

Distribution of Cr, Ni, Cu, and Zn in Prambatan River-Cultivation Pond, Batu, East Java

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Abstract— Heavy metals are pollutants that pose a potential threat to aquatic environments because they can accumulate in sediments and benthic organisms, thereby potentially affecting the quality of aquaculture environments. This study aims to analyze variations in the accumulation of Cr, Ni, Cu, and Zn in sediments and *Sulcospira testudinaria* in the inlet river, aquaculture ponds, and outlet river, as well as to evaluate the potential of *Sulcospira testudinaria* as a bioindicator of heavy metal pollution. The study was conducted at six stations using purposive sampling. Metal concentrations in sediments and *Sulcospira testudinaria* were analyzed using the ICP-AES method, while bioaccumulation capacity was evaluated by calculating the Biota-Sediment Accumulation Factor (BSAF). The results showed that metal concentrations varied across stations, with Cr and Zn in the sediments remaining below the Interim Sediment Quality Guideline (ISQG) values, Cu falling within the ISQG-Probable Effect Level (PEL) range, and Ni exceeding the PEL at most stations. Metal concentrations in *Sulcospira testudinaria* followed the order Zn>Cu>Ni>Cr. The average BSAF values indicated the highest accumulation for Zn (2.97), followed by Cu (1.72), Cr (0.34), and Ni (0.25). Therefore, *Sulcospira testudinaria* has the potential to be used as a bioindicator of heavy metal pollution in freshwater systems.

Keywords— bioaccumulation; heavy metals; sediment; *Sulcospira testudinaria*

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I. INTRODUCTION

Heavy metal pollution is one of the primary threats to aquatic ecosystems and human health. Industrial activities, domestic wastewater, agriculture, and residential drainage lead to the release of heavy metals into water bodies, where they can accumulate in aquatic organisms and enter the human food chain through the consumption of fish and other aquatic products [1]. Heavy metal contamination in aquatic ecosystems has the potential to impair water quality and pose a threat to human health and the survival of aquatic organisms [41]. The safety of aquaculture products is greatly influenced by water and sediment conditions, as these serve as sites for the accumulation of heavy metals originating from agricultural runoff, industrial activities, and mineral additives in fish feed, such as Zn, Fe, Cu, Co, I, and Se. Heavy metals deposited in sediments can be re-released into the water through hydrodynamic processes, thereby increasing the risk of bioaccumulation in aquatic organisms [2]. Heavy metals are among the pollutants that pose a potential threat to aquatic environments because their toxic properties can disrupt ecological balance and harm aquatic organisms when they

accumulate in high concentrations. Heavy metals are classified as hazardous pollutants because they are persistent (non-degradable), meaning they do not break down easily in the environment and are readily absorbed by various media. Once they enter aquatic ecosystems, some heavy metals accumulate in sediments, while others continue to be carried along with river currents [3]. Among the various types of heavy metals of concern in aquatic environments, chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) are the elements most commonly accumulated in freshwater sediments. At certain concentrations, the presence of these metals can have toxic effects on aquatic organisms [4].

Aquaculture serves as an anthropogenic factor contributing to the introduction of heavy metals into freshwater ecosystems. The intensive application of commercial feed, the use of mineral supplements, and various additives during the aquaculture process can increase the accumulation of metals, such as Cu and Zn, in both water and sediments. Heavy metal levels in pond water tend to increase as the aquaculture cycle progresses, while metal concentrations in sediments remain high and exceed natural levels, indicating sustained metal accumulation due to aquaculture activities [5]. Sedimented uneaten feed and metabolic waste from farmed organisms serve as the primary medium for transporting heavy metals into pond sediments, thereby increasing the accumulation of contaminants at the bottom of the water body [6]. A study by Hossain et al. [42] shows that sediments in aquaculture areas contain various metallic elements, such as Cr, Ni, Cu, and Zn, the presence of which is influenced by human activities and management practices in aquaculture environments.

Sediments contaminated with heavy metals act as a reservoir of pollutants that can serve as a source of exposure for benthic organisms. Metal uptake can occur through contact with the pore water in the sediment or

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through the ingestion of sediment particles containing metals. The accumulation of metals such as Cd, Cr, Pb, Zn, Cu, and Ni in the tissues of benthic organisms can subsequently be transferred to biota occupying the next trophic level through predator-prey relationships, thereby increasing the potential for biomagnification in the food chain [7]. Organisms can be used as environmental indicators by observing the types and levels of contaminants accumulated in their body tissues. Each aquatic organism has a different capacity to absorb and accumulate pollutants, which is related to the species' characteristics and the environmental conditions in which it lives. Based on these differences, certain types of organisms are selected as bioindicators because they have the ability to accumulate toxic compounds in their bodies at relatively high concentrations [43].

One benthic gastropod species with potential as a bioindicator is the Susuh kura (*Sulcospira testudinaria*), which has been used in various studies as an indicator of aquatic environmental quality. *Sulcospira testudinaria* is effective in detecting the presence of metals in aquatic environments. The presence of this species can reflect the movement of heavy metals within the food web and serves as a key indicator in assessing environmental quality as well as the potential ecological risks resulting from heavy metal exposure [8]. Gastropods are benthic organisms characterized by relatively slow movement, living on the aquatic substrate, and feeding on detritus. These characteristics enable gastropods to accumulate various chemical compounds, including heavy metals, within their body tissues. Consequently, these organisms are widely used as bioindicators to assess the level of heavy metal contamination in aquatic ecosystems [9].

The Prambatan River is part of the Brantas River Basin located in Batu City, East Java, and is used as a water source for aquaculture activities. As the longest river basin in East Java, the Brantas River is subject to pollution pressures stemming from various anthropogenic activities, such as agriculture, industry, and residential development, which can lead to increased accumulation of heavy metals in the aquatic ecosystem.

Previous studies have shown that the Brantas River Basin has been affected by heavy metal pollution. Water quality analyses recorded average concentrations of Pb, Cd, Cu, Ni, Fe, Cr, and Mn at 2.63, 1.09, 0.74, 0.40, 0.26, 0.10, and 0.02 mg L⁻¹, respectively [10]. A study by Hertika et al. [8], showed that *Sulcospira testudinaria* in the Brantas River Basin can serve as an indicator of heavy metal pollution. The study detected Pb, Hg, and Cd in *Sulcospira testudinaria* samples, with Pb ranging from 0.001 to 0.006 mg L⁻¹, Hg from 0.001 to 0.005 mg L⁻¹, and Cd from 0.005 to 0.03 mg L⁻¹. In the context of this study, the Prambatan River is significant because the study site not only represents the river as a natural ecosystem but also illustrates the relationship between the river as a water source and the aquaculture pond system. Although various studies on heavy metals have been published, the majority of these studies still focus on rivers or aquaculture ponds as ecosystems studied separately. Studies evaluating the distribution of Cr, Ni, Cu, and Zn in sediments and *Sulcospira testudinaria* along a connected flow system including the river upstream of the aquaculture pond (inlet), the aquaculture pond itself, and the river downstream of the pond (outlet)-remain limited. Given these conditions, this study aims to analyze variations in the accumulation of Cr, Ni, Cu, and Zn in sediments and *Sulcospira testudinaria* across these three zones to describe the distribution patterns of heavy metals within aquaculture water systems and to evaluate the potential of *Sulcospira testudinaria* as a bioindicator of heavy metal pollution in freshwater.

II. METHOD

A. Research Time and Location

This study was conducted from January to March 2026 along the Prambatan River and in aquaculture ponds in Batu City, East Java (Figure 1). There were six sampling stations: two in the Prambatan River upstream of the ponds, two at the aquaculture ponds, and two in the Prambatan River downstream of the aquaculture ponds.

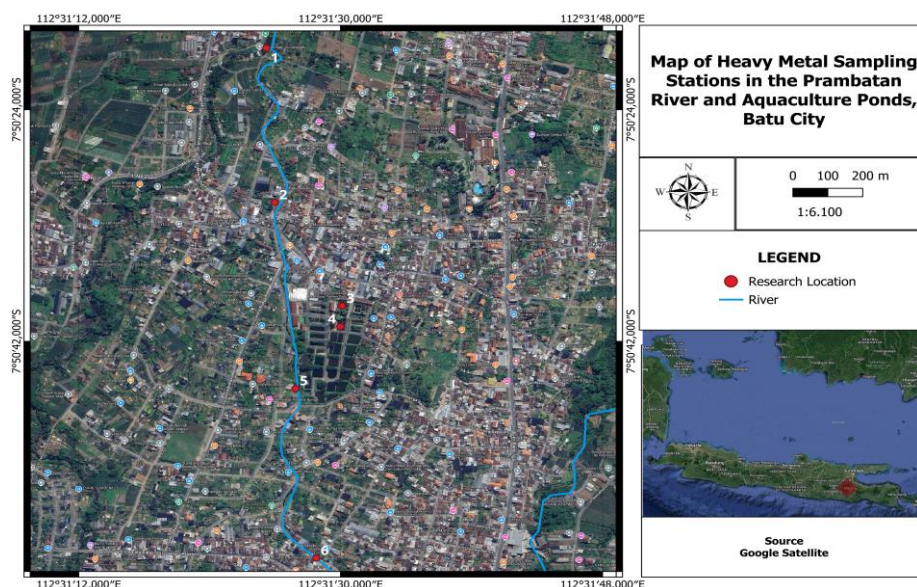


Figure 1. Heavy metal sampling location in the Prambatan River, Batu City, East Java, Indonesia.

The research stations were determined using purposive sampling, taking into account river flow, land use, and ease of access. Sampling and water quality measurements were conducted twice during the study, with a one-month interval between samplings. Heavy metal analysis of sediment samples and *Sulcospira testudinaria* was performed at the Integrated Research Laboratory of Brawijaya University. Meanwhile, TSS water quality was measured at the Hydrobiology Laboratory of the Faculty of Fisheries and Marine Sciences, Brawijaya University.

B. Tools and Materials

The instruments and equipment used during this study were a Lutron DO-5510 dissolved oxygen (DO) meter, a water quality tester, an oven, a desiccator, a vacuum pump, a microwave digestion system, and an ICP-AES (model ICPE-9820-Shimadzu). The materials used were Whatman No. 41 filter paper, 65% HNO₃, and 37% HCl.

C. Heavy Metal Analysis

The sediment samples were dried in an oven and then weighed to 0.5 g. 9 mL of 65% HNO₃ and 3 mL of 37% HCl were added to the sediment samples to carry out the digestion process using the microwave digestion system for 20 minutes. The *Sulcospira testudinaria* samples were separated from their shells and dried in an oven until completely dry. The sample was weighed to 0.5 g, and 6 mL of 65% HNO₃ and 1 mL of 37% HCl were added to perform digestion using the microwave digestion system for 50 minutes. After the digestion process was complete for all samples, they were diluted with distilled water to 50 mL, and 15 mL of the sample was filtered for heavy metal analysis [11]. Heavy metal analysis was performed using an ICP-AES instrument

(model ICPE-9820-Shimadzu) with the following wavelengths: Cr 267.716, Ni 231.604, Cu 327.396, and Zn 213.856.

D. Water Quality Measurement

Water quality analysis was conducted using two methods: in situ measurements taken directly at the sampling stations, and ex situ measurements conducted through laboratory analysis. In situ measurements included temperature, TDS, DO, and pH, while ex situ measurements included TSS using the gravimetric method [12]. Water quality measurements were taken twice over a one-month period.

E. Biota-Sediment Accumulation Factor (BSAF) Analysis

The biota-sediment accumulation factor (BSAF) is calculated as the ratio of the metal concentration in *Sulcospira testudinaria* to the metal concentration in the sediment. The BSAF value is obtained using the equation presented below:

$$BSAF = C_{biota}/C_{sediment} \quad (1)$$

where C_{biota} is the average concentration of metals in an organism's tissues, while $C_{sediment}$ is the average concentration of metals detected in sediments [13].

III. RESULTS AND DISCUSSION

A. Heavy metals in sediments

Heavy metal concentrations in sediments are one of the key indicators for assessing long-term water pollution. The results of Cr, Ni, Cu, and Zn measurements in sediments are presented in Figure 2.

Based on Figure 2., the concentration of chromium (Cr) in the sediment at sampling site 1 ranged from 19.52

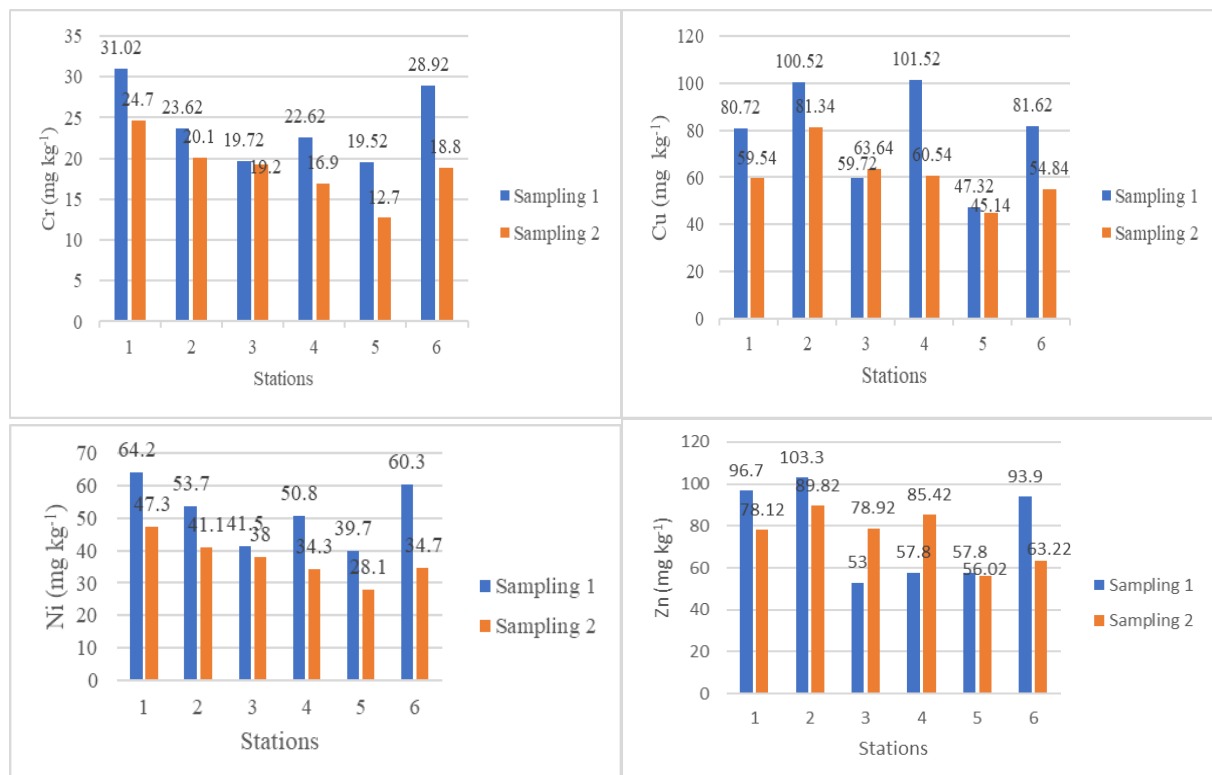


Figure 2. Cr, Ni, Cu, and Zn in sediments of the prambatan river-cultivation pond

to 31.02 mg kg⁻¹ and at sampling site 2 ranged from 12.7 to 24.7 mg kg⁻¹, with an average ranging from 16.11 to 27.86 mg kg⁻¹. The highest concentrations for Samples 1 and 2 were found at Station 1, while the lowest concentrations were found at Station 2 (Sampling 1) and Station 5 (Sampling 2). Chromium concentrations in the sediment showed variation between stations, with relatively high values in the inlet zone (Stations 1-2), then a general decrease in the aquaculture pond zone (Stations 3-4), and a subsequent increase at Station 6, which is part of the outlet zone. The high chromium levels in the inlet section indicate that chromium-bearing material entered the system via the river flow before reaching the ponds. The decrease observed at several subsequent stations may be related to sedimentation and metal redistribution processes during transport. According to the Canadian Council of Ministers of the Environment (CCME) 2002 [14], all measured chromium concentrations remained below the Interim Sediment Quality Guideline (ISQG) value of 37.3 mg kg⁻¹. These results indicate that Cr concentrations in the sediment have not yet caused adverse biological effects on benthic organisms.

Ni concentrations show a relatively fluctuating pattern across stations. Ni concentrations in Sample 1 ranged from 39.7 to 64.2 mg kg⁻¹, and in Sample 2 ranged from 28.1 to 47.3 mg kg⁻¹. Samples 1 and 2 show that the highest concentration was found at Station 1 and the lowest concentration was found at Station 5. The high Ni concentration at Station 1 may indicate Ni input from river flow, while the increase at Station 6 suggests the redistribution or deposition of Ni-bearing material at a specific location. All Ni concentrations exceeded the ISQG value of 18 mg kg⁻¹, and at Sampling 1, concentrations at all six stations even exceeded the PEL value of 36 mg kg⁻¹. Only Stations 4-6 in Sampling 2 fell below the PEL range, yet they still indicated a potential biological risk to benthic organisms. These conditions indicate that the sediments at the study site have accumulated Ni at levels that could potentially cause ecological impacts, particularly for organisms that live in and interact directly with the sediments. High Ni concentrations in aquatic ecosystems are influenced by natural processes and human activities. Geological processes such as rock weathering, soil erosion, and sediment transport by water flow also contribute to the natural introduction of nickel into aquatic environments. Naturally, nickel is one of the elements found in the Earth's crust, with an average concentration of approximately 75 mg kg⁻¹ [15]. High concentrations of Ni can be toxic to microorganisms because they can disrupt cell membrane integrity, inhibit enzyme activity, and increase oxidative stress. In aquatic environments, nickel generally originates from industrial activities particularly electroplating and the use of phosphate fertilizers on agricultural land. Waste generated from these two activities, combined with domestic wastewater entering river basins, can lead to increased nickel accumulation in sediments [16].

The Cu concentrations in Sample 1 ranged from 47.32 to 101.52 mg kg⁻¹ and in Sample 2 ranged from 45.14 to 81.34 mg kg⁻¹. The highest concentration in

Sample 1 was found at Station 4, and in Sample 2, it was found at Station 2. Meanwhile, the lowest concentrations in both Sampling 1 and Sampling 2 were found at Station 5. This pattern indicates that Cu tends to accumulate at the inlet, and the increase observed at Station 4 may be related to pond conditions that facilitate the settling of Cu-bearing suspended material. All Cu concentrations were above the ISQG value of 35.6 mg kg⁻¹, but remained below the Probable Effect Level (PEL) of 197 mg kg⁻¹ [14]. These conditions indicate that Cu has reached a level that has the potential to cause biological effects on benthic organisms, although the likelihood of such impacts remains relatively low since the concentrations have not yet exceeded the PEL. Zn concentrations in Sampling 1 ranged from 53 to 103.3 mg kg⁻¹, and in Sampling 2, they ranged from 56.02 to 89.82 mg kg⁻¹. The average Zn concentrations in samples 1 and 2 in the sediment ranged from 56.91 to 96.56 mg kg⁻¹. The highest Zn concentration was found at Station 2, while the lowest concentration in sample 1 was found at Station 3 and in sample 2 at Station 5. The high Zn levels at Stations 1-2 indicate that the inlet area is a key location for Zn entering the system. All Zn concentrations remain below the ISQG value of 123 mg kg⁻¹, indicating that the Zn content in the sediment is not expected to cause adverse biological effects on benthic organisms [4].

The results of the study show that there is a distribution of heavy metals among the stations. The concentrations of Cr and Ni were higher at Station 1 (inlet) and then decreased toward the aquaculture pond and the outlet, indicating that both metals originated from the Prambatan River. In contrast, Cu showed the highest concentrations at Station 4 (Sampling 1) in the aquaculture pond area and at Station 2 (Sampling 2), while Zn was highest at Station 2 (inlet), reflecting differences in the transport and accumulation processes of each metal. The distribution patterns of heavy metals in sediments are influenced by transport processes, sedimentation, the geochemical properties of sediments, and the dynamics of the physical and chemical conditions of the water [17]. The high concentration of Ni in the sediment indicates that this metal accumulates more easily than other metals. Ni accumulation can result from natural rock weathering processes as well as anthropogenic activities such as agricultural runoff, the use of fertilizers and pesticides, and domestic wastewater carried through river basins. Meanwhile, Cu and Zn are essential metals widely used in agricultural and domestic activities, so their presence in sediments is also influenced by inputs from the surrounding environment. On the other hand, the low concentration of Cr suggests that the input of this metal is relatively smaller or that it is predominantly present in a stable form in the sediments [18].

The presence of organic matter in sediments plays a key role in binding heavy metals, but each metal's ability to form bonds is influenced by its chemical characteristics. Copper (Cu) is known to have a high affinity for organic matter, but zinc (Zn) is often more dominant due to its higher mobility and bioavailability. Furthermore, high Zn inputs from various human

activities increase this metal's ability to compete for binding sites on organic matter. Therefore, the concentration of metals in water bodies serves as one of the parameters in determining the level of adsorption in sediments and their availability for uptake by aquatic organisms [19]. Organic matter in sediments provides various active sites capable of binding heavy metal ions. Therefore, metals associated with organic matter are classified as part of the potentially mobile fraction, as they can be re-released during the mineralization of organic matter and subsequently enter the sediment or the water column. Consequently, the amount and characteristics of organic matter are key factors determining the distribution and bioavailable fractions of heavy metals in aquatic environments [20]. In aquaculture pond environments, fish feed residues that settle at the bottom of the aquaculture water body are believed to be one of the primary sources of heavy metals in sediments. The continuous accumulation of feed residues at the bottom of the aquaculture water body can cause the heavy metals they contain to accumulate in the sediments. Aquatic feed can release heavy metals into the water, which then settle and accumulate in the sediment [44].

Sediment serves as a long-term reservoir for heavy metals, but it can also release them back into the aquatic environment when physicochemical conditions change. Fluctuations in pH, changes in redox potential, and sediment resuspension can increase the mobilization of metals into pore water, thereby increasing their bioavailability and the potential for exposure to benthic organisms [21]. In addition, sediment grain size is also a

factor influencing the accumulation of heavy metals in aquatic environments. Fine-grained sediments have a greater capacity to adsorb and accumulate heavy metals than coarse-grained sediments because they have a larger surface area. Conversely, sediments with larger particle sizes have a smaller specific surface area, resulting in a lower capacity to bind heavy metals [22]. The distribution of metals in aquatic bottom sediments is influenced not only by chemical conditions but also by the physical characteristics of the environment. Water movement due to turbulence, particle resuspension, and sediment deposition are key processes that affect the distribution of metals in the aquatic bottom layer. In locations with relatively high water energy, fine-grained material is more easily lifted and carried by currents, while coarser particles tend to remain on the bottom and serve as sites for the deposition of metals bound to oxide or carbonate minerals. Thus, the distribution patterns of metals in sediments are shaped by the interplay between the physical processes that govern particle movement and the chemical mechanisms that control the interaction of metals with sediments [45].

B. Heavy Metals in *Sulcospira testudinaria*

An analysis of heavy metal concentrations in *Sulcospira testudinaria* was conducted to assess the level of metal accumulation in biota inhabiting the bottom substrate of the water body. The results of Cr, Ni, Cu, and Zn concentration measurements in *Sulcospira testudinaria* tissue at all research stations are presented in Figure 3.

Based on Figure 3., the concentrations of heavy

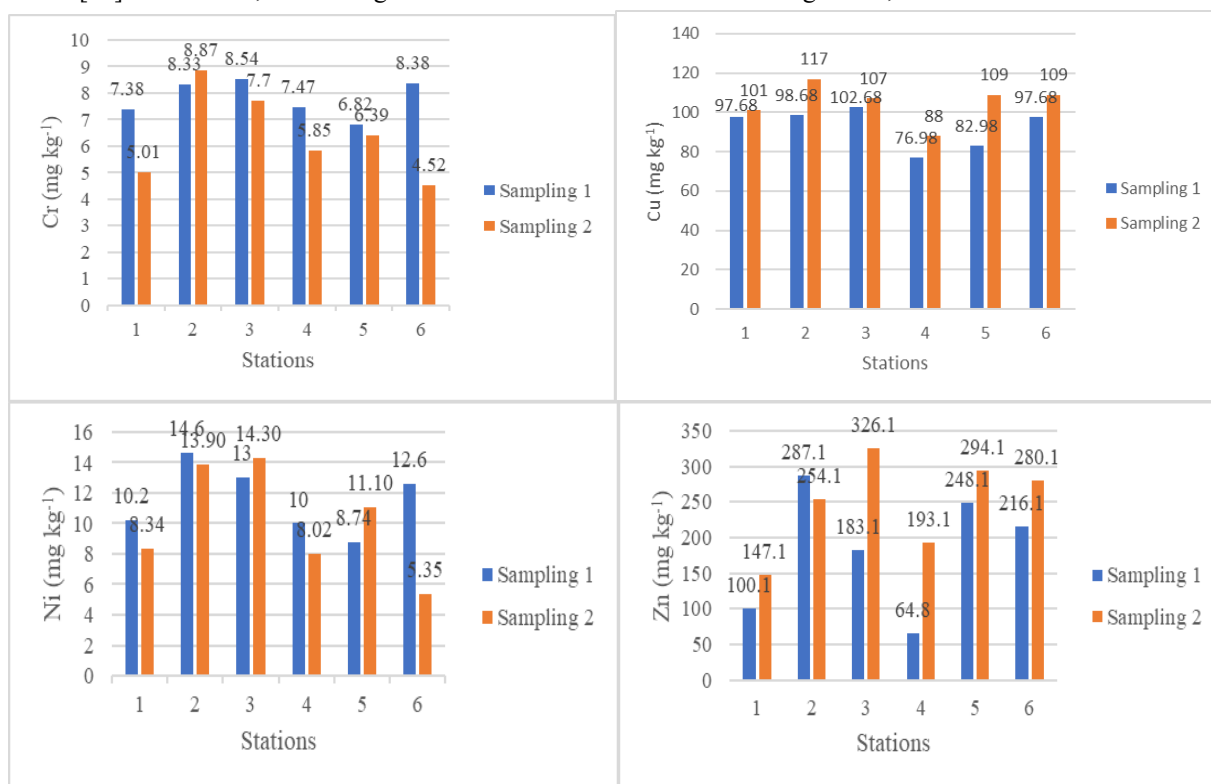


Figure 3. Cr, Ni, Cu, and Zn in *Sulcospira testudinaria* of the prambatan river-cultivation pond

metals in *Sulcospira testudinaria* vary depending on the type of metal. Chromium (Cr) concentrations in Sample 1 ranged from 6.82 to 8.54 mg kg⁻¹ and in Sample 2 from 4.52 to 8.87 mg kg⁻¹, with the highest concentrations found at Station 3 for Sample 1 and Station 2 for Sample 2. Meanwhile, the lowest concentrations were found at Station 5 and Station 6 for both Sampling 1 and Sampling 2. The maximum concentration of chromium (Cr) in mollusks is 12 mg kg⁻¹ [23], so the Cr concentrations at all study stations remain within a safe range that is, below the established maximum limit. The distribution of Cr within the bodies of benthic organisms is not uniform but depends on the type of tissue. Because they are in direct contact with the water, gills play a crucial role in Cr uptake and can account for up to 42% of the total Cr accumulated in the body. Unlike the gills, the digestive glands primarily function as sites for the inactivation and storage of Cr(III) through chelation, with the amount of Cr accumulated there reaching more than 35% of the total Cr accumulation in the body [46]. The Ni concentrations in Sampling 1 of *Sulcospira testudinaria* ranged from 8.74 to 14.6 mg kg⁻¹, and the Ni concentrations in Sampling 2 ranged from 5.35 to 14.3 mg kg⁻¹. The highest concentrations were found at Station 2 in Sampling 1 and at Station 3 in Sampling 2, while the lowest concentrations were found at Station 5 and, in Sampling 2, at Station 6. The permissible Ni concentration in mollusks is 80 mg kg⁻¹ [23], indicating that the Ni concentrations at the study stations remain within the permissible range.

The concentration of copper (Cu) in Sample 1 of *Sulcospira testudinaria* ranged from 76.98 to 102.68 mg kg⁻¹, and in Sample 2, it ranged from 88.1 to 117 mg kg⁻¹. The highest concentrations were found at Station 3 in Sample 1 and at Station 2 in Sample 2, while the lowest concentrations were found at Station 4. The zinc (Zn) concentrations in Sample 1 of *Sulcospira testudinaria* ranged from 64.8 to 287.1 mg kg⁻¹, and in Sample 2, they ranged from 147 to 326.1 mg kg⁻¹. The highest zinc concentration in Sampling 1 was found at Station 2, and in Sampling 2, it was found at Station 3. Meanwhile, the lowest concentrations were found at Station 4 during the first sampling and at Station 1 during Sampling 1. The permissible copper concentrations for mollusks are 50 and 150 mg kg⁻¹. The maximum permissible concentration of Zn in mollusks is 200-500 mg kg⁻¹ [24]. The concentrations of Cu and Zn at all study stations remained within the permissible limits. The presence and distribution of Cu in the environment are influenced by various factors, including human activities, the physicochemical properties of sediments, hydrodynamic dynamics, and the interactions

between sediments and aquatic organisms [48]. The essential metals Cu and Zn are required by aquatic organisms to support various metabolic processes. However, if their concentrations exceed the organisms' tolerance limits, these metals can be toxic; therefore, their presence in aquatic environments must be properly managed [25]. Zinc (Zn) is an essential element that plays a role in various biological processes, including growth and reproduction. High concentrations of Zn in organisms and sediments indicate that the element is quite abundant and available to biota. Zn accumulation in biota can occur through exposure to contaminated water and sediments; the metal is then absorbed and accumulated through biological processes within the body [47]. Zn can enter the environment through various materials and activities, particularly the use of fungicides, preservatives, and paint-based products. Meanwhile, the presence of Cu in sediments may stem from anthropogenic activities in the surrounding area, particularly agricultural activities involving the use of pesticides and fungicides, as well as construction activities such as the use of roofing materials and plumbing installations [49].

The results of the study show that the distribution of heavy metals in *Sulcospira testudinaria* varies between stations and among metal types. Concentrations of Cr, Ni, Cu, and Zn tend to be higher at the inlet station and in the aquaculture pond area, indicating that metal concentrations in the upstream water source tend to be high. The processes of metal uptake and accumulation in aquatic organisms are influenced by various factors, including geographic conditions, the physicochemical characteristics of the water, and the morphology and behavior of the organisms [26]. Overall, the pattern of metal accumulation in *Sulcospira testudinaria* follows the order Zn > Cu > Ni > Cr. These differences in patterns indicate that metal accumulation capacity is influenced not only by metal concentrations in the environment, but also by the chemical properties of each metal, its bioavailability, sediment characteristics, and the physiological mechanisms by which organisms regulate metal uptake, storage, and excretion [18;27]. As a benthic gastropod with low mobility that is closely associated with sediments, *Sulcospira testudinaria* is capable of reflecting long-term metal exposure, making it a potential bioindicator for evaluating aquatic environmental quality [8].

C. Biota-Sediment Accumulation Factor (BSAF)

The ability of *Sulcospira testudinaria* to accumulate metals from sediments was evaluated using the Biota-Sediment Accumulation Factor (BSAF). The results of the BSAF analysis in this study are presented in Table 1.

Based on Table 1., the BSAF values for Cr range from 0.22 to 0.42, with an average of 0.34, while those

is the primary source of exposure; therefore, metal concentrations in an organism's tissues generally

TABLE 1.
BIOTA-SEDIMENT ACCUMULATION FACTOR (BSAF) IN *SULCOSPIRA TESTUDINARIA* IN PRAMBATAN RIVER-CULTIVATION POND

Metals	Stations						Average
	1	2	3	4	5	6	
Cr	0.22	0.39	0.42	0.34	0.41	0.27	0.34
Ni	0.17	0.30	0.34	0.21	0.29	0.19	0.25
Cu	1.42	2.62	1.70	1.02	2.08	1.51	1.72
Zn	1.41	2.80	3.86	1.80	4.76	3.16	2.97

for Ni range from 0.17 to 0.34, with an average of 0.25. The BSAF values for Cu range from 1.02 to 2.62 with an average of 1.72, while those for Zn range from 1.41 to 4.76 with an average of 2.97. All BSAF values for Cr and Ni are below one, indicating that *Sulcospira testudinaria* has a relatively low accumulation capacity for Cr and Ni. This finding is consistent with the results of metal concentrations in the sediment, where Cr remains below the CCME ISQG values. While Ni has a relatively high concentration in the sediment, only a small fraction is bioavailable and can be absorbed by organisms. BSAF value < 1 indicates that the organism is a deconcentrator; a value of 1-2 is categorized as a microconcentrator; and a value > 2 indicates that the organism acts as a macroconcentrator [13]. Based on these values, the BSAF results for Cr and Ni are categorized as deconcentrators, the BSAF results for Cu can be categorized as microconcentrators, while the BSAF for Zn is categorized as a macroconcentrator. These results are consistent with the concentrations of Cu and Zn in *Sulcospira testudinaria* tissues, which are significantly higher than those of Cr and Ni, even though the Zn content in the sediment remains below the CCME ISQG threshold. Invertebrates have the ability to accumulate essential metals, such as Zn and Cu, as part of a physiological mechanism to maintain metabolic processes and homeostasis [28].

The BSAF value represents the ratio of the concentration of metals accumulated in an organism's tissues to the concentration of metals present in the

correlate with metal concentrations in the sediment. Heavy metals can enter an organism's body through absorption from water, consumption of contaminated food or sediment, and adsorption onto the body's surface [30]. High concentrations of heavy metals in sediments and the internal organs of freshwater snails may indicate pollution in aquatic environments. This is related to the ability of sediments to bind and store heavy metals, as well as the habits of snails, which live on the riverbed and obtain food from the sediments. These high levels of heavy metals may also be linked to the discharge of wastewater into rivers, with sediments serving as the primary site for the deposition and accumulation of heavy metals in aquatic environments [50]. Variations in metal accumulation among different organisms result from the interaction between the organisms' biological characteristics and their environmental conditions. Factors such as species, age, body size, physiological condition, as well as differences in the physicochemical properties of the water and regional characteristics contribute to differences in organisms' ability to absorb and accumulate metals [9].

D. Water Quality Parameters

Water quality parameters play a significant role in influencing heavy metals in water bodies. The results of water quality analyses from all research stations are presented in Table 2.

Based on Table 2, the results of the water quality parameter analysis at the six research stations showed

TABLE 2.
WATER QUALITY PARAMETERS IN PRAMBATAN RIVER-CULTIVATION POND

Parameters	Units	Stations						Quality standards
		1	2	3	4	5	6	
Temperature	°C	23.4	23.2	25.1	24.9	23.9	23.3	Dev 3
TSS	mg L ⁻¹	63	61	57.5	59	82.5	60	100
TDS	mg L ⁻¹	101	92	96	110	121	139	1000
pH	-	7.23	7.1	7.5	7.59	7.34	7.4	6-9
DO	mg L ⁻¹	8.7	8.8	6.6	6.3	8.4	8.7	>3

sediment. In general, a BSAF value >1 indicates that organisms are able to effectively accumulate metals from sediments, whereas a BSAF value <1 suggests that metals tend to remain bound to sediments or have lower bioavailability to organisms [29]. The accumulation of heavy metals in organisms depends on the bioavailability of metals in the environment as well as the organism's ability to absorb, assimilate, and excrete them. Sediment

temperature values of 23.2-25.1°C, TSS of 57.5-82.5 mg L⁻¹, TDS of 92-139 mg L⁻¹, pH of 7.10-7.59, and DO of 6.3-8.8 mg L⁻¹. According to Government Regulation No. 22 of 2021, Class 3 [31], all water quality parameters remain within the water quality standards, namely temperature Dev 3, TSS < 100 mg L⁻¹, TDS < 1000 mg L⁻¹, pH 6-9, and DO > 3 mg L⁻¹. The analysis results for these parameters remain within ranges that

support the survival of aquatic biota, including *Sulcospira testudinaria*. Water quality parameters are critical factors that support aquatic life while also influencing the accumulation of heavy metals in water bodies. Therefore, water quality measurements serve as the initial step in evaluating the level of heavy metal pollution. Rising temperatures can increase the bioaccumulation and toxicity of heavy metals by accelerating ion formation and enhancing the solubility of metals in water [33].

Temperature is one of the environmental factors that control metal dynamics in sediments. An increase or decrease in temperature not only affects the chemical reactions of metals but also alters dissolved oxygen (DO) levels as well as the dissolution of carbonates and hydroxides, thereby impacting the release of metals from sediments into the water. The adsorption of heavy metals onto sediments is thermodynamically exothermic and can occur spontaneously. Rising temperatures promote the desorption of metal ions from the surfaces of sediment particles, thereby accelerating the release of metals into the aquatic environment. Organic matter and sulfides are known to bind heavy metals through selective adsorption, but the effectiveness of these bonds is influenced by temperature changes. The higher the temperature, the greater the tendency for metals to be released from sediments due to increased desorption [33].

Total Suspended Solids (TSS) are solid particles suspended in the water column. An increase in TSS causes the water to become more turbid, thereby reducing the intensity of light penetrating the water column and disrupting the photosynthesis of aquatic organisms [34]. Suspended particles generally contain heavy metals because their constituent materials can bind to and accumulate metals present in the aquatic environment [35]. Total Dissolved Solids (TDS) refers to the concentration of dissolved substances in water, including minerals, salts, and various metallic elements. TDS concentrations exceeding quality standards can degrade water quality by altering the physical properties of the water and increasing the potential for toxic effects on aquatic biota [36]. A high TDS value indicates a high concentration of dissolved minerals, which can affect the behavior of heavy metals in water, particularly their dissolution and transport. The presence of these ions allows them to form complexes with heavy metals, thereby altering their bioavailability [30].

Acidity (pH) is one of the factors that control the solubility of metals in water columns. An increase in pH generally causes metal solubility to decrease, making it easier for metals to precipitate and accumulate in sediments [37]. pH is an indicator that influences the release of heavy metals from sediments into water bodies through changes in H^+ ion concentration. However, under conditions with a relatively narrow pH range, the effect of pH on metal mobility may be overshadowed by other factors, such as anthropogenic activities. Nickel (Ni) is more sensitive to pH changes than other metals, making it potentially more easily mobilized even under near-neutral pH conditions [38].

Dissolved oxygen (DO) is a key parameter in water quality assessment that affects the survival of *Sulcospira testudinaria* as a benthic organism. A DO range of 6.2-10 mg L^{-1} is considered optimal for supporting respiration, metabolism, and the physiological activity of gastropods [39]. Dissolved oxygen (DO) is one of the key parameters that characterize a water body's ability to support the life of aerobic organisms. A decrease in DO levels to the point of hypoxia can affect heavy metal dynamics by promoting anaerobic reduction processes, which in turn increase the release of heavy metals previously bound to sediments into the water column [40].

IV. CONCLUSION

This study shows variations in the accumulation of the heavy metals Cr, Ni, Cu, and Zn in sediments and *Sulcospira testudinaria* in the inlet river, aquaculture ponds, and outlet river. metal concentrations varied across stations, with Cr and Zn in the sediments remaining below the Interim Sediment Quality Guideline (ISQG) values, Cu falling within the ISQG-Probable Effect Level (PEL) range, and Ni exceeding the PEL at most stations. The distribution pattern of metals in sediments differs from that in *Sulcospira testudinaria*, with the concentration order in the organism being $Zn > Cu > Ni > Cr$. BSAF values show Zn (2.97), followed by Cu (1.72), Cr (0.34), and Ni (0.25). Based on the BSAF values, Zn and Cu exhibit higher bioaccumulation potential than Cr and Ni. The results of this study indicate that *Sulcospira testudinaria* has the potential to be used as a bioindicator of heavy metal pollution in freshwater systems utilized as aquaculture water sources.

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REFERENCES

- [1] H. Xu, R. Newton, D. C. Love, Y. Zhao, J. Toppe and W. Zhang, "Heavy metal risks in aquatic foods," *Environment International*, no. 109831, 2025.
- [2] S. Liu, K. Wu, L. Yao, Y. Li, R. Chen, L. Zhang, Z. Wu and Q. Zhou, "Characteristics and correlation analysis of heavy metal distribution in China's freshwater aquaculture pond sediments," *Science of the Total Environment*, vol. 931, p. 172909, 2024.
- [3] D. Xu, H. Xiong, Q. Wu, W. Xiao, S. L. Simpson, Q.-G. Tan, R. Chen and M. Xie, "Sediment Ballet: Unveiling the Dynamics of Metal Bioavailability in Sediments Following Resuspension and Reequilibration," *Environmental Science & Technology*, vol. 51, no. 58, p. 22755–22765, 2024.
- [4] F. Algül and M. Beyhan, "Concentrations and sources of heavy metals in shallow sediments in Lake Bafa, Turkey," *Scientific Reports*, vol. 1, no. 10, p. 11782, 2020.
- [5] B. Mao, Z. Huang, F. Zeng, H. Du, H. Fang, S. Lin, Y. Zhang and L. Shi, "Assessment of Heavy Metal Pollution in the Water, Sediment and Fish during a Complete Breeding Cycle in the Pond of the Pearl River Delta, China," *Journal of Environmental Protection*, vol. 11, no. 6, pp. 509-530, 2020.
- [6] M. Lv, H. Gan, Z. Ruan, H. Yang, R. Wang, L. Shafique, H. Naz and H. Ma, "Distributions of and Correlations between Cd, Cr, and Hg Concentrations in Suspended Particles and Sediment in Aquaculture Ponds and in *Cirrhinus molitorella* Tissues," *Pakistan Journal of Zoology*, vol. 5, no. 52, pp. 1735-1743, 2020.
- [7] M. El-Sharkawy, M. O. Alotaibi, J. Li, D. Du and E. Mahmoud, "Heavy Metal Pollution in Coastal Environments: Ecological Implications and Management Strategies: A Review," *Sustainability*, vol. 2, no. 17, p. 701, 2025.

- [8] A. M. S. Hertika, D. Arfiati, E. D. Lusiana and R. B. Putra, "Performance of Metallothionein Biomarker from *Sulcospira testudinaria* to Assess Heavy Metal Pollution in the Brantas River Watershed, Indonesia," *Journal of Ecological Engineering*, vol. 3, no. 24, pp. 276-286, 2023.
- [9] I. D. Muslim, A. Rafii and G. Ghitara, "Bioaccumulation of Cadmium (Cd), Lead (Pb), and Cadmium (Cu) in Gastropods in Kersik Village, Kutai Kartanegara Regency, East Kalimantan," *Jurnal Ilmu Perikanan Tropis Nusantara*, vol. 2, no. 1, pp. 30-40, 2023.
- [10] R. Irawanto, A. F. M. Affudin, A. A. Putri, N. W. Cahyani, F. N. Rahmania, Soemarno, A. S. Leksono, B. Yanuwadi, C. Retnaningdyah, H. Riniwati and Sugiyanto, "Water Quality Analysis and Water Pollution Effect from Upstream to Downstream of Brantas River-East Java," *Jurnal Pembangunan dan Alam Lestari*, vol. 15, no. 1, pp. 24-30, 2024.
- [11] A. Paar, "Microwave Digestion for ICP Analysis," [Online]. Available: <https://wiki.anton-paar.com/en/microwave-digestion-for-icp-analysis/>. [Accessed Mei 2026].
- [12] B. S. Nasional, SNI 6989.3:2019-Water and Wastewater-Part 3, Jakarta: Badan Standardisasi Nasional (BSN), 2019.
- [13] R. H. Tan, C. C. Ng, T. Gu and P. P. Y. Tek, "Evaluation of potentially toxic elements (PTEs) contamination in seawater, sediment, and sea snails (*Nerita articulata* and *Cerithidea obtusa*) from Kukup Fishing Village, Johor, Malaysia," *Environmental Monitoring and Assessment*, vol. 197, p. 565, 2025.
- [14] C. C. o. M. o. t. Environment, Canadian Environmental Quality Guidelines, Winnipeg, Manitoba, Canada: Canadian Council of Ministers of the Environment, 2002.
- [15] W. A. E. Putri, A. I. S. Purwiyanto, J. Meiyerani, Melki, Rozirwan, B. S. Barus, G. Diansyah, A. Haryati and Y. Suteja, "Heavy Metals Nickel (Ni) and Zinc (Zn) in the Lower Musi River, South Sumatra," *Indonesian Journal of Oceanography*, vol. 8, no. 1, pp. 64-71, 2026.
- [16] Harmesa, Lestari and F. Budiyo, "Distribution of Heavy Metals in Seawater and Sediments in the Waters of Cimanuk, West Java, Indonesia," *Oceanology and Limnology in Indonesia*, vol. 5, no. 1, pp. 19-32, 2020.
- [17] Y. Liang, R. Wang, G. D. Sheng, L. Pan, E. Lian, X. Tang, S. Yang, D. Yin and N. Su, "Geochemical controls on the distribution and bioavailability of heavy metals in sediments from Yangtze River to the East China Sea: Assessed by sequential extraction versus diffusive gradients in thin-films (DGT) technique," *Journal of Hazardous Materials*, vol. 452, p. 131253, 2023.
- [18] H. Jeong, E. Byeon, D.-H. Kim, P. Maszczyk and J.-S. Lee, "Heavy metals and metalloid in aquatic invertebrates: A review of single/mixed forms, combination with other pollutants, and environmental factors," *Marine Pollution Bulletin*, vol. 191, p. 114959, 2023.
- [19] L. S. Miranda, G. A. Ayoko, P. Egodawatta and A. Goonetilleke, "Adsorption-desorption behavior of heavy metals in aquatic environments: Influence of sediment, water and metal ionic properties," *Journal of Hazardous Materials*, vol. 421, p. 126743, 2022.
- [20] S. Basti, C. Sahu, S. S. Pati and S. K. Sahu, "Impact of organic carbon on heavy metals of river sediments and aquatic ecosystems: A review," *Environmental Quality Management*, vol. 34, no. 2, p. e22253, 2024.
- [21] D. Xu, H. Xiong, Q. Wu, W. Xiao, S. L. Simpson, Q.-G. Tan, R. Chen and M. Xie, "Sediment Ballet: Unveiling the Dynamics of Metal Bioavailability in Sediments Following Resuspension and Re-equilibration," *Environmental Science & Technology*, vol. 58, no. 51, pp. 22755-22765, 2024.
- [22] J. Rohman, M. A. Nugraha and I. Akhrianti, "Contamination And Distribution Of Copper (Cu) And Zinc (Zn) Heavy Metals In The Sediment Of The Baturusa, Bangka Belitung Islands Province," *Journal of Tropical Marine Science*, vol. 6, no. 2, pp. 155-166, 2023.
- [23] U. F. a. D. Administration, "Guidance Document for Nickel in Shellfish," U.S. Department of Health and Human Services, Public Health Service, Center for Food Safety and Applied Nutrition, Office of Seafood, 1993.
- [24] E. B. B. İlhan, S. Çağlar, A. Mülâyim, E. Karabâyır, A. Aksu and N. Ç. Balkıs, "Spatial Variability of Metal Concentrations in Seaweeds, Mussels and Surface Sediments in Gemlik Bay: an Extensive Assessment of Contamination Sources and Associated Health Risks," *Biological Trace Element Research*, vol. 204, pp. 4323-4347, 2026.
- [25] W. A. E. Putri, M. I. Susanti, Rozirwan, M. Hendri and F. Agustriani, "Heavy Metal Contamination Status in the Sediments of the Musi River Estuary, South Sumatra," *Marine Oceanography Bulletin*, vol. 11, no. 2, pp. 177-184, 2022.
- [26] M. Menon, R. Mohanraj, J. V. B. and A. P. R. V., "Bioaccumulation of heavy metals in a gastropod species at the Kole wetland agroecosystem, a Ramsar site," *Journal of Environmental Management*, vol. 329, p. 117027, 2023.
- [27] N. D. Nnaji, H. O. T. Miri and C. Ugwa, "Bioaccumulation for heavy metal removal: a review," *SN Applied Sciences*, vol. 5, p. 125, 2023.
- [28] R. Liu, W. Jiang, F. Li, Y. Pan and C. Wang, "Occurrence, partition, and risk of seven heavy metals in sediments, seawater, and organisms from the eastern sea area of Shandong Peninsula, Yellow Sea, China," *Journal of Environmental Management*, vol. 279, p. 111771, 2021.
- [29] B. A. Melake, S. M. Endalew, T. S. Alamirew and L. M. Temesegen, "Bioaccumulation and Biota-Sediment Accumulation Factor of Metals and Metalloids in Edible Fish: A Systematic Review in Ethiopian Surface Waters," *Environmental Health Insights*, vol. 17, 2023.
- [30] N. Geng, Y. Xia, D. Li, F. Bai and C. Xu, "Migration and Transformation of Heavy Metal and Its Fate in Intertidal Sediments: A Review," *Processes*, vol. 12, no. 2, p. 311, 2024.
- [31] R. o. i. Government, "Government Regulation [PP] Number 22 of 2021 Concerning the Implementation of Environmental Protection and Management," 2021.
- [32] W. Tirtama, D. G. Bengen and Rastina, "Bioaccumulation of Lead (Pb) on The Dog Conch (*Strombus canarium*) in Madong Waters, Tanjung Pinang," *Journal of Tropical Marine Science*, vol. 27, no. 2, pp. 287-295, 2024.
- [33] S. Zhao, Y. Zhao, Z. Cui, H. Zhang and J. Zhang, "Effect of pH, temperature, and salinity levels on heavy metal fraction in lake sediments," *Toxics*, vol. 12, no. 7, p. 494, 2024.
- [34] N. Wadi'ah, M. Pandiangan, S. Irlamaida, A. Nuryadin and L. Subagiyo, "Effectiveness of Activated Carbon on TSS, TDS, and pH of Mahakam River Water," *Jurnal Redoks*, vol. 10, no. 2, pp. 153-161, 2025.
- [35] L. N. Fadlillah, A. N. Indrastuti, A. F. Azahra and M. Widyastuti, "Evaluation of Heavy Metal Toxicity Levels in Water, Suspended Sediment, and Bottom Sediment in the Winongo River, D.I. Yogyakarta," *Journal of Environmental Science*, vol. 20, no. 1, pp. 30-36, 2022.
- [36] A. Alfathiah, H. Latuconsina and H. D. Prasetyo, "Water Quality Analysis Based on Physical and Chemical Parameters in Patrean river waters, Sumenep regency," *AQUACOASTMARINE: J. Aquat. Fish. Sci.*, vol. 1, no. 2, pp. 76-84, 2022.
- [37] T. Nurhidayah, L. Maslukah, S. Y. Wulandari and Kurnia, "Vertical Distribution of Pb, Zn, and Cr Metals and Their Relationship with Sediment Organic Carbon at Marunda Beach, Jakarta," *Buletin Oseanografi Marine*, vol. 9, no. 2, pp. 125-132, 2020.
- [38] L. S. Miranda, B. Wijesiri, G. A. Ayoko, P. Egodawatta and A. Goonetilleke, "Water-sediment interactions and mobility of heavy metals in aquatic environments," *Water Research*, vol. 202, p. 117386, 2021.
- [39] S. Lailiyah, D. Arfiati, A. M. S. Hertika, N. D. K. Arum and C. B. Noviya, "The Effectiveness of *Filopaludina javanica* and *Sulcospira testudinaria* in Reducing Organic Matter in Catfish (*Clarias* sp.) Aquaculture Wastewater," *Scientific Journal of Fisheries and Marine Science*, vol. 13, no. 1, pp. 106-113, 2021.
- [40] L. Zeng, F. Yang, Y. Chen, S. Chen, M. Xu and C. Gu, "Temperature and Dissolved Oxygen Drive Arsenic Mobility at the Sediment—Water Interface in the Lake Taihu," *Toxics*, vol. 12, no. 7, p. 471, 2024.

- [41] M. B. Hossain, R. Miazie, A.-A. U. Nur, S. K. Paul, M. A. Bakar, B. A. Paray and T. Arai, "Assessment of Metal Contamination in Water of Freshwater Aquaculture Farms from a South Asian Tropical Coastal Area," *Toxics*, vol. 10, no. 9, p. 536, 2022.
- [42] M. B. Hossain, J. Sultana, F. H. Pingki, A.-A. U. Nur, M. S. Mia, M. A. Bakar, J. Yu, B. A. Paray and T. Arai, "Accumulation and contamination assessment of heavy metals in sediments of commercial aquaculture farms from a coastal area along the northern Bay of Bengal," *Frontiers in Environmental Science*, vol. 11, p. 1148360, 2023.
- [43] M. Chukaeva and D. Petrov, "Assessment and analysis of metal bioaccumulation in freshwater gastropods of urban river habitats, Saint Petersburg (Russia)," *Environmental Science and Pollution Research*, vol. 30, pp. 7162-7172, 2022.
- [44] W. Kong, Q. Xu, H. Lyu, J. Kong, X. Wang, B. Shen and Y. Bi, "Sediment and residual feed from aquaculture water bodies threaten aquatic environmental ecosystem: Interactions among algae, heavy metals, and nutrients.," *Journal of Environmental Management*, vol. 326, p. 116735, 2023.
- [45] A. Haryati, D. N. Ashari, I. Prihatiningsih and H. I. Januar, "Analysis of heavy metal pollution and ecological risk in the sediments of the Comal River estuary," *Buletin Oseanografi Marina*, vol. 15, no. 1, pp. 56-69, 2026.
- [46] M. Ao, R. Zhou, R. Meng, L. A. Bonaventure, B. Luo, X. Qian, X. Xu, S. Wang and P. Wu, "Chromium transformations and biological impacts in aquatic systems: From sediment-water interfaces to food web complexity," *Ecotoxicology and Environmental Safety*, vol. 303, p. 118850, 2025.
- [47] D. Vidyalakshmi, A. Yesudas, G. Sivan, E. A. Prakash and P. Priyaja, "Heavy metal accumulation analysis using bivalve, sponge, sea urchin, and gastropod species as bioindicators.," *Marine Pollution Bulletin*, vol. 202, p. 116374, 2024.
- [48] Rozirwan, D. A. Ananta, N. N. Khotimah, W. A. E. Putri, Fauziyah, G. Diansyah, Y. I. Siregar, Ramses, Isnaini, Melki, R. Aryawati, F. Agustriani and R. Y. Nugroho, "Copper and Lead Contamination in Sediment and Benthic Ecosystems of Sembilang National Park's Coastal Region, South Sumatra," *Science and Technology Indonesia*, vol. 10, no. 3, pp. 866-876, 2025.
- [49] M. M. Uddin, G. Peng, F. Xu and L. Huang, "Speciation, mobility, and risks of heavy metals in sediment and water of a freshwater Lake in Fujian Province, China," *Chemistry and Ecology*, vol. 40, no. 5, pp. 553-570, 2024.
- [50] O. O. Oloyede, J. Kolawole, U. L. Adaugo and T. A. Adesakin, "Heavy-metal bioavailability, water quality, and sediment characteristics in relation to freshwater snail distribution in Alaro River, southwestern Nigeria," *Toxicological & Environmental Chemistry*, vol. 108, no. 2, pp. 200-232, 2026.