

Assessing Cisanti Lake Sediments as Environmental Quality Indicators in the Upstream of the Citarum River

Dini Fitriani^{1*}, Eleonora Agustine¹, Kartika Hajar Kirana¹, Tiara Ayu Meiliani², Sinthia Anis Rofifah¹, Novia Chicilia², Irfan Handi Muhammad², Atiek Rostika Noviyanti³, Gerald Hendrik Tamuntuan⁴

¹ Geophysics Department, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Indonesia

² Geophysics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Indonesia

³ Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Indonesia

⁴ Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Sam Ratulangi, Indonesia.

Corresponding Author's E-mail: dini@geophys.unpad.ac.id

Article Info

Article info:

Received: 28-03-2025

Revised: 19-07-2025

Accepted: 28-07-2025

Keywords:

Cisanti Lake; magnetic susceptibility; heavy metals; pollution indices

How To Cite:

D. Fitriani, E. Agustine, K. H. Kirana, T. A. Melliani, S. A. Rofifah, N. Chicila, I. H. Muhammad, A. R. Noviyanti, G. H. Tamuntuan "Assessing Cisanti Lake Sediments as Environmental Quality Indicators in the Upstream of the Citarum River", *Indonesian Physical Review*, vol. 8, no. 3, p 734-744, 2025.

DOI:

<https://doi.org/10.29303/ipr.v8i3.490>.

Abstract

Environmental conditions in aquatic ecosystems could change due to the entry of additional materials, such as heavy metals and magnetic minerals. These materials, referred to as anthropogenic materials, could be derived from human activities. The presence of the materials could affect the magnetic properties and heavy metals content of river water and sediments. We have analyzed magnetic susceptibility and heavy metal concentration in sediments collected from Cisanti Lake. Cisanti Lake is known as "zero kilometers" of the Citarum River. Using the level of heavy metals in sediments, we calculated and evaluated pollution indices in the form of Contamination Factor (CF), Geoaccumulation Index (Igeo), and Pollution Load Index (PLI). The results showed that the magnetic susceptibility of sediments (χ_{LF}) was in the range of 317.2 - 2274.9 ($\times 10^{-8}$) m^3kg^{-1} , inferring the dominance of ferrimagnetic minerals in sediments. Based on bivariate analysis of χ_{LF} and the calculated frequency-dependent magnetic susceptibility or χ_{FD} (%), domain states of magnetic minerals are clustered at stable single domain (SSD)/multidomain (MD). Pollution indices of CF and Igeo showed that all sample points were contaminated by Cu at a considerable level. Moderate to significant contamination occurred in the studied area according to the PLI analysis. The positive strong correlation between χ_{LF} and PLI suggests that magnetic susceptibility serves as a proxy indicator of contamination.



Copyright (c) 2025 by Author(s). This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

Introduction

Aquatic ecosystems, such as seas, lakes, and rivers, perform many important environmental functions. As one of the freshwater ecosystems, river systems have significant roles, including providing aquatic habitats for flora and fauna, a water supply for domestic, agricultural, and

industrial activities, as well as regulating the hydrological cycle and providing signals of environmental changes. Domestic, agricultural, and industrial activities, known as anthropogenic activities, near river systems could negatively impact the quality of the environment. These activities could cause environmental problems since the activities produce pollutants that can alter the quality of water and sediments in the river systems.

The river upstream is an essential component for the sustainability of the entire river system. The upstream environmental quality is very closely related to the quality of river systems. Therefore, it is necessary to observe the environmental quality of the river upstream. Observing the environmental quality of the river upstream could be carried out by identifying the properties of sediments collected from upstream. Sediments could provide valuable information about environmental conditions, including the presence and effects of anthropogenic contaminants, since sediments represent natural collectors of pollutants.

Anthropogenic activities can produce several materials, including magnetic minerals and heavy metals. The presence of heavy metals has a harmful effect on human health and the environment [1]. Consequently, analysis of magnetic properties and heavy metal concentration in river sediments provides valuable information for assessing the quality of the river systems and identifying potential sources of pollution. The growing understanding of the negative impacts of pollution on human health and ecosystems, including river systems, has motivated the development of research on pollution due to anthropogenic sources. Many studies have demonstrated that magnetic properties and heavy metal content are closely related to river pollution. The study of [2] on river sediments in China investigates both magnetic susceptibility and heavy metal contamination. The magnetic properties of surface sediments were also studied in [3], and their environmental significance was analyzed. Magnetic analysis of river sediments has also been performed in several rivers in Indonesia, such as Bengawan Solo [4], Cikijing River [5], Brantas River, East Java [6], and Citarum River [7]. Numerous studies were also performed on sediments in lakes as other aquatic ecosystems, such as in Wulungu Lake [8] and Maninjau Lake [9].

This study focuses on assessing the environmental quality of the upstream section of the Citarum River, specifically Cisanti Lake, which serves as the river's "zero kilometer" point in West Java, Indonesia. As the longest and most economically significant river in the region, the Citarum supports agricultural, industrial, and domestic activities. Previous research has examined the water quality of Cisanti Lake, including mapping parameters such as pH, EC, and TDS [10], as well as evaluating biological indicators [11]. Sediment characteristics have also been investigated in other parts of the Citarum River, particularly in the midstream and downstream areas [5, 7, 12]. However, a comprehensive assessment of sediment quality at Cisanti Lake using an integrated approach remains limited. This study addressed the research gap by combining magnetic susceptibility measurements of sediments with chemical analyses of heavy metal concentrations. To strengthen the environmental evaluation, pollution indices such as the Contamination Factor (CF), Geoaccumulation Index (I_{geo}), and Pollution Load Index (PLI) were also applied. These pollution indices are effective tools for evaluating the degree of contamination [13]. Many studies use pollution indices of CF, I_{geo}, and PLI [14-16] for assessing environmental conditions. The integrated use of magnetic and chemical parameters at Cisanti Lake represents a novel approach for this upstream region and offers a more comprehensive evaluation of sediment quality in the river upstream.

Experimental Method

Cisanti Lake is located in Tarumajaya Village, West Java (7°12'33"S and 107°39'28"E). As a volcanic crater lake, the Cisanti Lake area may consist of various volcanic rocks and formations. The primary sources of water for Cisanti Lake come from seven different springs. Cisanti Lake serves as the upstream and the source of the Citarum River. Citarum River stands as the longest and largest river in West Java, Indonesia. In Java, the Citarum River is the third longest river, after the Bengawan Solo and the Brantas River. As an upstream, Cisanti Lake plays a significant role in maintaining the water quality of the Citarum River. As an upstream, Cisanti Lake also serves as a water supply for domestic use, industry, and agriculture.

Sediment samples were collected from various natural groundwater sources, as well as from the inlet and outlet of Cisanti Lake. Each sampling point is labeled as S1 to S9, where the specific location of the research area is shown in Figure 1. Sediment samples were collected from the top layer using a grab sampler. The samples were placed into clean polyethylene bags, sealed, and transported to the laboratory for further analysis. In the laboratory, the collected samples (illustrated in Figure 2a) were cleaned of macroscopic impurities and allowed to dry at room temperature (Figure 2b). All samples were prepared in 10 cm³ cylindrical holders for magnetic susceptibility assessment, which was conducted using the Bartington Magnetic Susceptibility System (MS2) with a type B sensor. The measurements were performed at dual frequencies of low (470 Hz) and high frequency (4700 Hz) to obtain volume-specific magnetic susceptibility of κ_{LF} and κ_{HF} , respectively. The correlation between volume-specific magnetic susceptibility and mass-specific magnetic susceptibility at two frequencies (χ_{LF} and χ_{HF}) can be derived from the formula

$$\chi = \frac{\kappa}{\rho} \quad (1)$$

The ρ represents the mass of the samples divided by their volume. The relative difference between χ_{LF} and χ_{HF} , expressed as a percentage, results in a parameter known as frequency-dependent magnetic susceptibility or χ_{FD} (%) [17]. This can be calculated by the following equation

$$\chi_{FD} (\%) = 100\% \times \frac{(\chi_{LF} - \chi_{HF})}{\chi_{LF}} \quad (2)$$

Frequency-dependent magnetic susceptibility implies the existence of ultrafine superparamagnetic (SP) grains [17, 18].

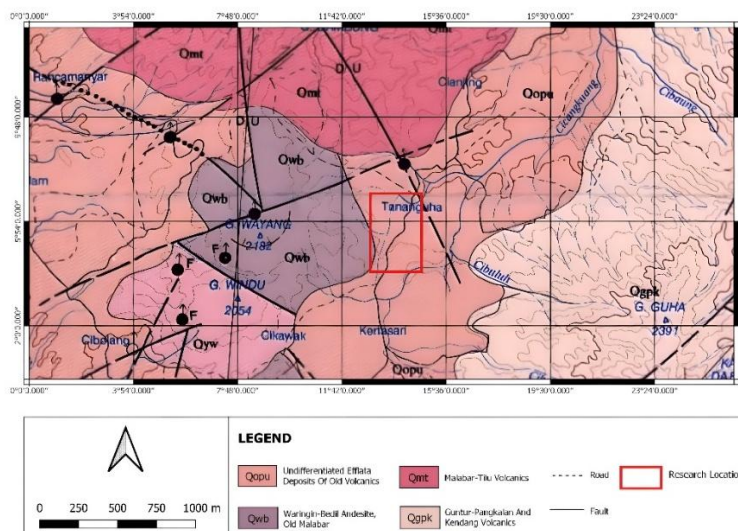


Figure 1. Area under investigation, denoted by the red box. Sediments were collected from a number of sampling points.



Figure 2. (a). The collected sediment samples from the studied area, and (b). sediment samples after cleaning up and drying at room temperature.

Several selected samples were analyzed chemically to determine the concentration of eight elements: arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn). The selection of elements is based on their environmental significance and potential toxicity. These metals are commonly used as indicators of anthropogenic pollution, particularly in aquatic environments impacted by domestic, agricultural, and industrial activities. The analysis was performed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The concentrations of these elements were used to assess pollution level by calculating various pollution indices, including Contamination Factor (CF), geoaccumulation index (Igeo), and Pollution Load Index (PLI). These indices were computed by comparing the concentration of each element to the baseline value. In this research, the baseline value for each element in sediments was set as the lowest concentration observed. The lowest value is assumed to represent the local natural background under minimal anthropogenic influence. The indices of Igeo and CF are applied to determine the contamination level of individual elements in the sediments. The geoaccumulation index,

introduced by [19], is specifically designed to assess pollution levels caused by heavy metals. According to [19], the Igeo values can be classified into seven categories, ranging from unpolluted ($I_{geo} < 0$), to very strongly polluted ($I_{geo} \geq 5$). A complete classification is provided in Table 1. The CF index can be calculated using the formula provided in [20]. There are four categories of CF, which are defined in Table 2.

Table 1. Classification of Igeo referring to [19].

Classification	Description
$I_{geo} < 0$	Uncontaminated
$0 \leq I_{geo} < 1$	Uncontaminated to moderately contaminated
$1 \leq I_{geo} < 2$	Moderately contaminated
$2 \leq I_{geo} < 3$	Moderately to strongly contaminated
$3 \leq I_{geo} < 4$	Strongly contaminated
$4 \leq I_{geo} < 5$	Strongly contaminated to very strongly contaminated
$I_{geo} \geq 5$	Very strongly contaminated

Table 2. Classification of CF referring to [20].

Classification	Description
$CF < 1$	Low-level contamination
$0 \leq CF < 3$	Moderately contamination
$3 \leq CF < 6$	Considerable contamination
$CF \geq 6$	Very high contamination

The index of PLI is suitable for assessing contamination within different sites. The PLI is suitable for assessing overall contamination across different sites, as it provides a cumulative measure of pollution. The PLI involves CF in the calculation. The index of PLI was first proposed by [21]. In a study carried out by [22], PLI was performed in four groups, as shown in Table 3. The values of PLI between 0 and 1 indicate absence of contamination, moderate contamination for PLI between 1 and 2, significant contamination for PLI between 2 and 3, and PLI values higher than 3 indicate strong contamination.

Table 3. Classification of PLI based on [22].

Classification	Description
$CF < 1$	Low-level contamination
$0 \leq CF < 3$	Moderately contamination
$3 \leq CF < 6$	Considerable contamination
$CF \geq 6$	Very high contamination

Result and Discussion

The collected sediments from Cisanti Lake have χ_{LF} ranging from 317.2 - 2274.9 ($\times 10^{-8}$) m^3kg^{-1} with a mean value of $1291.9 \times 10^{-8} m^3kg^{-1}$. The χ_{LF} of sediments from Cisanti Lake is higher compared with other studies, such as those reported in [7] for river sediments from the Citarum River. Sediments from Cisanti Lake also show higher χ_{LF} with significant differences than sediments originating from Cikijing River, as studied by [5]. The higher magnetic susceptibility of the sediments from Cisanti Lake is probably due to their volcanic rock composition. Generally, the magnetic susceptibility of a material relates to the content of magnetic minerals, especially ferrimagnetic minerals [23] within the material. Domination of ferrimagnetic minerals is found in samples that have χ_{LF} higher than $10 \times 10^{-8} m^3kg^{-1}$ [17]. In accordance with the standard, all samples in this research are dominated by ferrimagnetic minerals since the $\chi_{LF} > 10 \times 10^{-8} m^3kg^{-1}$.

The studied sediments have varying χ_{FD} (%) from 0.7% to 2.7% with an average of 1.8 %. The low values of χ_{FD} (%) indicate that grains of SP do not significantly contribute to the magnetic component. According to [17], the scattergram of bivariate χ_{LF} - χ_{FD} (%) could be used to determine the domain state of magnetic minerals. As shown in Figure 3, the majority of data points cluster around stable single domain (SSD)/multi domain (MD). Referring to [24], which expressed the LF and FD (%) scattergrams in another form, the same results were obtained as the scattergram in [17], which showed that magnetic minerals have an SSD/MD state (Figure 4).

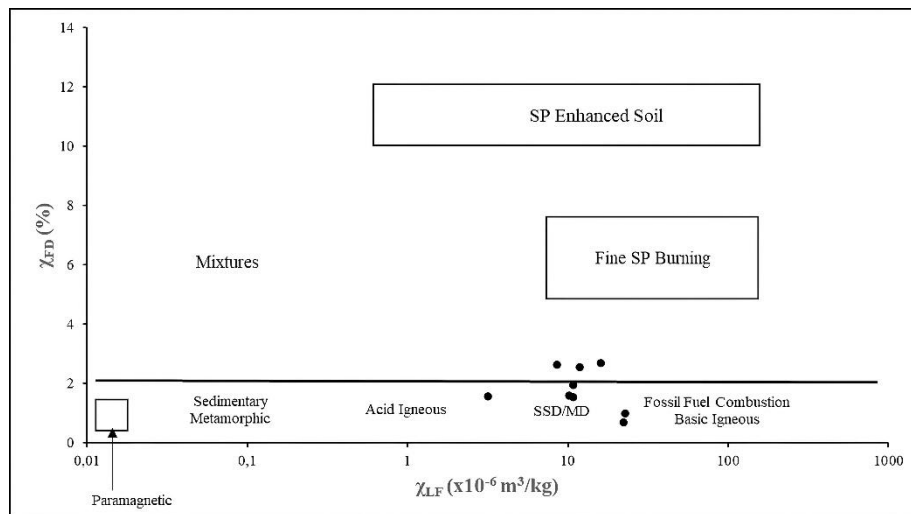


Figure 3. Scattergram of χ_{LF} - χ_{FD} (%) shows the data points cluster at stable single domain (SSD)/multi domain (MD).

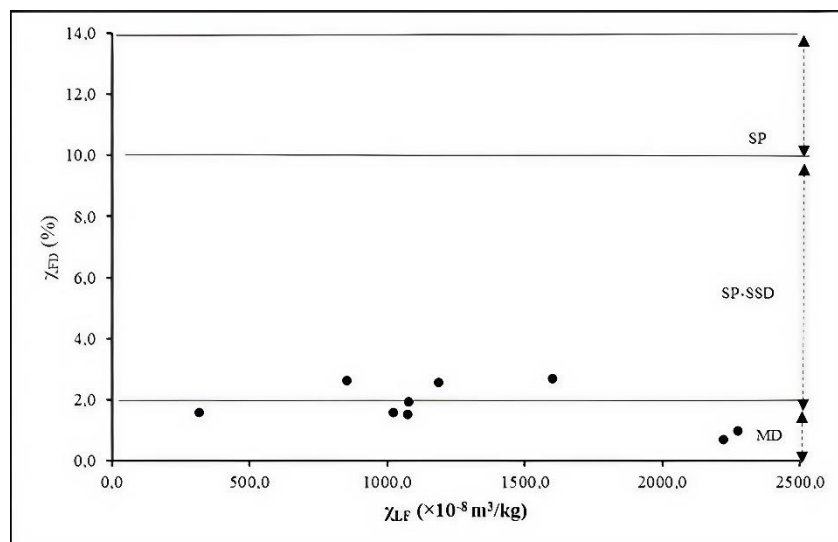


Figure 4. Scattergram of χ_{LF} and χ_{FD} (%) referring to [20] suggests the domain state of magnetic minerals.

Table 4 presents chemical results obtained for some selected samples (sampling points S1, S2, S3, and S4). Sediment sample from sampling point S3 has a lower content of metals among other sites, except for the concentration of Ni. This could be due to the S3 sampling point serves as the main hydrological input. Therefore, the concentrations of metals from S3 are used as baseline values for the calculation of pollution indices. Chemical results indicate that each element shows a different degree of accumulation. Fe has the highest level among others. The mean concentration of metals in the sediments can be arranged in the following order: Fe > Zn > Cu > Pb > Cr > Ni > As > Cd.

Table 4. Statistics of metal content according to chemical measurements for selected samples (in mg/kg).

Sample	As	Cd	Cr	Cu	Fe	Ni	Pb	Zn
S1	39.26	5.53	70.82	197.29	15,411.34	51.67	74.61	294.49
S2	33.33	9.94	86.60	262.11	21,989.92	63.79	256.08	290.02
S3	22.84	4.45	44.21	55.93	9,615.47	56.26	48.97	169.36
S4	60.31	7.23	76.78	244.39	16,251.19	60.31	76.09	294.58
mean	38.93	6.79	69.60	189.93	15,816.98	58.01	113.94	262.11

Pearson's correlation coefficient was computed to evaluate the statistical correlation among metals, as listed in Table 5. The Pearson correlation analysis revealed that Cd, Cr, and Cu have a strong correlation (> 0.80) with each other. The element of Fe shows a notable correlation with Cd, Cr, Cu, and Zn, except for As and Ni. Element of As demonstrated strong positive correlations with Cr, Cu, and Zn, moderate positive correlation with Fe, and weak positive correlation with Cd. Meanwhile, As and Pb show a weak negative correlation.

According to the metal levels in each sampling point and baseline values of S3, several CF can be derived for different metals at each sampling point, as presented in Table 6. Based on the classification of CF values, low contamination only occurs in sampling point S1 by the element

Ni. Meanwhile, sampling points S2 and S4 were contaminated by Ni at moderate degree. The CF values suggest that all sediments from all sampling points are contaminated by As, Cd, Cr, Fe, Pb (except S2), and Zn at a moderate level. Considerable contaminations are observed in all samples by the element of Cu and point S2 by Pb.

Table 5. Pearson correlation coefficient of all elements

	As	Cd	Cr	Cu	Fe	Ni	Pb
Cd	0.25						
Cr	0.54	0.88					
Cu	0.66	0.83	0.99				
Fe	0.31	0.95	0.96	0.91			
Ni	0.17	0.83	0.53	0.50	0.63		
Pb	-0.13	0.92	0.72	0.62	0.88	0.73	
Zn	0.70	0.63	0.92	0.95	0.80	0.20	0.42

Table 6. Distribution of Contamination Factor at different sampling points.

Elements	S1	S2	S4
As	1,72	1,46	2,64
Cd	1,24	2,23	1,62
Cr	1,60	1,96	1,74
Cu	3,53	4,69	4,37
Fe	1,60	2,29	1,69
Ni	0,92	1,13	1,07
Pb	1,52	5,23	1,55
Zn	1,74	1,71	1,74

The calculated values of Igeo are summarized in Table 7. Following contamination criteria as listed in Table 1, in general, sediments from Cisanti Lake are classified as unpolluted to moderately polluted by As, Cd, Cr, Fe, Ni, Pb (except in S2), and Zn. At all sampling points, the Igeo values for these metals are between 0 -1. A higher degree of pollution was observed at all sampling points by Cu and at S2 by Pb. Contamination levels based on Igeo values show similar results to those based on CF values.

Table 7. Statistics of Igeo values for sediment samples at different sampling points.

Elements	S1	S2	S4
As	0,20	-0,04	0,82
Cd	-0,27	0,57	0,11
Cr	0,09	0,39	0,21
Cu	1,23	1,64	1,54
Fe	0,10	0,61	0,17
Ni	-0,71	-0,40	-0,48
Pb	0,02	1,80	0,05
Zn	0,21	0,19	0,21

The index of PLI involves the calculation of all elements contained in sediments. The distribution of PLI in sampling points varies from moderate to significant contamination. Sediments from Cisanti Lake at sampling points S1 and S4 have PLI values of 1.62 and 1.88, respectively. It infers that moderate contamination occurred at points S1 and S4. Meanwhile, at sampling point S2, the PLI value is 2.27, which suggests significant contamination at that point. We also analyzed the correlation of magnetic parameters (χ_{LF}) and PLI. The result shows that χ_{LF} and PLI have a strong positive correlation ($R^2=0.78$ or $r=0.88$), as shown in Figure 5. A moderate to strong correlation between χ_{LF} and PLI infers that magnetic susceptibility can be used as a proxy indicator of contamination. It also suggests that there is a close relationship between magnetic susceptibility and heavy metals.

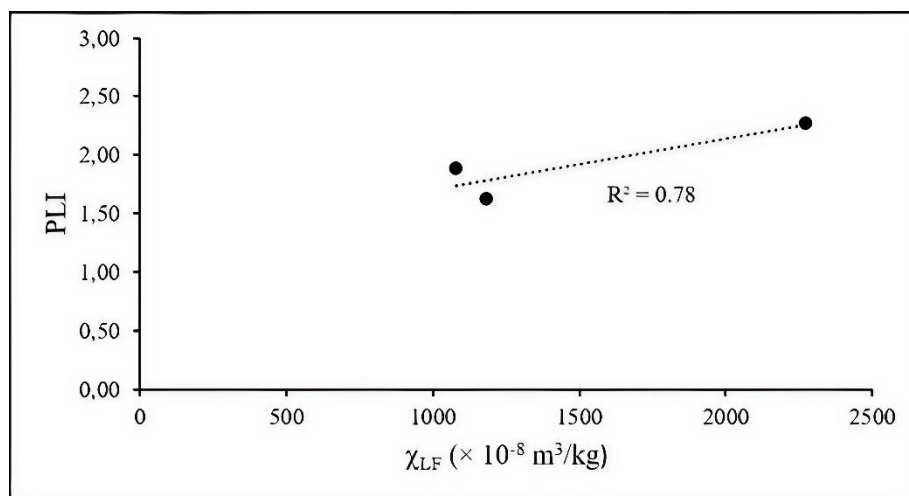


Figure 5. The χ_{LF} and PLI shows strong positive correlation.

Conclusion

Based on magnetic susceptibility values, it reveals that sediments from Cisanti Lake are predominantly composed of ferrimagnetic minerals. Bivariate analysis of χ_{LF} and χ_{FD} (%) values infers that magnetic mineral is clustered at the stable single domain (SSD)/multi domain (MD). Pollution indices of CF and Igeo show similar results. Considerable contaminations are identified in all sampling points by Cu and in sampling point S2 by Pb. Based on the PLI values, it is suggested that contamination occurred in the studied area to a moderate to significant degree. Magnetic signal (in the form of χ_{LF}) and index of PLI show a strong positive correlation that infers magnetic susceptibility values are useful as a proxy indicator of contamination.

Acknowledgment

The authors express gratitude to Universitas Padjadjaran for funding this research under the Hibah Riset Unpad (HRU)-Academic Leadership Grant (ALG), project number of 1419/UN6.3.1/PT.00/2024.

References

- [1]. L.A. Melinia, M. Naibaho, E. Puspita, Ramlan, and M. Ginting, "Review on The Adsorption of Heavy Metals in Water by $MnFe_2O_4$ and Zeolite," *Indonesian Physical Review*, Vol 6 No. 2, pp.196-219, May 2023.
- [2]. S. Rong, J. Wu, J. Liu, Q. LI, C. Ren and X. Cao, "Environmental magnetic characteristics and heavy metal pollution assessment of sediments in the Le'an River, China", *Minerals*, 13(2), 145, pp. 1-14, Jan 2023.
- [3]. E. Zheng, Y. Bai, M. Li, K.L. T. Ouyang. F. Zhang, M. Yu, G. Lei and Z. Pan, "Magnetic Properties of Surface Sediments from Liuxi River, Southern China and Their Environmental Significance," *Journal of Soils and Sediments*, vol 22, pp.1286-1301, Feb 2022.
- [4]. B. Legowo, S. Putra, H. Purwanto, H. Rifai, W. Suryanto and B. Purnama, "Magnetic Properties of Ancient Sediments Bengawan Solo, Central Java-East Java, Indonesia," *Trends Sci*, vol 20 no 5, pp. 6626, Mar 2023.
- [5]. D. Fitriani, W. Utami, K.H. Kirana, E. Agustine and S. Zulaikah, "Magnetic signatures on river sediments and agricultural soils as proxy indicators of anthropogenic-derived pollution (Case Study: Cikijing River, Rancaekek, West Java)," *JPPIPA*, vol 7 no 3, pp.381-387, Jul 2021.
- [6]. M. Maryanto, M.F. Amir, W. Utama, A.H. Hamdan, S. Bijaksana, A. Pratama, R. Yunginger and S. Sudarningsih, "Heavy metal contents and magnetic properties of surface sediments in volcanic and tropical environment from Brantas River, Jawa Timur Province, Indonesia," *Sci. Total Environ*, vol. 675, pp.632-641, Apr 2019.
- [7]. S. Sudarningsih, S. Bijaksana, R. Ramdani, A. Hafidz, A. Pratama, W. Widodo, I. Iskandar, D. Dahrin, S.J. Fajar and N.A. Santoso, "Variations in the concentration of magnetic minerals and heavy metals in suspended sediments from Citarum River and its tributaries, West Java, Indonesia," *Geosciences*, vol 7 (3), pp.1-13, Aug 2017.
- [8]. F. Liu, S. He, Y. Tong, M. Wang, M. Li and J. Lu, "Pollution characteristics and risk assessment of heavy metals in the water and surface sediments of Wulungu Lake, Xinjiang China", *Soil and Sediment Contamination: An International Journal*, vol 32 no. 1, pp. 85-104.
- [9]. I.J. Prasetyo, H. Rifai, Syafriani and R. Putra, "Morphological characteristics and elemental composition of magnetic minerals from the volcanic activity of Lake Maninjau sediments," *Trends Sci*, vol 19 no 8, pp. 3428, Jun 2022.
- [10]. S.D. Hanifah, R. Hendrayani, R. Carrisa, M.I. Rizki, M.A. Rohman, M.A. Hutabalian, J.S. Rahman, F.R. Sihombing, F. Ramadhan, A.Z. Ramadan, A. Nugraha, K.H. Kirana and D. Fitriani, "Mapping of pH, EC, and TDS Parameters to Identify Water Quality in Situ Cisanti", *Phi: Jurnal Pendidikan Fisika dan Terapan*, vol 10 no 1, pp.91-97, Jan 2024.
- [11]. S. Musayaroh and B.S. Muntalif, "Determination of surface water quality based on macrozoobenthos biodiversity and the prevalence of trematode cercariae in freshwater molluscs", *Malaysian Applied Biology*, vol 49 no 2, pp. 19-25, Jun 2020.
- [12]. D. Fitriani, R.A. Baraba, N. Chicilia, S.A. Rofifah, T.A. Meiliani, I.H. Muhammad, E.A. Agustine, K.H. Kirana, E. Supriyana, I.H. Mohammad and G.H. Tamuntuan,

- “Distribution of Magnetic Properties in Sediments from Cimande River as Tracers of Anthropogenic Pollutants”, *AIP Conf. Proc.*, vol 2694, April 2023.
- [13].J.B. Kowalska, R. Mazurek and M. Gasiorek, “Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination – A review,” *Environ. Geochem. Health*, vol 40, pp. 2395-2420, Apr 2018.
- [14] F.A.R. Laudino, R.J.M. Agtong, J.C.C. Jumawan, M. Fukuyama, M.V. Elvira, “Assessment of contamination and potential ecological risks of heavy metals in the bottom sediments of Lake Mainit, Philippines”, *Journal of Hazardous Materials Advances*, vol 15, pp. 1-7, Jun 2024.
- [15].W.M. Thabet, A.A. Moneer, O. Abdelwahab, H.H.H. Ahdy, M. Khedawy, N.A. Shabaan, “Ecological risk assessment of metal pollution in the surface sediments of delta region, Egypt”, *Environmental Monitoring and Assessment*, vol 196:351, pp. 1-18.
- [16] F. Kachoueian, P.A. Atmianlu, A. Rajabi, F. Ustaoglu and A. Karbassi A, “Contamination source, health and ecological risk assessment of hazardous elements in the sediment of the Shahid Rajae reservoir”, *Front. Environ. Sci.*, 12:1493547, pp. 1-10, October 2024.
- [17].J.A. Dearing, “Environmental magnetic susceptibility: using the Bartington MS2 System 2nd ed, 1999, pp. 1-43. [Online]. Available: https://gmw.com/wp-content/uploads/2019/03/JDearing-Handbook-OM0409.pdf?srsltid=AfmBOooUODPYuxvtCmsVUX6XIFH4XgWJWQLAS62TRt_PjQkzi8CfsIO0
- [18].M.H Evans and F. Heller, “Environmental magnetism - Principles and application of electromagnetics,” *Academic Press*, 2003; p 1-299.
- [19].G. Müller, “Schadstoffe in Sedimenten-Sedimente als Schadstoffe. Mitt, österr,” *Geol. Ges.*, vol 79, pp.107-126, Dec 1986. [Online]. Available: https://www.zobodat.at/pdf/MittGeolGes_79_0107-0126.pdf.
- [20].L. Hakanson, “An ecological risk index for aquatic pollution control. A sedimentological approach,” *Water Res.*, vol 14 (8), pp. 975-1001, Jan 1980.
- [21].D.L. Tomlinson, J.G. Wilson, C.R. Harris and D.W. Jeffrey,” Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index,” *Helgoländer Meeresuntersuchungen*, 33 (1), pp. 566-575, Mar 1980.
- [22].B.S.M. Kim, J.L.F. Angeli, P.A.L. Ferreira, M.M. de Mahiques and R.C.L. Figueira, “A multivariate approach and sediment quality index evaluation applied to Baixada Santista, Southeastern Brazil,” *Mar. Pollut. Bull*, vol 143, pp. 72-80, Jun 2019.
- [23].R. Thomson and F. Oldfield, “Environmental magnetism,” *Allen and Unwin*, 1986; p 1-227
- [24].M.O. Kanu, O.C. Meludu, and S.A. Oniku, “Comparative study of top soil magnetic susceptibility variation based on some human activities,” *Geofis. Int.*, vol 53-4, pp 411-423, Dec 2014.