Copper and Lead Contamination in Sediment and Benthic Ecosystems of Sembilang National Park's Coastal Region, South Sumatra

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Research Paper

Copper and Lead Contamination in Sediment and Benthic Ecosystems of Sembilang National Park's Coastal Region, South Sumatra

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Abstract

Littoral zone often face environmental pressure due to anthropogenic activities, which can impact the quality of their ecosystem. This study analyzes the concentrations of copper (Cu) and lead (Pb) in sediments and benthic (*Anadara granosa* and *Cerithidea cingulata*). Sampling procedures were implemented during September 2022 across the aquatic habitats of Sembilang National Park, in South Sumatra Province, using the purposive sampling method. Sediment grain size and substrate type were analyzed using Shepard's triangle. Metal detection using a spectrophotometric method based on atomic absorption. The results showed that the sediment fraction mostly consisted of clay, ranging from 92.03% to 94%. Cu concentrations in the sediment ranged from 5.01±0.017 to 5.71±0 mg/kg, while Pb concentrations ranged from 10.5±0.195 to 11.51±0.395 mg/kg. In the benthic, Cu concentrations ranged from 0.0037±0.00005773 to 0.0147±0.00000346 mg/kg, and Pb concentrations ranged from 0.0001±0.000227 to 0.005±0 mg/kg. According to the statistical evaluation testing via independent sample t-test showed that heavy metals differed significantly ($p < 0.05$) between sediment and benthic compartments. These results show that the environmental quality in Sembilang National Park is still comparatively well maintained and within current quality requirements, despite certain activities that have the potential to pollute the environment. To guarantee the long-term viability of this area, it is advised that environmental quality be frequently monitored as a mitigation action.

Keywords
Benthic, Bioaccumulation, Heavy Metals, Sediment, National Sembilang Park

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1. INTRODUCTION

The sustained presence of human-induced activities in nearshore environments results in pollutant production (Rozirwan et al., 2024b; Elliott and Kennish, 2024). Heavy metals, microplastics, pesticides, and other harmful organic compounds are frequently found as pollutants (Carvalho Ferreira and Lôbo-Hajdu, 2023; Khotimah et al., 2024; Charlena et al., 2025). Heavy metals are a type of pollutant with toxic and non-degradable properties that can cause negative effects on species inhabiting water bodies and humans throughout the organismal feeding sequence (Briffa et al., 2020; Mitra et al., 2022; Zaynab et al., 2022). Metals suspended in the water column are gradually deposited into the underlying sediments (Sankhla et al., 2019). Sediment then become the main accumulation place for heavy metals that can persist for a long time and potentially disrupt the balance of coastal ecosystems (Lv et al., 2021; Han et al., 2024). The incorporation of heavy metals into sediments primarily occurs through a range of physicochemical mechanisms, such as adsorption and desorption dynamics, redox reactions, and precipitation–dissolution (Dan et al., 2022; Miranda et al., 2022). As species adapted to life on or within the substrate of aquatic ecosystems, benthic communities are very vulnerable to contamination of these heavy metals (Dong et al., 2021; Li et al., 2024). Benthic fauna are capable of assimilating and bioaccumulating heavy metals originating from sediment deposits (Liu et al., 2017). Elevated levels of heavy metals detected in benthic organisms not only impacts their health but also leads to alterations in the ecological framework of benthic populations, ultimately disrupting the aggregate function of the coastal ecosystem (Oron et al., 2021; Korejwo et al., 2022)).

Quantification of heavy metal presence and their impact in littoral zones have shown significant impacts on environmental health and aquatic organisms. Previous studies have demonstrated that heavy metals like Cu and Pb can accumulate in sediments and benthic organisms, altering ecosystem structure and functionality (Rozirwan et al., 2023b; Angon et al., 2024). Previous studies have demonstrated that contamination by heavy metals can alter the structure of benthic communities and lead to the degradation of critical mangrove habitats (Rozirwan et al., 2023d). Anthropogenic activities can cause pollutant accumulation in the northeast and threaten benthic foraminifera growth and reproduction to reach the lowest level (Cong et al., 2022). Previous studies in the Taihu Basin, China, revealed that certain environmental variables play a dominant role in shaping benthic communities are the presence of arsenic (As) and copper (Cu). The study found that the abundance and biomass of *Oligochaeta* serve as potential indicators to appraise the ecological impact associated with heavy metal presence in the local environment (Bian et al., 2016). Similar to urbanization, the construction of land-based and marine aquaculture operations in Laoshan Bay (Yellow Sea, China) also produces heavy metal pollutants that impact commercially valuable species such as fish, shellfish, and seaweed (Dong et al., 2023). Studies on the bioaccumulation of heavy metals in various coastal areas show that benthic organisms are often early indicators of pollution (Lukhabi et al., 2024). In agreement with the perspective of Jayachandran et al. (2022), benthic communities are in a strategic position to absorb pollutants from sediments and transfer them to higher trophic levels.

Existing literature addressing the presence of heavy metals in coastal ecosystems have primarily focused on pollution levels, sources, and general ecological impacts (Chormare and Kumar, 2022; Chahouri et al., 2023). However, limited research has specifically examined the bioaccumulation of Cu and Pb in both sediments and benthic organisms within a designated conservation area such as Sembilang National Park. This study provides a novel contribution by integrating bioaccumulation analysis with an ecological risk assessment, offering a thorough evaluation of how heavy metal pollution affects the structural complexity and ecosystem functions of benthic assemblages in a protected shoreline habitat (Liu et al., 2020; Fadlillah et al., 2023). The Sembilang National Park Coast is included as a conservation area (Silvius et al., 2016; Fauziyah et al., 2023). Sembilang National Park is a protected area with the main objective of conserving biodiversity and maintaining important ecosystem functions (Rozirwan et al., 2022, 2023b). Protected zones frequently serve as habitats for numerous endangered species and have ecosystems that are very vulnerable to disturbance (Pulido-Chadid et al., 2023; Wu et al., 2023). Furthermore, this research highlights the potential threats posed by anthropogenic activities near conservation areas (Holenstein et al., 2021; Le et al., 2023). This study aimed to analyze the level of bioaccumulation of Pb and Cu in sediments and benthic organisms on the coast of Sembilang National Park, identify potential sources of pollution, and assess its impact on the configuration of benthic biota and the sustainability of coastal ecosystems as a whole.

2. EXPERIMENTAL SECTION

2.1 Materials

Sediment and two benthic species (*Anadara granosa* and *Cerithidea cingulata*) served as the main materials in this investigation. Wet destruction of samples using HNO_3, HCl, H_2SO_4, distilled water, and filter paper. Supporting tools include hotplates, fume hoods, sieve shakers, and atomic absorption spectrophotometers. Identification, preparation, and sample destruction were accomplished at the Marine Bioecology Laboratory; heavy metal content tests were undertaken at the Integrated Service Unit of the Palembang City Environmental Service.

2.2 Instrumentation

Supporting tools include hotplates (C-MAG HS7), fume hood (BFSD-202), sieve shakers (AS 200 basic), and atomic absorption spectrophotometers (Shimadzu AA-7000).

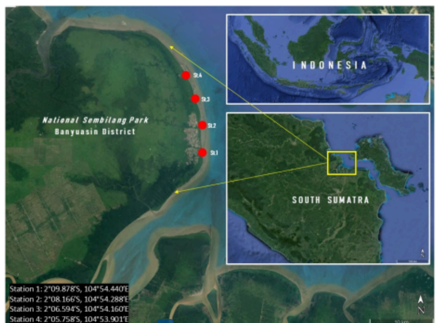

Figure 1. Study Area and Sampling

2.3 Location

This research was conducted around the Sembilang National Park site within Banyuasin, South Sumatra province, Indonesia, at four sampling stations (Figure 1). Sampling was carried out at four stations, each representing different estuarine and coastal environments within the park: Station 1 (2°09.878′S, 104°54.440′E), Station 2 (2°08.166′S, 104°54.288′E), Station 3 (2°06.594′S, 104°54.160′E), and Station 4 (2°05.758′S, 104°53.901′E). Located along the western coast of the Bangka Strait, Sembilang National Park serves as a conservation area. This estuarine region is created by the mixing of freshwater from the Sumatran mainland and seawater sourced from both the Malacca Strait and South China Sea (Sarno et al., 2017;

Rozirwan et al., 2019). Several previous research reports, although included in conservation areas, are also influenced by Various human-related activities including aquaculture, agricultural practices, vessel traffic corridors, and fisheries (Rozirwan et al., 2022; Fitria et al., 2023). Sediment and benthic sampling for species *Cerithidea cingulata* (stations 1 and 2) and *Anadara Granosa* (stations 3 and 4) were conducted in the mangrove ecosystem around Sembilang National Park. These two benthic species were selected due to their ecological roles, availability, and their capacity to bioaccumulate heavy metals, making them appropriate bioindicators. The choice of only two species was based on their dominance and abundance in the observation area during the period of sampling.

The Laboratory of Oceanography and Marine Instrumentation at Sriwijaya University was used for sample preparation and digestion. Meanwhile, laboratory analysis was conducted at the Laboratory of the Environmental and Land Service, Palembang, using the method of the atomic absorption spectrophotometer (AAS). Sediment sampling is referred to in (Abdel Gawad, 2018; Rozirwan et al., 2024a), collection of sediment samples was performed employing a grab sampler, then put into a 1 kg plastic clip. Sampling of benthic organisms was conducted From the top layer of sediment down through the first 30 cm. The samples were placed in a filtered through a 1 cm mesh and washed using seawater. After collection, the samples were immediately labeled, packed in zip-lock bags, and stored in a cooler box to maintain preservation. The samples obtained were then identified in the laboratory, referring to the book (Carpenter and Niem, 1998).

Figure 2. Benthic Species. A). *C. cingulata* and B). *A. granosa*

2.4 Procedure

2.4.1 Environmental Quality Measurement

Direct field measurements of water quality indicators (pH, dissolved oxygen, salinity, and temperature) were conducted in triplicate (Rozirwan et al., 2021).

2.4.2 Sediment Grain Measurment

Grain size distribution was analyzed using both the sieve and pipette techniques (Romano et al., 2017). The sediment substrate classification was identified through triangular diagram analysis based on Shepard's method, performed using Microsoft Excel version 202 (Poppe and Eliason, 2008; Anggraini et al., 2020). The type of sediment grain fraction identified was assigned according to the component with the highest percentage in the dataset.

2.4.3 Preparation and Destruction Sample

Preparation of sediment samples is cleaned from foreign items such as fragments of plastic, leaves, etc, followed by drying under room temperature conditions, then grind the sample until homogeneous and stored in a bottle polyethylene covered. Next, the benthic samples were cleaned and separated between the body organs and meat and then ground. Heavy metal samples are destroyed. Quantification of Cu and Pb in sediment and benthic samples utilizing wet digestion refers to Gao et al. (2021); Rizk et al. (2022).

2.4.4 Atomic Absorption Spectroscopic Measurments

Copper and lead concentrations were analyzed with the aid of an AAS at wavelengths of 324.7 nm for copper and 283.3 nm for lead. The analysis was carried out using a Shimadzu AA-7000, which was calibrated with standard solutions of known concentrations. The detection limits for detection system were 0.07 mg/L for Cu and 0.01 mg/L for Pb, while its sensitivity was 0.003 mg/L for Cu and 0.005 mg/L for Pb. Instrument precision was evaluated based on the relative standard deviation (RSD) obtained from triplicate analyses, was maintained below 5% for both metals, ensuring the reliability and reproducibility of the results (Zhong et al., 2016).

2.5 Data Analysis

2.5.1 Reference Standards

Measured levels of heavy metals in sediments and benthic organisms were assessed in relation to recognized regulatory standards (Table 1).

Table 1. Heavy Metal Quality Standards (mg/kg)

Object	Pb	Cu	Refrences
Sediment	50	65	(ANZECC and ARMCANZ, 2000)
Benthic	1.5	10	(FAO, 1983)

2.5.2 Statistical Analysis

An independent sample t-test was used to evaluate the concentrations of heavy metals differed significantly between sediment and benthic organisms (Rozirwan et al., 2024b). PCA was employed to identify patterns and correlations among various water parameters (dissolved oxygen, salinity, temperature, and pH) and Amounts of heavy metals accumulated in sediment and benthic organisms. PCA analysis was executed through XLSTAT (v16.16.27), and qualitative variables were quantified in terms of percentages (Colot et al., 2022).

3. RESULTS AND DISCUSSION

3.1 Environmental Parameter Overview

The parameters related to environmental conditions that were measured from stations 1-4 are pH, DO, temperature and salinity (Table 2). The pH value at all stations tends to be homogeneous, with a range of values 6.5±0.53 to 8.2±0.26. DO has varying values, ranging from 7±0.26 to 11.7±0.20 mg/L. Temperature and salinity at all stations tend to be homogeneous, with a temperature range of 26±0.50-30.7±1.41°C and salinity of 5±0.26–21±0.56 PSU.

Table 2. Environmental Parameters

Station	pH	DO (mg/L)	Temperature (°C)	Salinity (PSU)
1	6.5 ±0.53	11.7±0.20	26±0.50	5±0.26
2	6.7±0.62	9.5±0.60	28.7±1.30	10±5.02
3	8.2±0.26	7±0.26	30.7±1.41	21±0.56
4	7.6±0.30	9.8±0.46	29.6±0.62	20±0.46

Based on the measurement results, the waters of Sembilang National Park are influenced by seawater inflow from the Bangka Strait and freshwater inflow from the Banyuasin River during tidal ebb and flow. Changes in water quality parameters can result from the mixing of different water masses (Rozirwan et al., 2021, 2023a). Based on the research results, the pH, temperature, and salinity values tend to be constant, but the DO values vary. The high and low DO values are susceptible to contamination from waste substances present in the aquatic environment. The quality of the water parameters pH, DO, temperature, and salinity show excellent values for growth. *C. cingulata* and *A. granosa*. The concentration of heavy metals is affected by environmental factors like pH, temperature, oxygen availability, and salinity. The presence, mobility, and toxicity of these metals are commonly affected by variations in physicochemical factors (Ramses et al., 2020; Luo et al., 2022). Water quality parameters can be used as indicators of pollution (Dolbeth et al., 2007).

3.2 Description of Benthic

Benthic species observed in the study area comprised *C. cingulata* and *A. granosa* (Figure 2). *C. cingulata* and *A. granosa* are benthic which are generally found in estuary or estuary waters. The *C. cingulata* species found in the waters of Sembilang National Park belongs to the cerithidae family, which is about 2-2.5 cm long and has a long and narrow shell; the opening of the shell is oval, and the operculum is brown. Meanwhile, *A. granosa* has a slightly brownish white to somewhat dark shell color with a size of 4-6 mm. The benthic species *C. cingulata* and *A. granosa* are two types of organisms commonly found in estuarine waters (Kalat-Meimari et al., 2018; Rahmatin et al., 2024). *C. cingulata* is a gastropod with a cone-shaped shell that has spiral grooves, is dark in color, and is relatively small in size. It is often found in large numbers in muddy or sandy habitats in estuary areas (Kalat-Meimari et al., 2018; Li and Dong, 2020). *C. cingulata*, which is often found in muddy or sandy habitats, has the potential to absorb heavy metals accumulated in sediment through direct contact and feeding activities at the sediment-water interface (Vahidi et al., 2020).

On the other hand, *A. granosa* has a round shell with thick stripes containing thick, reddish flesh, which is often consumed by humans as seafood (Rozirwan et al., 2023c,e). As a filter feeder, *A. granosa* has the ability to filter food particles from water that may contain heavy metals (Mohan et al., 2024). These heavy metals then accumulate in their body tissues, especially in their reddish flesh. Because of its ability to filter water and accumulate heavy metals, *A. granosa* is an important bioindicator in monitoring water quality (Yona et al., 2020). Therefore, analyzing the heavy metal content in these two species can offer valuable insights concerning the concentration of heavy metals in estuarine areas.

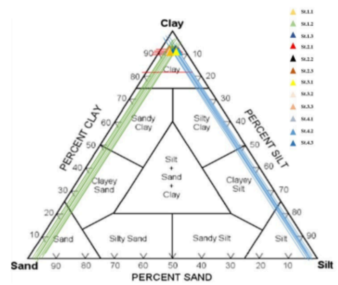

Figure 3. Grain Size Analysis with Triangles Shepard

Table 3. Sediment Grain Size Analysis.

Station	Sediment Fraction Percentage %				Substrate Type
	Gravel	Sand	Mud	Clay	
1	0.00	6.45	1.5	92.03	Clay
2	0.00	2.38	3.6	93.99	Clay
3	0.00	2.33	3.74	93.91	Clay
4	0.00	1.34	4.09	94.55	Clay

3.3 Size Classification of Sediment Grains

Results of substrate type identification at the study area were derived through the Shepard triangular method (Figure 3). Four types of sediment substrates (mud, gravel, clay, and sand) were identified in the area surrounding Sembilang National Park. The study's results indicated that clay was the predominant substrate type across all sampling stations. The sediment substrate in the waters surrounding Sembilang National Park is predominantly clay. The clay content across all stations ranges from 92.03% to 94.55%. Station 4 recorded the highest percentage of clay, while station 1 had the lowest percentage (Table 3).

The sediment substrate, which is dominated by clay in Sembilang National Park Waters, provides some important insights into the local ecosystem conditions. The high percentage of clay at all stations, ranging from 92.03% to 94.55%, indicates that this area has environmental characteristics that tend to be calm and stable. The dominance of clay also indicates that the sedimentation process in this area may be influenced by the supply of fine material from the mainland, such as from river flow or surface runoff (Rozirwan et al., 2020; Cao et al., 2024; Ling et al., 2024). This is relevant considering that the mangrove ecosystems around this area are often the site of fine material deposition, consequently altering the spatial structure and community composition of benthic biota. Soegianto et al. (2022) stated that *C. cingulata* and *A. granosa* have a smooth substrate (clay) as a habitat. This is because the clay substrate type makes it easier for *C. cingulata* and *A. granosa* in to make holes to hide from predators. Sediments were predominantly clay, indicating stable environmental conditions conducive to heavy metal accumulation. High clay content supports the adsorption of heavy metals due to its fine particle size and large surface area (Song et al., 2014).

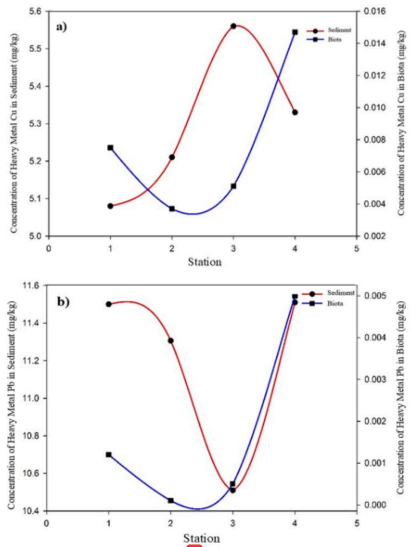

Figure 4. Distribution of Heavy Metals Cu and Pb

3.4 Heavy Metals Concentration

The data revealed that the levels of heavy metals, Cu and Pb were predominantly concentrated within the sediment than in the *C. cingulata* and *A. granosa* at all sampling stations (Table 4). The highest Cu concentration in sediment was recorded at Station 2 (5.71±0 mg/kg) and the lowest at Station 1 (5.01±0.017 mg/kg). Meanwhile, the highest recorded level of Pb in sediment was recorded at Station 1 (11.5±0.395 mg/kg) and the lowest at Station 3 (10.5±0.195 mg/kg).

Pb reached its highest concentration in *C. cingulata* at Station 2 (0.005±0 mg/kg) and the lowest at *A. granosa* at Station 3 (0.0001±0.000227 mg/kg). In contrast, the highest concentration of Cu was detected in *C. cingulata* at Station 2, with a value of 0.0147±0.00000346 mg/kg and the lowest at *A. granosa* at Station 3 (0.0037±0.00005773 mg/kg). These results indicate variations in heavy metal bioaccumulation between different types of benthic, with *C. cingulata* showing a tendency to accumulate higher Cu compared to *A. granosa*, while Pb accumulation in both biota was relatively low.

Analysis outcomes demonstrated that the levels of Cu and Pb were greater in sediments compared to those in biota. *C. cingulata* and *A. granosa* at all sampling stations. This is in line with the general understanding that sediment functions as the main storage of heavy metals in aquatic ecosystems (Das et al., 2023). Heavy metals progressively settle and concentrate in sediments through adsorption and precipitation processes, causing metal concentrations in sediments to be higher than in organism tissue (Sankhla et al., 2019; Dan et al., 2022). The variation in heavy metal concentrations between sediments and biota indicates that *C. cingulata* and *A. granosa* have different bioaccumulation capabilities. *C. cingulata* showed a tendency to accumulate more Cu compared to *A. granosa*, which may be reflect interspecific differences in physiology, foraging behavior, and ecological niches. *C. cingulata* more on the substrate surface, which allows for more direct exposure to heavy metals bound to sediment particles (Raj and Das, 2023). Mean while, *A. granosa* located in deeper substrate layers (Rozirwan et al., 2023f, 2024c). Pb accumulation in both species was relatively low, which may indicate that Pb may be less bioavailable for accumulation by benthic organisms (Espejo et al., 2019; Raj and Das, 2023). These differences in heavy metal bioaccumulation suggest that the risk of heavy metal toxicity may vary between species and between different heavy metals. The statistical analysis with an independent t-test showed that the significance values for both Cu and Pb levels were below 0.05, meaning there were important differences in the amount of heavy metals found in sediments compared to the organisms living on the bottom.

Table 4. Heavy Metal Concentrations in Sediment and Benthic (mg/kg).

Station	Cu		Pb	
	Sediment	Biota	Sediment	Biota
1 (*C. cingulata*)	5.01±0.017	0.0075±0.000003191	11.5±0.395	0.0012±0.00000732
2 (*C. cingulata*)	5.71±0	0.0147±0.00000346	11.3±0.114	0.005±0
3 (*A. granosa*)	5.66±0.042	0.0037±0.000005773	10.5±0.195	0.0001±0.000227
4 (*A. granosa*)	5.32±0.017	0.0051±0.000001249	10.51±0	0.0005±0

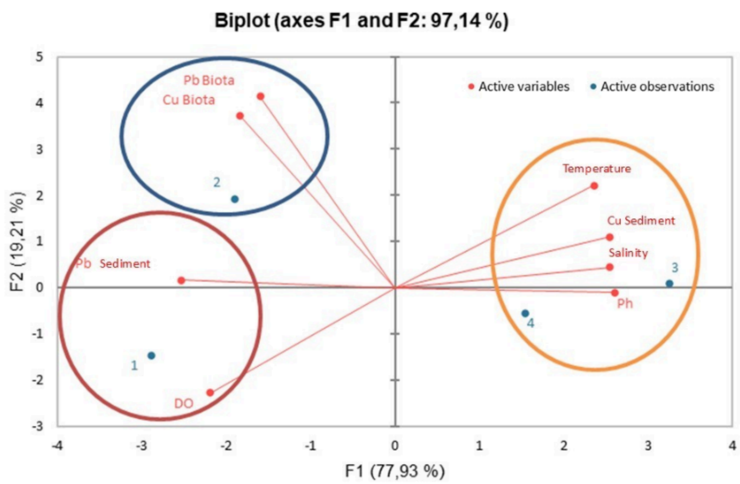

Figure 5. PCA

3.5 Heavy Metal Contamination Profiles in Sediment and Benthic Ecosystem

Visualization of Cu and Pb heavy metal distribution across sediment and organisms was performed with Sigma Plot (Figure 4). The results indicated that the concentration of Cu logan had varying patterns. Meanwhile, Pb concentrations in sediment and biota fluctuate.

Dispersion of Cu and Pb contaminants in sediment and biota revealed variations across research stations. The distribution graph of Cu metal concentration showed fluctuations between stations, with a significant increase in concentration at stations 2 and 3 in sediment, while the concentration of Cu in biota decreased at station 2. In contrast, the distribution of Pb showed a sharp decrease pattern at station 3 in sediment, followed by an upward trend in Pb in biota at the same station. An elevated level of lead was observed in sediment and biota collected from Station 4. This distribution pattern reflects variations in the accumulation and transport mechanisms of Cu and Pb, within the sediment ecosystem and biota at the research site. The distribution of Cu is significantly determined by a range of factors, including anthropogenic activities, the physicochemical properties of sediment, hydrodynamic conditions, and the interactions between sediment and biota (Hu et al., 2022; Bao et al., 2024). Higher concentrations of Cu in sediment at certain stations may be related to pollution sources originating from agricultural activities, passenger and fishing ship transportation, and the use of antifouling paint on ships and coastal buildings (Rozirwan et al., 2023d; Khotimah et al., 2024).

3.6 Principal Compenent Analysis (PCA)

PCA evaluating the relationship between water quality parameters and heavy metal pollution indices in sediment and benthic organisms yielded a cumulative Eigenvalue of 97.14%, identifying three primary component groups. Eigenvalue Variability, respectively, namely F1 (77.933%) and F2 (19.210%) (Figure

5).

PCA results revealed significant relationships between water quality parameters and heavy metal distribution. Stations 3 and 4 showed higher Cu sediment concentrations, while Pb bioaccumulation was prominent at Station 2. (Fatmi et al., 2024; Rozirwan et al., 2023f). In contrast, station 1 has higher DO and Pb values in sediment, indicating that the high DO at this station plays a role in the oxidation process that increases Pb concentration (Kutlu et al., 2024). The F2 axis separates station 2 as the third main group, with higher Cu and Pb concentrations in benthic biota, indicating a higher bioaccumulation ability at this station.

The relationship between copper (Cu) and lead (Pb) in the natural environment is often influenced by their similar sources and geochemical behaviors (Suheryanto and Ismarti, 2018; Zhang et al., 2025). Both metals can originate from anthropogenic inputs such as agricultural runoff, industrial discharges, port activities, and they tend to co-accumulate in sediments and benthic organisms due to their affinity for particulate matter (Zhang et al., 2019; Rozirwan et al., 2025). In aquatic environments, Cu and Pb often exhibit positive correlations, particularly in estuarine and coastal areas where fine sediments with high organic content act as sinks for heavy metals (Miranda et al., 2021; Bao et al., 2024).

The observed distribution patterns of Cu and Pb in both sediment and benthic organisms suggest a shared source and similar environmental fate, supporting the notion that these metals are likely transported and deposited together under similar physicochemical conditions. This correlation may also indicate a cumulative impact of pollution in the area, especially in stations 3 and 4, which show higher concentrations of Cu in sediment and a similar distribution pattern of Pb in both sediment and benthic biota. Similarity analysis also shows a significant relationship between stations 3 and 4, which have similar physicochemical conditions and heavy metal distribution. The results contribute substantially to the understanding of heavy metal distribution patterns within aquatic environments and may inform the development of more targeted management approaches to mitigate heavy metal contamination in the region (Rozirwan et al., 2023f; Plaß et al., 2024).

4. CONCLUSIONS

The concentrations of Pb and Cu in sediments and biota within Sembilang National Park remain below established quality standards, suggesting that contamination levels in this area do not pose an immediate environmental risk. However, the presence of potential pollution sources from anthropogenic activities highlights the need for continued vigilance. Maintaining the environmental quality of Sembilang National Park requires periodic monitoring to recognize early contamination symptoms and undertake immediate corrective actions. This proactive approach will help safeguard the ecosystem's health and ensure its long-term sustainability.

5. ACKNOWLEDGMENT

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