2025; Published: 20 June 2025

Abstract: Mercury is a hazardous chemical that significantly impacts both the environment and human health. In Central Kalimantan, gold mining activities contribute to mercury contamination, particularly in aquatic ecosystems. Lake Lais, an oxbow lake along the Kahayan River, is potentially affected by mercury from upstream mining activities. This study aims to assess mercury contamination in Lake Lais water and sediment, and evaluate the ecological risks associated with mercury pollution. In September 2024, water and sediment samples were collected from five sites in Lais Lake. Water samples were collected from the surface using polypropylene bottles with added nitric acid to preserve mercury content. Sediment samples were taken using an Ekman grab and analyzed for mercury using Atomic Absorption Spectrophotometry (AAS) at *Balai Standarisasi Pelayanan Jasa Industri* in Banjarbaru, South Kalimantan. The results showed that water mercury concentrations ranged from 0.00 to 0.002 mg/l, which is within the limits set by the Indonesian government (PP No. 22/2021). However, sediment mercury levels ranged from 0.14 to 0.47 mg/kg, which can negatively impact the ecosystem based on international standards. Lais Lake was classified as having mild to moderate mercury contamination, with an ecological risk ranging from moderate to very strong. The Risk Quotient (RQ) exceeded 1, indicating high ecological risk. These findings highlight the need for regular monitoring and stricter regulation of mercury use in mining. Future research should focus on long-term impacts and seasonal variations in mercury levels to better assess ecological risks.

Keywords: Index Geoaccumulation (I-Geo), Mercury Contamination, Risk Ecology (RI), Risk of Quotient (RQ), Gold Mining

DOI: https://doi.org/10.55981/limnotek.2025.8184

1. Introduction

Mercury or mercury (Hg) is a type of metal as an organic and inorganic compound. This type of metal is found in nature and is widely distributed in rocks, ore, soil, water, and air. Mercury (Hg) is liquid, grey in colour and odourless. At room temperature, mercury has liquid properties and has high electrical conductivity, which causes mercury to be widely used in industry, mining and laboratories. Mercury is very dangerous for both human life and other aquatic biota in waters containing mercury (Marsyalita et al., 2012). In general, mercury enters the waters in the form of elemental Hg (HgO) and has a high density. This element can be converted into organic mercury caused by the action of methane bacteria, namely methyl mercury. This element has toxic properties and strong binding properties, as well as good solubility in the body of fish and other aquatic biota (Elvince et al., 2008).

In Central Kalimantan, mercury has been using in gold processing since the 2000s.

p-ISSN 0854-8390 e-ISSN 2549-8029

Mercury left over from gold processing can enter the environment from several processes, namely the disposal of liquid waste that still contains mercury, tailings and smoke from the gold refining process. All of these processes can enter the surrounding environment and the aquatic environment. Mercury waste that enters the waters can settle into the sediments at the bottom of the waters and then mercury is converted into the very dangerous methylmercury. Methyl mercury is known to be one of the most dangerous types of mercury in fish. If fish containing methylmercury is consumed by humans, human health may be compromised. The presence of mercury in the aquatic environment can pose risks that can cause harm. Risk of ecology related to mercury have been conducted by some researchers such as Guo, et al (2010), Mulyaningsih, T.R, and Suprapti, S. (2015), Abdullah et al (2020), Kho, et al. (2022), Handayani, et al (2024)

Mercury contamination of river waters can occur in several ways, one of which is the extraction of gold from illegal gold mines located along river banks. Liquid mercury is used in gold extraction to form amalgam. Amalgam is then melted through a combustion process releasing mercury in gaseous form into the atmosphere. Mercury released into the atmosphere will be reabsorbed through various media by plants, animals and humans causing health problems (Nakazawa et al., 2021). Hg (0) emitted to the atmosphere isoxidized, trapped by the rain, and deposited in environmental waters; Hg is also discharged directly into environmental waters. These processes may increase Hg concentrations in aquatic organisms such as fish, potentially increasing the risk of Hg intake among people who eat fish on a daily basis. (Nakazawa, et al., 2016)

According to the US EPA (2024), ecological risk assessments can be used to predict the likelihood of future impacts (prospective); or to evaluate the likelihood that observed effects are due to past or ongoing exposure to specific stressors (retrospective). In addition, ecological risk assessments are used to support various types of actions, including regulation of hazardous waste disposal sites, industrial chemicals, and pesticides, watershed management; protection of ecosystems from chemical, physical, or biological stressors. Information from ecological risk assessments can be used by risk managers to communicate with interested parties and the general public; limit exposure to ecological stressors; negotiate remediation options with stakeholders; or develop monitoring plans to ensure risk reduction and ecosystem restoration.

Some research related to ecological risk of mercury in Indonesia has been conducted by some researchers (Maulana, et.al., 2023; Mulyaningsih and Suprapti, 2015; Nugrayani, et al., 2023; Astuti, et al., 2023)

Lake Lais is one of the lakes located in Tanjung Sangalang Village, Kahayan Tengah Sub-district, Pulang Pisau Regency, Central Kalimantan. Lais Lake is utilized by the community as a fishing ground area. As a source of protein, fish is one of the sources of mercury entry into the human body. This study aims to assess the ecological risk of mercury (Hg) concentrations in water and sediment in Lake Lais.

2. Materials and Method

2.1. Sampling Location

This research was conducted in Lake Lais on 03 September 2024. The lake located in Tanjung Sangalang Village, Kahayan Tengah District, Pulang Pisau Regency, Central Kalimantan Tengah (Figure 1). The lake is one of the oxbow lakes in Central Kalimantan with an area of 5,4 ha.

2.2. Research Procedure

Water and sediment sampling was carried out at each station (5 stations) by following procedures:

i. Water samples were taken from each station at the surface of the water using a 50 ml polypropylene bottle at each station. Then the water samples taken were added with nitric acid (HNO3) to stabilize the mercury concentration in the samples and put in a box filled with ice before the samples sent to the Balai Standarisasi dan Pelayanan Jasa Industri, Banjarbaru, South Kalimantan.
ii. Sediment samples were collected using an Ekman Grab at each sampling station and the sediment samples were put into a 50 ml polypropylene bottle that had been prepared and labelled, then put into

Styrofoam box before the samples were sent to the Balai Standarisasi dan Pelayanan Jasa Industri, Banjarbaru, South Kalimantan.

iii. Mercury analysis for both samples were analysis using Atomic Absorption Spectrometry (AAS) method.

2.3. Data analysis

Pollutant accumulation index

Index of Geographic Accumulation (I-Geo) is used to assess mercury pollution of Lake Lais. In order to obtain the I-Geo value or the level of mercury pollution, the formula is used as follows (Nugraha et al., 2022).

$$\textbf{I-Geo} = \textbf{Log2}\,(\textbf{Cn}/\textbf{1.5 Bn}) \quad \text{.... Eq.1}$$

where:

Cn: Heavy metal concentration in sediment

Bn: Normal concentration of metal (background) in nature 0.08 mg/kg (Panggabean et al., 2022).

Table 1. Classification of Geoaccumulation Index

I-Geo Range	Pollution Class
I-Geo ≤ 0	Unpolluted
0 < I-Geo ≤ 1	Unpolluted to moderately polluted
1 < I-Geo ≤ 2	Moderately polluted
2 < I-Geo ≤ 3	Moderately to heavily polluted
3 < I-Geo ≤ 4	Heavily polluted
4 < I-Geo ≤ 5	Heavily to extremely polluted
I-Geo > 5	Extremely polluted

The CF was calculated by dividing the metal concentration in the sediment by the background value (Huang, et al., 2023)

$$\textbf{CF} = \textbf{C (contaminants)}/\textbf{C (background)} = \textbf{Ci}/\textbf{Cb} \quad \text{.... Eq.2}$$

where:

Ci: the Hg concentration in the sediment sample

Cb: Cb is background concentration of metal in nature 0.08 mg/kg (Panggabean et al., 2022).

Risk of Ecology (RI)

The RI evaluating the degree of contamination of sediments according to the toxicity of pollutants was calculated:

$$\textbf{RI} = \sum E_{ir} = \textbf{T}_{ir} \textbf{x} \textbf{C}_{if} \quad \text{.... Eq.3}$$

where:

RI : Total environmental potential index

$\sum Eir$: Sigma of the potential environmental index

Eir : index of potential environmental risk of one heavy metal element

Tir : toxic response factor (Hg = 40)

Table 2. Classification of ecological risk index

RI Range	Ecological Risk Level
RI ≤ 40	Low ecological risk
40 < RI ≤ 80	Moderate ecological risk
80 < RI ≤ 160	Strong ecological risk
160 < RI ≤ 320	Very strong ecological risk
RI > 320	Extremely high ecological risk

To describe the potential risk of toxic pollutants, the following formula (Huang et al., 2023) was used:

$$\textbf{RQ} = \textbf{Ci}/\textbf{PNEC} \quad \text{.... Eq.4}$$

where RQ is the Risk Qouitient; Ci is the Hg concentration in the sediment sample and PNEC is the concentration predicted to have no effect. According to Portezuela et. al. (2019), the PNEC of Hg is estimated at 0.04 mg/kg. RQ ≥ 1 indicates high risk, and RQ < 1 indicates low risk (Huang et al., 2023).

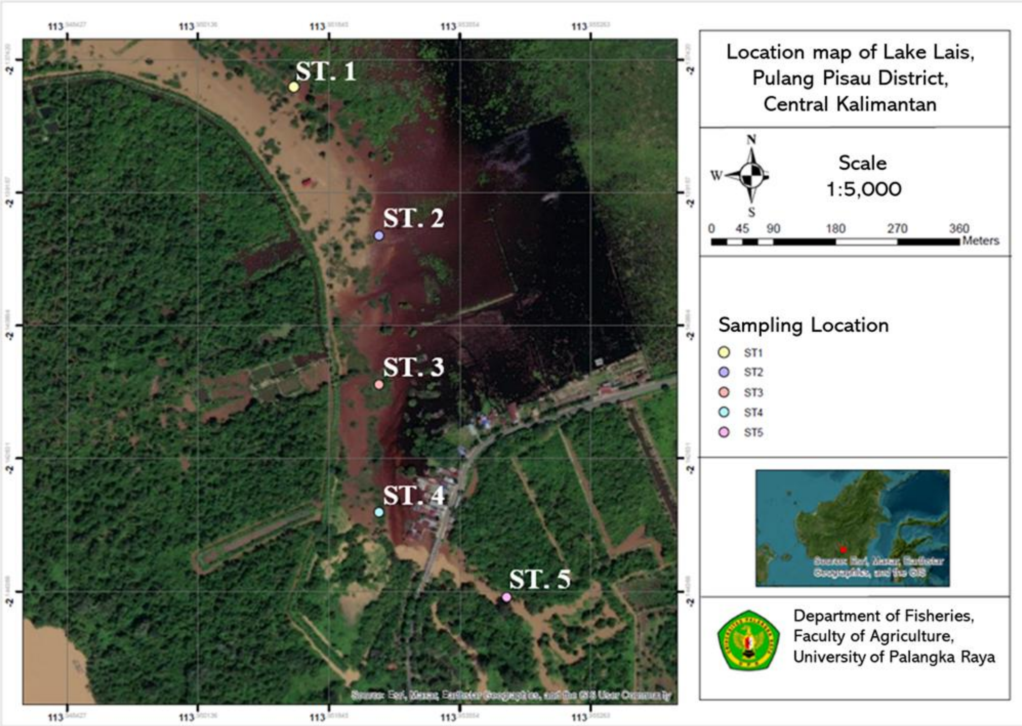

Figure 1. Location map of Lake Lais showing the sampling stations, Pulang Pisau District, Central Kalimantan, Indonesia

3. Result and Discussion

3.1. Mercury Content in Water and Sediment

The presence of mercury in water and sediment in Lais Lake might come from several pathways, such as rainwater containing mercury, particles from the air entering the lake and also from the Kahayan River water entering the lake. The sources of mercury to the environment consist of natural and anthropogenic sources (Guentzel et al., 2007; Mao, et al. 2023). Natural sources of mercury include volcanic eruptions and marine emissions. Anthropogenic (human-caused) emissions include mercury released from fuels or raw materials or industrial products or processes (US EPA, 2024).

Mercury released from natural and anthropogenic sources enters aquatic ecosystems primarily through river flow and atmospheric deposition. It is then converted to highly toxic methylmercury (MeHg) through methylation by microbes in sediments and the water column. Sediments are considered a repository of pollutants and environmental changes. Therefore, the aquatic environment is critical to the Hg cycle and human exposure (Mao, et al. 2023).

Based on the results presented in Table 2, the mercury content in Lais Lake water ranged from 0.001 to 0.005 mg/l. The mercury content in lake water is still within the prescribed range by Republik Indonesia (2021). Compared to another research location in Central Kalimantan, the mercury content in Lais Lake water is much higher than the mercury content in Tilap Lake water, which was below 0.000007 mg/l (Elvince, et al. 2008) and Payawan Lake (0,000069 mg/l) (Indrajaya and Virgiyanti, 2019). Therefore, the mercury content in Lais Lake water was lower than that in water from Limboto Lake (0.0146 mg/l) (Niode, et al. 2021).

Mercury content in Lais Lake sediments ranged from 0.142 to 0.473 mg/kg. Mercury content in sediments can have a negative impact on organisms in the water. Sediment mercury can be converted by microorganisms into methylmercury, a highly toxic chemical that builds up in fish, shellfish and animals that eat fish (US EPA, 2024). Some countries set the mercury content in sediments to prevent the adverse effects of mercury presence in sediments. The quality standard value of sediment Hg from ANZECC & ARMACANZ is divided into two categories, namely low (0.15

mg/kg) which indicates low toxicity effects but needs further attention and high (1.00 mg/kg) indicates the reference value as an evaluation of the adverse effects experienced by half the exposed population. Meanwhile, Canadian quality standards in the CCME also show an Interim Sediment Quality Guidline (ISGQ) value of 0.13 mg/kg as the limit of negative effects experienced by biota and a Probable Effect Level (PEL) of 0.70 mg/g as an adverse biological effect experienced by biota due to exposure to contaminants. In addition, the National Oceanic and Atmospheric Administration (NOAA) sets quality standards based on the Effect Range Low (ERL) value of 0.15 mg/kg and Effect Range Medium (ERM) of 0.71 mg/kg which shows the criteria for the relationship between chemical concentrations in sediments and indicators of biological damage caused (Haryati, et. al., 2022). Based on the references, the mercury toxicity in sediment from Lais Lake indicates low adverse effects.

Table 3. Mercury Concentration in Water and Sediment Samples from Lake Lais

Station	Mercury in Water (mg/L)	Mercury in Sediment (mg/kg)	Quality Standards
ST.1	0.001	0.473	**Water:** 0.0001–0.0005 (PP No. 22/2021) **Sediment:** - 0.15–1.00 (ANZECC & ARMCANZ) - 0.1–0.7 (Canadian Guidelines) - 0.1–0.7 (NOAA, US)
ST.2	0.002	0.317	
ST.3	0.002	0.217	
ST.4	0.001	0.263	
ST.5	0.001	0.142	

3.2. Ecological Risk Assessment of Mercury in Lake Lais

Ecological risk assessment is used to understand the likelihood and consequences of these impacts on ecosystem receptors (Kho, et al., 2022). The geo-accumulation index (Igeo) is widely used to assess pollution levels and sediment health status by comparing the current concentration status with pre-industrial levels (Abdullah, et al., 2020). The geo-accumulation index (Igeo) is calculated to determine the adsorption rate of heavy metals in sediments. It is determined by comparing sediment heavy metal concentrations and initial concentrations (Ananga et al., 2023).

Based on Table 4, the geoaccumulation index of mercury in Lake Lais is categorized as lightly to moderately polluted. ST. 1, ST. 2 and ST. 4 are included in the moderately polluted (1 < I-Geo < 2), while ST. 3 and ST. 5, are categorized in the lightly polluted criteria (0 < I-Geo < 1).

Table 4. Contamination Factor (CF), Geoaccumulation Index (I-Geo), Risk Index (RI), and Risk Quotient (RQ) Calculated from Mercury Content in Sediments of Lake Lais

Station	Ci	CF	I-Geo	RI=Eir	RQ
ST.1	0,473	5,91	1,979	236,50	11,83
ST.2	0,317	3,96	1,401	158,50	7,93
ST.3	0,217	2,71	0,855	108,50	5,43
ST.4	0,263	3,29	1,132	131,50	6,58
ST.5	0,142	1,78	0,243	71,00	3,55

Ecological risk assessment is a process to evaluate how likely it is that the environment will be impacted as a result of exposure to one or more environmental stressors, such as chemicals, land use change, disease, and invasive species (US EPA, 2024). Table 5 shows the ecological risk caused by the presence of mercury in sediments from each station. ST, 1 has a very strong ecological risk (160<RI<320), ST. 2, ST.3 and ST.4 have strong ecological risk (80<RI<160) and ST. 5 has moderate ecological risk (40<RI<80). In general, Lake

Lais appears to have a strong ecological risk from the presence of mercury. Some mercury risks to human health and ecology are reproductive disruption, genotoxicity, endocrine disruption, carcinogenicity, and immunosuppression (Huang, et al., 2023).

The risk quotient (RQ) index is estimated to describe the possible hazards of mercury contaminants in the ecosystem (Maulana, et al., 2023). Based on Table 3, the RQ value of each has exceeded 1 (RQ>1), which means that mercury content in sediments in Lais Lake has a high risk to the ecosystem.

4. Conclusion

The findings of this study indicate that mercury content in water samples from Lake Lais (0.001–0.002 mg/L) remains within the permissible limits established by the Government of Indonesia under Regulation PP No. 22 of 2021. In contrast, mercury concentrations in sediment samples, ranging from 0.01 to 0.47 mg/kg, approach or exceed the threshold values recommended by international guidelines (e.g., ANZECC, NOAA, and Canadian sediment quality standards), highlighting a potential ecological risk.

According to the Index of Geoaccumulation (I-Geo), Lake Lais is classified as lightly to moderately polluted. The Ecological Risk Index (RI) categorizes mercury contamination as posing a low to very strong ecological risk. Additionally, Risk Quotient (RQ) values greater than 1 further underscore that mercury contamination in the sediments of Lake Lais represents a significant ecological threat to the aquatic environment.

Future research should focus on identifying pollution sources, expanding spatial and temporal coverage, and assessing bioaccumulation in aquatic biota to evaluate potential human health impacts. Policymakers are encouraged to use this data to develop mitigation strategies, particularly by implementing stricter controls on gold mining and industrial runoff. Ongoing monitoring, public awareness, and integrated management are essential for protecting this vulnerable ecosystem.

Data availability statement

Data will be made available on request.

Funding Agencies

This study was funded by Faculty of Agriculture, University of Palangka Raya, Indonesia

Conflict of interests

The authors declare they have no competing interests

Acknowledgment

We would like to thank the Faculty of Agriculture, University of Palangka Raya for supporting the data collection in this research

References

Abdullah, M. I. C., Sah, A. S., R., M., and Haris, H. 2020. Geoaccumulation Index and Enrichment Factor of Arsenic in Surface Sediment of Bukit Merah Reservoir, Malaysia. *Tropical Life Science Research*, 31(3).

Ananga, E., Bernard Walter Lawson, B. W., Aduboffour, V. K. A., Meshack Teid, and Antwie, A. B. 2023. Mercury and lead pollution in rivers in Ghana: geo-accumulation index, contamination factor, and water quality index. *Water Practice & Technology*, Vol. 18 No. 5, 1273. doi: 10.2166/wpt.2023.070.

Astuti, R.D.P, Mallongi, A., Rauf, A.U. 2021. Risk identification of Hg and Pb in soil: a case study from Pangkep Regency, Indonesia. *Soil Science Annual*, 72(1): 1-12.

Elvince R & Kembarawati. 2021. Kajian Kualitas Air Danau Hanjalutung Kegiatan Perikanan di Kelurahan Petuk Katimpun, Kota Palangka Raya, Kalimantan Tengah. *Jurnal Teknologi Lingkungan Lahan Basah*, Vol. 09, No. 1, 029-041.

Elvince R, Inoue T, Darung U Ardianor, Kawakami T, Nagafuchi O, Tsushima K. 2008. Mercury Contamination in Lake Tilap, Central Kalimantan, Indonesia. *Journal Of Ecotechnology Research*, 13(4), 291-294.

Guentzel, J. L., Portilla, E., Keith, K. M., Keith, E. O. 2007. Mercury transport and bioaccumulation in riverbank communities of the Alvarado Lagoon System, Veracruz State, Mexico. *Science of the Total Environment*, 388: 316–324.

Guo, W., Liu, X, Liu, Z, Li, G. 2010. Pollution and Potential Ecological Risk Evaluation of Heavy Metals in the Sediments around Dongjiang Harbor, Tianjin. *Procedia Environmental Sciences*, 2: 729–736.

Handayani, C.O, Sukarjo, Zu'amah, H, Dewi, T. 2024. Penilaian Status dan Risiko Ekologi Cemaran Logam Berat di Lahan Pertanian Kota Malang, Provinsi Jawa Timur. *Jurnal Ilmu Lingkungan*, 22(1): 60-68.

Haryati, A., Prartono, T. & Hindarti, D. 2022. Konsentrasi Merkuri (Hg) Di Sedimen Perairan Cirebon, Jawa Barat Pada Musim Peralihan Timur. *J. Ilmu Dan Teknologi Kelautan Tropis*, 14(3): 321-335. Doi: https://doi.org/10.29244/jitkt.v14i3.33788.

Huang, W.Y, Huang, S.W, Li, Y.L, Huang, S.P, Lin, C, Ngo, H.H., Bui, X. T. 2023. Reduced pollution level and ecological risk of mercury-polluted sediment in an alkali-chlorine factory's brine water storage pond after corrective actions: A case study in Southern Taiwan. *Environmental Technology & Innovation*, 29: 1-11.

Indrajaya, F, Virgiyanti, L. 2019. Analisa Kandungan Merkuri (Hg) Di Wilayah Penambangan Emas Danau Payawan Desa Tumbang Panggo Kecamatan Tasik Payawan Kabupaten Katingan. *PROMINE*, 7(2), 59–64.

Kho, F., Koppel, D.J., von Hellfeld, R, Astley Hastings, A., Gissi, F., Cresswell, T., Higgins, S. 2022. Current understanding of the ecological risk of mercury from subsea oil and gas infrastructure to marine ecosystems. *Journal of Hazardous Materials*, 438.

Mao, L., Ren, W., Liu, X., He, M., Zhang, B., Lin, C., Ouyang, W. 2023. Mercury contamination in the water and sediments of a typical inland river – Lake basin in China: Occurrence, sources, migration and risk assessment. *Journal of Hazardous Materials*, 446. https://doi.org/10.1016/j.jhazmat.2023.130724.

Marsyalita, F., Rahardja, S. B. & Cahyoko, Y. 2012. Analisis Kandungan Merkuri (Hg) Pada Air, Sedimen, Ikan Keting (Arius caelatus), Dan Ikan Mujair (Oreochromis mossambicus) Di Kali Jagir Surabaya. *Jurnal Ilmiah Perikanan dan Kelautan*, 4(2): 113-118.

Maulana, A., Harianti, M., Prasetyo, T.B, Herviyanti. 2023. Index of contamination/pollution factor, geo-accumulation and ecological risk in ex-gold mining soil contaminated with mercury. *Journal of Degraded and Mining Lands Management*, 10(4): 4791-4799.

Mulyaningsih, T.R, and Suprapti, S. 2015. Penaksiran Kontaminasi Logam Berat Dan Kualitas Sedimen Sungai Cimadur, Banten. *Jurnal Iptek Nuklir*, 18(1): 11 - 21.

Nakazawa, K., Nagafuchi O., Kawakami, T., Inoue, T., Elvince, R., Kanefuji, K., Nur, I., Napitupulu, M., Basir, M., Kinoshita, H. & Shinozuka, K. 2021. Human Health Risk Assessment of Atmospheric Mercury Inhalation Around Three Artisanal Small-scale Gold Mining Areas in Indonesia. *Environmental Science: Atmospheres*, 1: 423-433.

Nakazawa, K., Nagafuchi, O, Kawakami, T, Inoue, T., Yokota, K., Serikawa, Y, Cyio, B, Elvince, R. 2016. Human health risk assessment of mercury vapor around artisanal small-scale gold mining area, Palu city, Central Sulawesi, Indonesia. *Ecotoxicology and Environmental Safety*, 124: 155-162.

Niode, S. N., Hasim, H., & Kasim, F. 2021. Tingkat Kontaminasi Logam Berat Merkuri (Hg) di Perairan Danau Limboto. *Jurnal Ilmiah Perikanan dan Kelautan*, 9(3), 58–63. https://ejurnal.ung.ac.id/index.php/nike/article/view/7799.

Nugraha, M. A., Pamungkas, A., Syari, I. A., Sari, S. P., Umroh, Hudatwi, M., Utami, E., Akhrianti, I., & Priyambada, A. 2022. Penilaian Pencemaran Logam Berat Cd, Pb, Cu dan Zn Pada Sedimen Permukaan Perairan Matras, Sungailiat, Bangka. *Jurnal Kelautan Tropis*, 24(1): 70-78.

Nugrayani, D, Hidayati, N.V, Muslih, Cahyo, T.N., Putri, A.A, Putri, N.A, Ummah, A.N, Santoso, F.S. 2023. Potensi Resiko Ekologis Logam Berat (Cd, Cr, Fe) Pada Sedimen Anak Sungai Pelus Sekitar Home Industry Batik Kauman Sokaraja, Banyumas. *Journal Perikanan*, 13(3), 796-805.

Panggabean, S. S. P., Rodhiyah, Z., Ilfan, F., & Ihsan, M. 2022. Indeks Beban Pencemar Sebagai Penentu Tingkat Pencemaran Pada Lahan Bekas Pertambangan Emas Tanpa Izin. *INSOLOGI: Jurnal Sains dan Teknologi*, 1(5), 565-573.

Portezuela, M., García, M., & González, J. 2019. Derivation of sediment mercury quality standards for the protection of benthic invertebrates. *Environmental Pollution*, 255, 113-120. https://doi.org/10.1016/j.envpol.2019.113120

Republik Indonesia. (2021). Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup. https://peraturan.bpk.go.id/Details/161852/pp-no-22-tahun-2021

Sukarjo, Zulaehah, I., Harsanti, E. S., & Ardiwinata, A. N. 2021. Penilaian Spasial Potensi Risiko Ekologis Logam Berat di Lapisan Olah Tanah Sawah DAS Serayu Hilir, Jawa Tengah. *Jurnal Tanah dan Iklim*, 45(1), 69-77.

US EPA. 2024. Mercury Emissions: The Global Context. https://www.epa.gov/international-cooperation/mercury-emissions-global-context.

US EPA. 2024. Climate Change Indicators: Lake Temperature. https://www.epa.gov/climate-indicators/climate-change-indicators-lake-temperature.

US EPA. 2024. Ecological Risk Assessment. https://www.epa.gov/risk/ecological-risk-assessment.

US EPA. 2024. Electrical Conductivity and Resistivity. https://www.epa.gov/environmental-geophysics/electrical-conductivity-and-resistivity#:~:text=Electrical%20conductivity%20(%CF%83)%20is%20a,meter%20(mS%2Fm).

US EPA. 2024. Indicators: Sediment Mercury. https://www.epa.gov/national-aquatic-resource-surveys/indicators-sediment-mercury#:~:text=Why%20is%20sediment%20mercury%20important%3F&text=Mercury%20is%20a%20common%20pollutant,and%20animals%20that%20eat%20fish.

US EPA. 2024. pH. https://www.epa.gov/caddis/ph.