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Bioaccumulation and Ecological Risk Assessment of Heavy Metal Contamination (Lead and Copper) Build Up in the Roots of *Avicennia alba* and *Excoecaria agallocha*

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ABSTRACT

Mangrove roots play an important role in reducing heavy metal pollution in their surroundings. This study aimed to assess the bioaccumulation and ecological risk assessment of heavy metal pollution in mangrove roots. Mangrove root samples consisting of two species (*Avicennia alba* and *Excoecaria agallocha*) were collected from two observation stations in the mangrove ecosystem of Payung Island, Banyuasin District, South Sumatra, Indonesia. Heavy metal concentrations were measured by atomic absorption spectrometry. Then, statistical analysis was carried out by one-way analysis of variance (ANOVA). Ecological risk assessment used the bioconcentration factor (BCF), geoaccumulation index (I_{geo}), contamination factor (Cf), and pollution load index (PLI). On the basis of the results, the highest sediment heavy metal concentration at station 2 was Pb amounted to 13.57 ± 0.46 mg/kg, and Cu amounted to 11.08 ± 0.38 mg/kg. In turn, the highest heavy metal concentration of mangrove roots in *E. agallocha* species for Pb amounted to 2.89 ± 0.033 mg/kg and *A. alba* for Cu amounted to 10.57 ± 0.38, BCF was classified as exclusion (BCF < 1), except for the BCF of Cu station 1, which was classified as hyperaccumulator (BCF > 1). Igeo shows that the level of pollution is not contaminated ($I_{geo} < 0$), and Cf shows low pollution (Cf < 1), except Cf Pb station 2 is classified as moderate pollution. Conversely, PLI is included in the category of not polluted (PLI < 0). Mangrove roots play an important role in reducing heavy metal pollution in the surrounding area. Therefore, an in-depth understanding of heavy metal dynamics can be the basis for designing effective coastal environmental conservation strategies.

Keywords: bioaccumulation, ecological risk assessment, heavy metal, mangrove roots, sediment.

INTRODUCTION

Heavy metal pollution is a serious matter in mangrove ecosystems. Most heavy metals are naturally occurring, but some are derived from anthropogenic sources (Mitra et al., 2022). In coastal areas where mangrove ecosystems exist, sources of heavy metal contamination can come from industrial activities, domestic waste, mining, and pesticide use (Fitria et al., 2023). Some examples of heavy metals of common concern in the mangrove context are lead (Pb) and copper (Cu) (Hewindati et al., 2022; Mosa et al., 2022). Sources of Pb from industrial waste, ship fuel, and ship paint tend to persist in the environment and can accumulate in plants as well as animals (Ytreberg et al., 2022; Raj and Das 2023). Furthermore, the use of copper-containing fertilizers and pesticides in agriculture can also contribute to the Cu exposure in coastal environments (Li et al., 2020).

Heavy metals are chemical elements that have a high atomic mass and can be toxic to living organisms when accumulated in high concentrations (Briffa et al., 2020; Nnaji et al., 2023).

Heavy metal toxicity can inhibit plant growth, enzymatic activity, stomatal function, photosynthetic activity, and the accumulation of other nutrients (Guo et al., 2023; Feng et al., 2023). In addition, high concentrations of heavy metals can also cause damage to the root system. Roots, as the main part, have the ability to accumulate heavy metals from the environment and translocate them to other parts of the mangrove (Luthansa et al., 2021a; Yadav et al., 2023). According to Szafranski and Granek (2023), the factors affecting heavy metal bioaccumulation in mangrove roots involve the chemical properties of the metals, the physical and chemical conditions of the environment, as well as the biological characteristics of the mangrove itself. Some types of roots, such as pneumatophores, can allow gas and nutrient exchange but can also contribute to the bioaccumulation process (Robin et al., 2021).

The bioaccumulation of heavy metals in mangrove roots has significant ecological impacts. High bioaccumulation rates can lead to toxicity risks for the mangrove plants themselves and other organisms that depend on the mangrove ecosystem (Chowdhury et al., 2021; Bhuiyan et al., 2022). Other organisms in the mangrove ecosystem that rely on mangrove plants for habitat or food sources may also be exposed to toxicity risks. Animals such as crustaceans, molluscs, and annelids that live around mangrove roots can be affected by the heavy metals that accumulate in the plant tissue (Rozirwan et al., 2023a; Rozirwan et al., 2024). This can affect the abundance, reproduction, and sustainability of organism populations, and increase the risk of buildup in the food chain (Zheng et al., 2023). The organisms that consume mangrove plants, such as invertebrates and fish, can accumulate heavy metals in their tissues (Yousif et al., 2021). Furthermore, higher predatory organisms, such as birds and mammals may be impacted to a greater extent, as they may consume the organisms that have accumulated significant amounts of heavy metals (Zaynab et al., 2022; Rozirwan et al., 2022a; Khan et al., 2023).

Heavy metal contamination can have serious impacts on the balance of coastal ecosystems. Through this study, it is expected to identify the ecological risk level of heavy metal bioaccumulation in mangrove roots, so as to design appropriate mitigation and conservation strategies. The species A. alba and E. agallocha were chosen because they are among the most dominant species found at the study site. These two species also have different root systems; studying their roots can provide more in-depth information on heavy metal bioaccumulation. Ecological risk assessments are important to understand the consequences of heavy metal bioaccumulation in mangrove plants. This information will be useful in designing the prevention and management measures that can minimize negative impacts on the coastal environment.

MATERIALS AND METHOD

Roots sampling

This research was conducted in September 2023. Mangrove roots and sediments were collected using a purposive sampling method at two observation stations with a purposive sampling method in the Payung Island mangrove ecosystem, Banyuasin Coast, South Sumatra (Figure 1).

Payung Island is an estuary area that is influenced by freshwater and seawater inputs from both the Musi River and Bangka Strait waters (Rozirwan et al., 2021; Rozirwan et al., 2022b; Meiyerani et al., 2024). Several previous studies have stated that this area is influenced by various activities, such as ship transportation, fishing areas, as well as agricultural and residential activities around Payung Island (Saputra et al., 2021; Rozirwan et al., 2023b). In addition, this area also has a lot of mangrove vegetation. According to Dalimunthe et al. (2023), mangroves on Payung Island consist of various species, such as *Avecennia alba*, *Bruguiera sexangula, Bruguiera sexangula, Excoecaria agallocha, Kandelia candel, Nypa fruticans,* and *Rhizophora apiculata*.

Identification of mangrove species is referred to Giesen et al. (2007). Preparations and destruction of sediment samples and mangrove roots were carried out in the Marine Bioecology laboratory at the Faculty of Mathematics and Natural Sciences, Sriwijaya University. Quantitative analysis of heavy metal concentrations was conducted at the Environmental Agency Laboratory, South Sumatra.

Sediment grain size measurement

Sediment grain size analysis has been conducted using sieving and pipetting methods

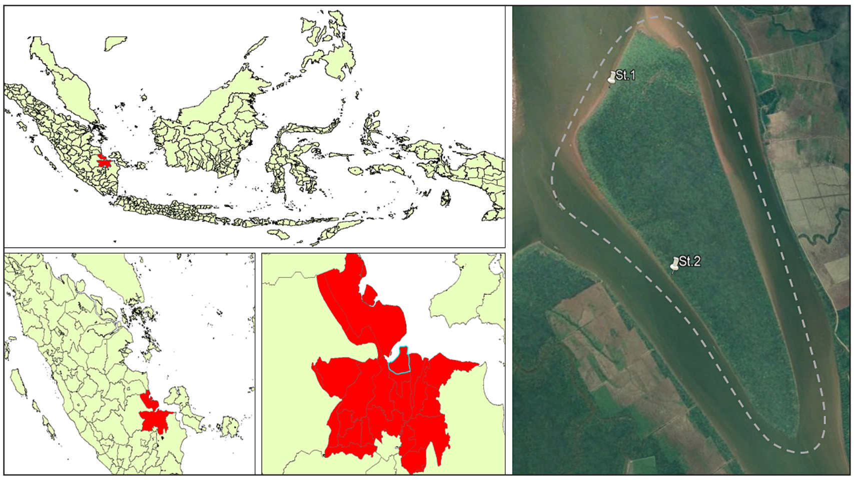

Figure 1. A map of mangrove root sampling locations on Payung Island, Banyuasin District, South Sumatra, Indonesia.

(Romano et al., 2017). Then, to determine the type of sediment substrate (gravel, sand, mud, and clay) using Shepard's triangle analysis with Microsoft Excel V.2021 (Poppe and Eliason, 2008; Anggraini et al., 2020). The determination of sediment fraction type was based on the most significant composition value from the data.

Sample preparation and destruction

Sediment sample preparation has been done by cleaning foreign objects such as plastic pieces, leaves, etc. and then drying them at room temperature, crushing them until homogeneous, and storing them in a polyethylene bottle with a lid. Furthermore, mangrove roots were cleaned and dried using the indirect sunlight method, then pulverized. Destruction of heavy metal samples of Pb and Cu in sediment samples and mangrove roots using wet deconstruction refers to (Rozirwan et al., 2023c; Rozirwan et al., 2024).

Atomic absorption spectroscopic measurement

Measuring the concentration of Pb and Cu was carried out using an atomic absorption spectrophotometer with a wavelength of 283.3 nm for Pb and 324.7 nm for Cu (Zhong et al., 2016).

DATA ANALYSIS

Quality standards and recovery values

Quality standards for Pb and Cu in sediment and plants are presented in Table 1. The recovery values for the heavy metals in the standard reference material are presented in Table 2.

Ecological risk assesment

In the environmental ecological risk assessment, there are calculations of the bioconcentration factor (BCF), geoaccumulation index (I_{geo}), contamination factor (Cf), and pollution load index (PLI) (Hakanson 1980).

Bioconcentration factor

Metal uptake by roots from sediments occurs through a process known as bioaccumulation. The use of BCF values aims to identify the level of metal bioaccumulation in mangrove roots derived from sediment (Maiti et al., 2022).

$$\text{BCF} = \frac{Concentration\ of\ root}{Concentration\ of\ sediment} \tag{1}$$

where: BCF < 1 is an excluder ; BCF = 1 is an indicator; and BCF = 1 is a hyperaccumulator (Almahasheer 2019).

Table 1. Quality standards (mg/kg)

Sample	Pb	Cu	References
Sediment	50	65	(ANZECC and ARMCANZ, 2000)
Plant	2	10	WHO (1996) in (Ogundele et al., 2015)

Geoacumulation index

Geoaccumulation index (I_{geo}) quantitatively assesses the level of heavy metal contamination and assigns pollution levels by detailing their classification (Nagarajan et al., 2019).

$$I_{geo} = log_2\left(\frac{Concentration\ heavy\ metals\ in\ sediment}{1{,}5.background}\right) \qquad (2)$$

where: the I_{geo} value classification consists of not contaminated ($I_{geo} \leq 0$), not contaminated to moderately contaminated (I_{geo} 0–1), moderately contaminated (I_{geo} 1–2), moderate to highly contaminated (I_{geo} 2–3), highly contaminated (I_{geo} 3–4), highly contaminated to very high (I_{geo} 4–5), and highly contaminated ($I_{geo} \geq 5$) (Muller, 1969).

Contamination factor (Cf)

The contamination factor is determined experimentally, as the ratio between the elemental concentration of the sample and its background (Gopal et al., 2023).

$$Contamination\ factor\ (Cf) = \frac{Concentration\ of\ heavy\ metals\ in\ sediment}{Background} \qquad (3)$$

where: contamination factor criteria according to (Shaheen et al., 2017): Cf < 1 = low level of contamination; 1 < Cf < 3 = moderate level of contamination; 3 < Cf < 6 = moderate level of contamination; Cf > 6 = very high level of contamination.

Pollution load index

The pollution load index (PLI) is used to determine the quality of pollution. The pollution load index value uses the formula (Shaheen et al., 2019).

$$PLI = (Cf1 \times Cf2 \times Cf3 .... \times Cfn)^{1/n} \qquad (4)$$

where: pollution load index criteria: PLI 2 = not polluted to lightly polluted; PLI 24 = moderately polluted; PLI 4–6 = heavily polluted; PLI 6–8 = heavily polluted; PLI 8–10 = heavily polluted.

Statistical analysis

The data were tested for homogeneity of variance with the Levene test and for normality of distribution with the Shapiro-Wilk test. Significant differences within each root by pollution source were assessed by one-way analysis of variance (ANOVA), followed by a post-hoc LSD test if the conditions were met (Carricavur et al., 2018; Rozirwan et al., 2023d). The level of significance was $p < 0.05$. All statistical analyses were performed using the IBM SPSS V.26 application.

Table 2. Recovery values (Ağca and Özdel, 2014)

Metals	Recovery (%)
Pb	75.8
Cu	92.4

RESULT AND DISCUSSION

Description of roots

The *A. alba* and *E. agallocha* mangroves found at the sampling sites are two species that have different characteristics. Differences are also seen in the type of roots owned, as presented in Figure 2. *A. alba* species includes a type of pneumatophore root that emerges vertically from the cord root. In line with the opinion of (Hao et al., 2021), the *Avicennia* genus has developed an advanced root system to increase resistance to muddy soil conditions and has downward-growing anchor roots and upward-growing aerial roots (pneumatophores).Pneumatophores provide a hard base that is often covered by a variety of creatures such as sponges, sea anemones, bryozoans, tunicates, barnacles, tubeworms, and molluscs, as well as various types of algae (Hogarth 2013). In addition, the type of pneumatophore can also facilitate the aeration process, which is important for root respiration (Schauss 2016; Siraj et al., 2023). In turn, *E. agallocha* has lateral roots that spread and mix with each other, supraterranean bands produce elbow-shaped pegs from pneumatophores (Mondal et al., 2016). According to Ragavan et al., (2015), the genus *Excoecaria* has roots that are above the sediment and grow creeping. Plants with lateral roots can enhance nutrient exchange (Zürcher and Müller 2016). Strong roots, which can penetrate deeper into the soil, have the properties that can help bind and store surrounding sediments. This helps prevent erosion and keeps the soil structure strong (Gao et al., 2016; Stachew et al., 2021).

Figure 2. Mangrove roots, A). A. alba, B). E. agallocha

Sediment grain size

The results of determining the type of substrate in sampling using the Shepard triangle method (Figure 3). The determination of sediment substrate in the Payung Island mangrove ecosystem is divided into four types: gravel, sand, mud, and clay. The results showed that the type of substrate at the two stations was clay. The sediment substrate around the Payung Island mangrove ecosystem is dominated by clay. The percentage of clay from the two stations ranged from 80.5–84.03%. The highest percentage of clay was at station 1 (Table 3). According to the sediment fraction results, Table 4 shows the characteristics of both mangrove species, *A. alba* and *E. agallocha*. According to Rozirwan et al. (2024), clay substrates are strong at absorbing organic matter, so many groups of macrozobenthos animals are found. Mangrove substrate characteristics are often found in mud, loam, and sandy areas (Saputra et al., 2021; Rozirwan et al., 2023). Fine substrate types such as loam make it easy to accumulate heavy metals, because clay particles have a high surface area for the absorption of heavy metals (Song et al., 2014; Rozirwan et al., 2020e). Mangrove forests have a low-energy aquatic environment

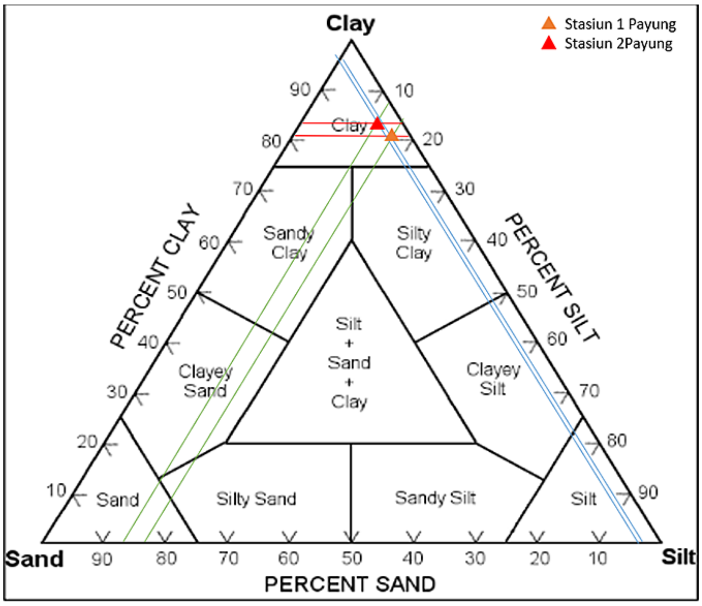

Figure 3. Classifications of sediment type with shepard triangle method

Table 3. Sediment grain size in each station

Station	Sediment fraction (%)				Grain size
	Gravel	Sand	Mud	Clay	
St.1	0.00	3.6	12.37	84.03	Clay
St.2	0.00	3.36	16.14	80.5	Clay

that is conducive to the sedimentation of clay particles (Das et al., 2019). In addition, clay-textured sediments have a higher ability to reject nutrients and are more active in chemical reactions than coarse-textured soils (Ayu et al., 2023; Rozirwan et al., 2023f).

Heavy metals concentration

The results of heavy metal concentrations of Pb and Cu in sediment and mangrove roots at both stations are summarized in Figure 4. According to the study findings, station 2 (*E. agallocha*) had the highest concentration of Pb in sediments

Table 4. Comparison of heavy metals concentration associated with mangrove roots in the world

Location	Species	Heavy metals (mg/kg)	References
The mangrove ecosystem in South Gujarat	*Avicennia marina*	0.068 ±0.003 (Pb) 0.022 ±0.011 (Cd) 0.048 ±0.010 (Ni) 0.012 ±0.016 (Cr) 0.012 ±0.016 (Cu) 0.490 ±0.028 (Zn) 0.490 ±0.028 (Mn) 5.04 ±1.195 (Fe)	(Ozyurt et al., 2017)
The coastal area of Subang, West Java, Indonesia	*Rhizophora apiculata*	4.272±0.397 (Cu) 0.075±0.017 (Cd) 5.786±0.424 (Pb)	(Hewindati et al., 2022)
	Sonneratia caseoralis	4.340±0.088 (Cu) 0.638±0.150 (Cd) 3.614±0.354 (Pb)	
River Blanakan in Subang regency, West Java province	*Avicennia marina*	18.08-54.64 (Zn) 0.33- 0.89 (Cu)	(Takarina, 2020)
	Rhizophora mucronata	9.75-54.75 (Zn) 0.2-54.75 (Cu)	
	Sonneratia caseoralis	19.58-33.33 (Zn) 0.4-0.99 (Cu)	
The Mangrove ecosystem of Payung Island, Banyuasin District, Sout Sumatra	*Sonneratia caseolaris*	2.596±0.002 (Pb) 5.459±0.030 (Cu) 11.881±0.015 (Zn)	(Rozirwan et al., 2023f)
	Rhizopora apiculata	1.340±0.075 (Pb) 1.532±0.016 (Cu) 5.428±0.004 (Zn)	
	Xylocarpus granatum	0.514±0.129 (Pb) 8.850±0.011(Cu) 3.933±0.010 (Zn)	
The Can Gio Mangrove Forest (Southern Vietnam)	*Rhizophora apiculata*	0.26 - 11.69 (Cr) 0.21-8.17 (Cu) 0.11 – 8.54 (Ni)	(Nguyen et al., 2020)
The embayments of Sydney estuary (Australia)	*Avicennia marina*	153 (Cu) 189 (Pb) 378 (Zn) 16 (Ar) 11 (Ni)	(Chaudhuri et al., 2014)
The Sirik mangrove forest is located in an arid environment along the Oman Sea	*Avicenna marina* *Rhizophora macronata*	6.09±1.12 (Pb) 6.89±0.74 (Pb)	(Keshavarz et al., 2012)

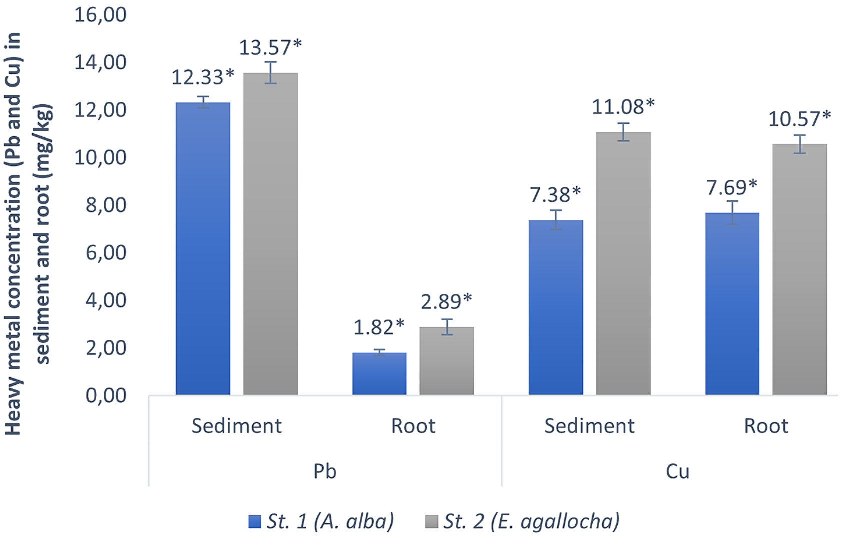

Figure 4. Heavy metal concentration (Pb and Cu) in sediment and mangrove roots (mg/kg)

and roots, at 13.57 ± 0.46 mg/kg and 2.89 ± 0.327 mg/kg, respectively. As for Cu in the sediment, the largest concentration at station 2 (*E. agallocha*) was 11.08 ± 0.38 mg/kg, and for roots at station 1 (A. alba) was 7.69 ± 0.48 mg/kg. Differences in each concentration of Pb and Cu at each station were analyzed statistically using one-way anova and post hoc LSD ($P < 0.05$) marked with (*) indicating that each sample is significantly different. Reference comparisons of heavy metal concentrations in roots from different species and locations are summarized in Table 2.

On the basis of Figure 4, the concentration of Pb sediment in this study is still below the quality standard set by ANZECC and ARMCANZ (2000), of 50 mg/kg. Station 1 is an area where A. alba species are found, or the coastal front zone is generally directly affected by tides, rather than the back zone of the area where *E. agallocha* species are found. The forefront zone often experiences dynamic movement of water during tides, heavy metals can be bound to sediment particles and transported by water during tides (Harahap et al., 2020; Maulana et al., 2023). The concentration of Pb in sediment is higher than that in roots, indicating that mangrove roots can effectively prevent heavy metals from entering the plant's upper area, but the metal concentration around the root area is still high (Wang et al., 2013).

The concentration of heavy metal Pb in E. agallocha roots of 2.89 ± 0.327 mg/kg has exceeded the quality standard set by WHO (1996) in (Ogundele et al., 2015) of 2 mg/kg. Differences in heavy metal concentrations in mangrove roots can also occur due to several factors, such as differences in species, root types, and habitats (Rezaei et al., 2021; Hossain et al., 2022). *E. agallocha* roots contained higher Pb concentrations than *A. alba*. Mangrove roots are able to release oxygen to avoid the toxic effects of anaerobic sediment conditions (Castro et al., 2022). According to the opinion of Lin et al. (2021), the roots that are submerged in sediments will differ from some types of roots that grow outside the sediment surface. The lateral roots of *E. agallocha* spread along the soil surface and have the highest heavy metal concentrations compared to the breathing roots and pneumatophores of *A. alba*. Breathing roots and pneumatophores are often found in frontier zone mangrove species that are able to store a lot of water to dilute heavy metal concentrations in their body tissues, thereby reducing the toxicity of these metals (Dhalaria et al., 2020; Huang et al., 2020).

In this study, the concentration of Cu sediment is still below the quality standard set of 65 mg/kg (anzecc and Armcanz, 2000). The Cu concentrations that are still below the quality standard over time will continue to increase and have an impact on the surrounding ecosystem (Briffa et al., 2020; Najamuddin et al., 2023). The Cu adsorbed on sediments can still be bioavailable (Zhang et al., 2014). This condition indicates that Cu can be taken up by organisms as an essential metal that functions as a cofactor for several enzymes in the metabolic process even in controlled and limited concentrations (Kim et al., 2015; Hao et al. 2021). According to Shabbir et al. (2020), Cu can be toxic in high concentrations and can have a negative impact on the health of organisms and the aquatic ecosystem as a whole. Just like Pb, the concentration of Cu in sediments is higher than that in roots. In addition, the concentration of Cu in the roots of *E. agallocha* detected in both areas exceeded the established quality standard of 10.57 ± 0.38 mg/kg. High concentrations of Cu can cause toxicity in plants that can interfere with the photosynthesis process, damage cell membranes, and inhibit root growth (Yuce et al., 2024).

Bioaccumulation and ecological risk assessments

The results of the bioaccumulation and ecological risk assessment of heavy metal pollution in mangrove roots and sediments are summarized in Table 5. Overall, the bioconcentration factor (BCF) results of roots bioaccumulating heavy metals from sediments were exclusionary for all Pb (0.15 and 0.21). In contrast, BCF Cu *A. alba* was 1.04 and *E. agallocha* amounted to 0.95, . The geoaccumulation index showed uncontaminated nature for Pb (– 0.60 and – 0.47) and Cu (3.48 and – 3.42). The contamination factor (CF) showed low and moderate contamination for Pb (0.99–1.09) and Cu (0.13 and 0.20). PLI ranged from 0.37 to 0.47, indicating that the two station points were not polluted.

According to Table 5, the BCF of Cu in roots was higher than that of Pb. This suggests that the accumulation rate of Cu in roots is higher than that of Pb, which in this context can be influenced by several factors, including the chemical properties of the two metals and the selectivity of plants in absorbing heavy metals (Rezapour and Moazzeni 2016; Čurlík et al., 2016). According to Shabbir et al., (2020), copper is an essential metal required for biochemical processes and the biological functions of plants. However, excess Cu induces oxidative stress in the plant through increased production of reactive oxygen species (ROS). Meanwhile, Pb is a non-essential metal that has toxic properties and has no physiological or biochemical purpose (Collin et al., 2022). BCF describes the transfer and bioavailability of heavy metals from sediments to plants. BCF > 1 indicates that the heavy metal uptake in plants is higher than in sediments, while BCF < 1 indicates that the heavy metal concentrations in sediments are higher than those absorbed by plants (Hellen, 2016). BCF < 1, which is an excluder, is due to the ability of plants to limit pollutants from entering other tissues (Aljahdali and Alhassan 2020; Luthansa et al., 2021b). In turn, BCF > 1 acts as a hypoximator, which absorbs pollutants and is able to tolerate continuing to grow and develop in a polluted environment (Skuza et al., 2022). Previous BCF studies on mangroves were also conducted by Analuddin et al., (2023), showing BCF Hg, Cu, Mn, Pb, and Zn > 1. This is likely related to the anthropogenic impact of the densely populated city of Kendari. Furthermore, the Igeo values observed in this study indicate that the sediments in the mangrove ecosystem at the study site are not contaminated ($I_{geo} < 0$).

The contaminants originating from human activities are also influenced by the dynamic nature of coastal areas, which are influenced by tides and currents, resulting in low levels of heavy metals (Chai et al., 2019; Akhtar et al., 2021; Chedadi et al., 2023). The Contamination Factor (Cf) of this study shows that each metal causes low contamination, except for Pb, which is included in moderate contamination. This is attributed to anthropogenic sources originating from around the Payung Island area, such as fishing boats, cargo ships, and household waste (Rozirwan et al., 2024). In line with the findings (Rezaei et al., 2021), the CF values are 1.65 for Mn and 1.35 for Pb, respectively, indicating that the surface sediments in the Lishui River are moderately polluted by Mn and Pb. This is attributed to the source of Mn coming from agricultural and industrial activities and to the source of Pb coming from shipping activities. PLI can be used to characterize or make inferences about the pollution status of the ecosystem (Hummel et al., 2021; Jiang et al., 2020). The PLI value of sediments collected from mangrove ecosystems is classified as unpolluted (PLI = 0 – 2). In contrast to the results of the study (Gopal et al., 2023), the PLI values of all samples studied showed values above 1, indicating polluted sediments in the Vedaranyam coastline in

Table 5. Bioaccumulation and ecological risk assessment of heavy metal concentrations

Station	BCF		Igeo		Cf		PLI
	Pb	Cu	Pb	Cu	Pb	Cu	
St. 1 (*A. alba*)	0.15	1.04	-0.60	-3.48	0.99	0.13	0.36
St. 2 (*E. agallocha*)	0.21	0.95	-0.47	-3.42	1.09	0.20	0.47

Nagapattinam District, Tamil Nadu, India. This was attributed to the entire study area having metals contaminated by fluvial inputs transporting untreated wastewater to the marine environment.

CONCLUSIONS

The concentrations of Pb and Cu in the roots of *A. alba* and *E. agallocha* showed that despite the highest concentrations of heavy metals in the sediments, the ecological risk assessment indicated that the accumulation rates of mangrove roots were mostly in the low or non-polluting category. The overall risk assessment, including the bioconcentration factor, geoaccumulation index, contamination factor, and pollution load index, indicated that the environment around the mangrove roots was unlikely to be significantly polluted.

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