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Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment

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Abstract. *Rozirwan, Khotimah NN, Putri WAE, Fauziyah, Aryawati R, Damiri N, Isnaini, Nugroho RY. 2023. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. Biodiversitas 24: 6733-6742.* Mangroves as the largest coastal ecosystem can accumulate heavy metals from their environment. This study aimed to evaluate the environmental risk associated with heavy metal pollution accumulated in the roots of mangroves and the surrounding sediments. The mangrove roots consisted of three species *Sonneratia caseolaris*, *Rhizopora apiculata*, and *Xylocarpus granatum*, collected from three observation stations within the Payung Island mangrove ecosystem in South Sumatra, Indonesia. The concentrations of heavy metals were determined using atomic absorption spectrometry. Statistical analysis employed one-way Analysis of Variance (ANOVA). At the same time, ecological risk assessment utilized the Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination factor (Cf), and Pollution Load Index (PLI). The highest sediment concentrations of heavy metals at station 3 were 12.786±0.26 mg/kg for Pb, 10.413±0.011 mg/kg for Cu, 42.752±0.053 mg/kg for Zn, and Cd was not detected. In mangrove roots, the highest concentrations were found in *S. caseolaris*, with 2.596±0.002 mg/kg for Pb and 11.881±0.015 mg/kg for Zn, while *X. granatum* exhibited 8.850±0.011 mg/kg for Cu and 0.160±0.020 mg/kg for Cd. BCF values <1 were categorized as exclusion, Igeo<0 indicated non-contamination, Cf<1 signified low pollution, and PLI<0 denoted an unpolluted status. Based on the results, the quality of the mangrove ecosystems affected by heavy metal pollution is currently considered safe regarding environmental risk assessment.

Keywords: Environmental risk assessment, heavy metals, mangrove roots, sediment

INTRODUCTION

Mangroves have important ecological functions in coastal ecosystems. In addition to playing a role in biodiversity conservation, it also provides a stable environment for the surrounding coastal landscape (Henriques et al. 2021; Cahyaningsih et al. 2022). Mangroves with a complete network system can adapt to tidal changes and reduce coastal erosion (Montgomery et al. 2018; Nizam et al. 2022; Amos and Akib 2023). In coastal areas, mangroves are very vulnerable to the spread of heavy metals due to anthropogenic activities (Rozirwan et al. 2023a). Oil discharges from ships, pesticides, and other types of pollutants, both carried by river flow and directly discharged into the waters, greatly affect the preservation of mangrove functions (Almaniar et al. 2021; Fitria et al. 2023).

Pollutants emitted by anthropogenic activities such As, Cu, Zn, Co, Ni, Fe, Cr, Mn, I, and Se play an important role in the metabolic and physiological activities of mangroves depending on their concentration (Bhardwaj et al. 2017; Mariam and Alamgir 2020). On the other hand, heavy metals such As, Ag, Hg, Cd, and Pb do not have biological relevance and are harmful at concentrations exceeding the threshold (Almahasheer et al. 2018). Concentrations of heavy metals that exceed standards can poison the aquatic environment and inhibit the growth and development of mangroves (Rezaei et al. 2021). Naturally, mangroves have the ability to store metals, remove them from sediments, and translocate them in roots, stems, and leaves (Thanh-Nho et al. 2019; Khan and Aljahdali 2022). Mangroves remove metals through sorption, cation exchange, filtration, and chemical changes through root accumulation processes (Razif and Farhan 2017; Yap and Al-Mutairi 2023). Mangrove roots have a function in attenuating toxic effects through dilution by storing water to dilute the concentration of heavy metals in their body tissues to reduce toxicity in heavy metals (Hanarisanty and Titah 2019; Purwaningdyah and Takarina 2020). Moreover, mangrove roots also have major and trace elements, which are part of the natural biogeochemical cycle (Ray et al. 2021). The major elements as macro nutrients such as Ca, Mg, N, P, and K are important for plant development and growth (Savarino et al. 2021). Meanwhile, trace elements/micro-nutrients like Cu, Mn, Fe, Ni, Co, Zn, and Mo also play a role in the growth and development of mangroves within concentrations that do not exceed the threshold. However, there is also a group of trace elements that are non-essential and often toxic to plant growth, such as Pb, Cd, Al, and Cr (Bhardwaj et al. 2017; Sreenivasulu et al. 2017).

Several studies have reported the important role of roots in the risk assessment of mangrove ecosystems. The metals detected with the highest concentrations in mangrove roots found in different locations were cu at Asaluyeh: 198 µg/g, Bord khun: 1,756 µg/g, and Mahshahr : 1,617 µg/g (Rezaei et al. 2021). Nazli and Hashim (2010) found Cu and Pb accumulation in the roots and leaves of *Sonneratia caseolaris* (L.) Engl. They concluded that the roots of this species have a high capacity to absorb heavy metals and could be a potential phytoremediation species for heavy metal treatment in Malaysian mangroves. Mangroves *Rhizopora apiculata* Blume, *Ceriops tagal* (Perr.) C.B.Rob., *Bruguiera gymnorhiza* (L.) Lam., *Lumnitzera racemosa* Willd., *Xylocarpus granatum* J.Koenig, *Sonneratia alba* Sm., and *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff. have heavy metal translocation and bioaccumulation factors that show varying trends (Analuddin et al. 2017). Monitoring the ecological risk level from heavy metal pollution is effective for monitoring heavy metal concentrations in the marine environment. Ecological risk is a condition in which the ecological function of an ecosystem is subject to external pressures, thus adversely affecting the health and productivity of coastal ecosystems, especially mangroves (Awuku-sowah et al. 2022; Rodrigues-Filho et al. 2023).

This study aims to assess the environmental risk due to heavy metals Pb, Cu, Zn, and Cd accumulation in mangrove roots and surrounding sediments. This assessment utilizes geochemical approaches such as Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI), which serve to interpret the quality and evaluate the effect of heavy metal pollutants on mangrove and their habitats. The author emphasizes that environmental quality research on mangrove species originating from areas with anthropogenic activities is based on zone and root differences is a form of novelty in this research.

MATERIALS AND METHODS

Study area and sampling

This study was conducted in September 2023. Mangrove roots and sediments were taken at three observation stations with the purposive sampling method in the Payung Island mangrove ecosystem, Banyuasin District, South Sumatra, Indonesia, namely: St.1 (2°21'42.55"S, 104°54'59.31"E), St.2 (2°21'48.74"S, 104°54'57.19"E), and St.3 (2°22'53.25"S, 104°55'3.39"E) (Figure 1). Coastal ecosystems are associated with anthropogenic activities such as ports, ship transportation, fisheries, agriculture, and other industrial activities that potentially produce waste and pollutants (Fitria et al. 2023; Rozirwan et al. 2023b). Pollutants that accumulate in coastal areas will have an impact on biota that causes damage and even death to an ecosystem if they exceed the tolerance threshold (Rozirwan et al. 2023c).

Sample handling: Samples were stored in ice boxes and wrapped in zip-lock plastic bags to prevent contamination of mangrove root and sediment. Samples were transported to the Marine Bioecology Laboratory at the Faculty of Mathematics and Natural Sciences, Sriwijaya University. Quantitative analysis of heavy metal concentrations was carried out at the Environmental Agency Laboratory, South Sumatra Province, Indonesia.

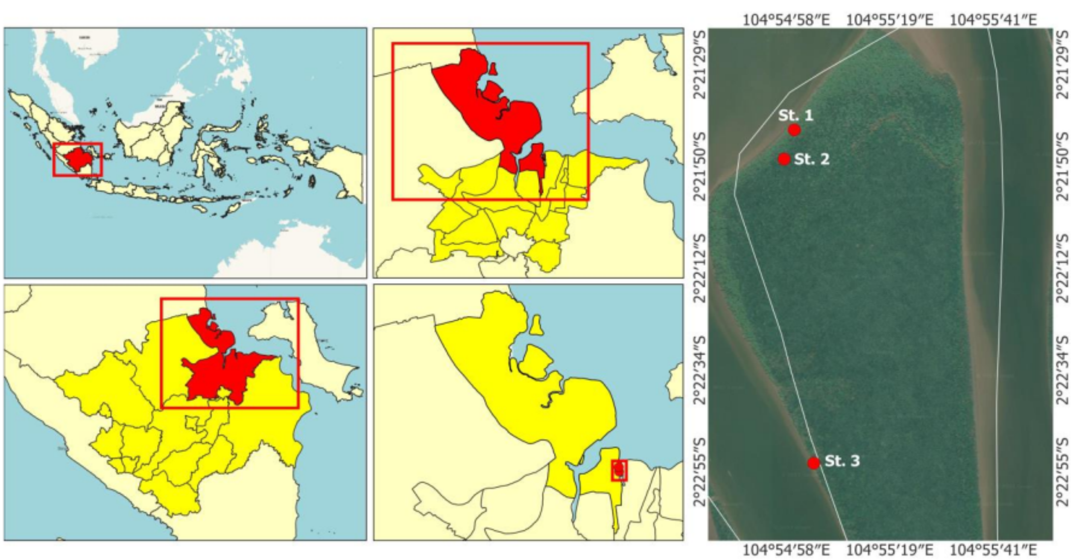

Figure 1. Map of sampling locations in Payung Island mangrove ecosystem, Banyuasin District, South Sumatra, Indonesia

Procedures

The destruction of mangrove roots was carried out by wet destruction to determine heavy metal elements (Nguyen et al. 2020a). The sample that has been weighed is put into an Erlenmeyer, and HNO_3 (5-10 mL) and H_2O_2 (2 mL) are added. Digestion is carried out by setting up a hotplate at 120°C. The digests were transferred to 50-mL vials with ultra-distilled water and stored in polyethylene containers at room temperature until further measurement. The sediment sample was prepared by cleaning it from foreign objects, drying it in an electric oven at 60°C for 30 minutes, grinding it into powder until it had fine particles, and storing it in a polyethylene bottle (Smeds et al. 2022). Next, the root samples were cleaned and crushed using a pestle mortar (Rapi et al. 2020). Destruction carried out using wet destruction refers to (Gao et al. 2021; Rizk et al. 2022). Put 50 mL of the water sample into the Erlenmeyer and add 5 mL of HNO_3, then heat it with a C-MAG HS 7 hotplate stirrer until the water sample reaches 15-20 mL. Furthermore, the sediment is destroyed by acid by weighing ±3 g of sample into the Erlenmeyer and adding 25 mL of distilled water to be heated on a hotplate at a temperature of 105°C-120°C. Mix 5 mL of HNO_3 and wait until the volume reaches 10 mL. Once removed and cooled, add 5 mL HNO_3 and 1 mL-3 mL $HClO_4$. The sample was heated again until white smoke appeared and was clear, followed by heating for 30 minutes. After cooling, it was filtered using quantitative filter paper with a pore size of 8.0 μm. Finally, measure Pb, Cu, Zn, and Cd concentrations using an atomic absorption spectrophotometer (Zhong et al. 2016; Susilowati et al. 2022).

Ecological risk assessment

There are calculations of the Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI) (Hakanson 1980). Heavy metal concentrations in sediments guided by Sediment Quality Guidelines (SQGs), which include Threshold Effect Level (TEL), Probable Effect Level (PEL), Low Effect Range (ERL), Severe Effect Level (SEL), Moderate Effect Range (ERM), and Lowest Effect Level (LEL), were applied to evaluate the possible biotic influence of metals estimated in sediment samples (Long and MacDonald 1998; Rahman et al. 2022).

Bioconcentration Factor (BCF)

Metal absorption by roots from sediments occurs through a process known as bioaccumulation. The BCF value determines metal bioaccumulation in mangrove roots from sediments (Almahasheer 2019). The formula is as follow: BCF = (Concentration of root)/(Concentration of sediment). BCF <1 implies that roots are an excluder; BCF = 1 implies that roots are an indicator; and BCF >1 implies that roots are a hyperaccumulator.

Geoacumulation index (I_{geo})

Igeo quantitatively evaluates the extent of heavy metal contamination and assigns pollution levels according to the classification criteria (Zhang et al. 2021; Xie et al. 2022). The formula of Igeo = $\log_2$((Concentration heavy metals in sediment)/(1,5.Background)). Igeo value criteria: Igeo<0 = not polluted; 0< I geo <1 = slightly polluted; 1< Igeo <2 = moderately polluted; 2< Igeo <3 = severely polluted; 3< I geo <4 = severely polluted; 4< Igeo <5 = extremely polluted; Igeo >5 = extremely severely polluted (Muller 1979; Xie et al. 2022).

Contamination factor (Cf)

A contamination factor is a condition in which something is polluted by another element with a certain effect (Antoniadis et al. 2019). The formula of Cf = (Concentration of heavy metals in sediment)/Background. Contamination Factor criteria according to (Shaheen et al. 2017): Cf< 1= low level of contamination; 1< Cf <3 = medium level of contamination; 3< Cf <6 = enough level of contamination; Cf> 6 = contamination level is very high.

Pollution Load Index (PLI)

The pollution load index is used to determine the quality of pollution. The pollution load index value uses the formula (Shaheen et al. 2019; Singh et al. 2020). The formula of Pollution Load Index (PLI) = $[Cf1 \times Cf2 \times Cf3 .... \times Cfn]^{1/n}$. Criteria for Pollution Load Index (PLI): PLI<0 = not polluted; PLI 0-2 = not polluted to slightly polluted; PLI 2-4 = moderately polluted; PLI 4-6 = severely polluted; PLI 6-8 = severely polluted; PLI 8-10 = extremely pollute.

Quality standards and recovery values

Quality standards for the heavy metals Pb, Cu, Zn, and Cd 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.

Data 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 Tukey test if the conditions were met (Carricavur et al. 2018; Rozirwan et al. 2023c). The level of significance was $p < 0.05$. All statistical analyses were performed using the IBM SPSS V.26 application.

Table 1. Quality standards (mg/kg)

Sample	Pb	Cu	Zn	Cd	References
Sediment	50	65	50	0.8	(ANZECC/ARMCANZ 2000)
Plant	2	10	0.60	0.02	WHO (1996) in (Ogundele et al. 2015)

Table 2. Recovery values (Ağca and Özdel 2014)

Metals	Recovery (%)
Pb	75.8
Cu	92.4
Zn	78.6
Cd	68.9

RESULTS AND DISCUSSION

Description of mangrove roots

The mangrove species found in the field were *Sonneratia caseolaris* (L.) Engl., *Rhizopora apiculata* Blume, and *Xylocarpus granatum* J.Koenig (Figure 2). In general, these three species have different root morphologies.

Based on the results, mangrove species have different root systems that adjust to their habitat. The roots found in *S. caseolaris* were breathing roots (vertical cone-shaped), *R. apiculata* were aerial roots, and *X. granatum* were plank roots.

Determination of heavy metals in sediment and mangrove root

The results of the concentrations of heavy metal elements Pb, Cu, Zn, and Cd in sediment and mangrove roots collected from all stations are summarized in Table 3. Station three (sediment) had the highest concentrations for Pb of 12.786±0.26 mg/kg, Cu was 10.405±0.011 mg/kg, Zn was 42.752±0.05mg/kg, and Cd (not detected). While in mangrove roots, the highest heavy metal concentration was in *S. caseolaris* for Pb was 2.596±0.002 and Zn was 11.881±0.015, while for Cu and Cd it was highest in *X. granatum* at 8.850±0.011 and 0.160±0.020. A comparative reference of heavy metal concentrations in roots with different species and locations is summarized in Table 4.

Based on the heavy metal concentration results (Table 1), the differences in each species statistically analyzed using ANOVA and post hoc Tukey (P <0.05) showed that each species was significantly different. Sediment heavy metal concentrations in this study were still below the quality standards set by Sediment Quality Guidelines (SQGs) (Batley and Simpson 2013). Mangrove root heavy metal concentrations varied with habitat conditions, zonation, and root species.

Ecological risk assessments of heavy metals concentration

The results of the ecological risk assessment of heavy metal pollution in mangrove roots and surrounding sediments are summarized in Figure 3. Overall, the Bioconcentration Factor (BCF) results of roots in bioaccumulating soil metals were exclusionary for all heavy metals: Pb (0.3535, 0.1504, 0.0402), Cu (0.8091, 0.2011, 0.8506), and Zn (0.2931, 0.1419, 0.0920). The geoaccumulation index showed uncontaminated properties for Pb (-1.3523, -1.0731, -0.5523), Cu (-3.6120, -3.4205, -2.9871), and Zn (-1.3732, -1.4566, -0.5523). 1,2963). The Contamination Factor (Cf) showed that the contamination was low and medium in Pb (0.5876, 0.7130, 1.0229), Cu (0.1227, 0.1401, 0.1892), and Zn (0.5790, 0.5465, 0.6107). The PLI ranges from 0.3856 - 0.5269, indicating that the pollution quality at the three stations and species points is not polluted.

Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI) were calculated for heavy metals Pb, Cu, and Zn which showed no decrease in BCF < 1, Igeo < 0, CF < 1, and PLI < 1). Meanwhile, the ecological risk assessment was not carried out for the heavy metal Cd because it was not detected in the sediment at each station; it was only detected in the roots of *X. granatum*. An evaluation of the ecological risk assessment of sediment pollution needs to be carried out to understand the extent to which the sediment can affect plant health.

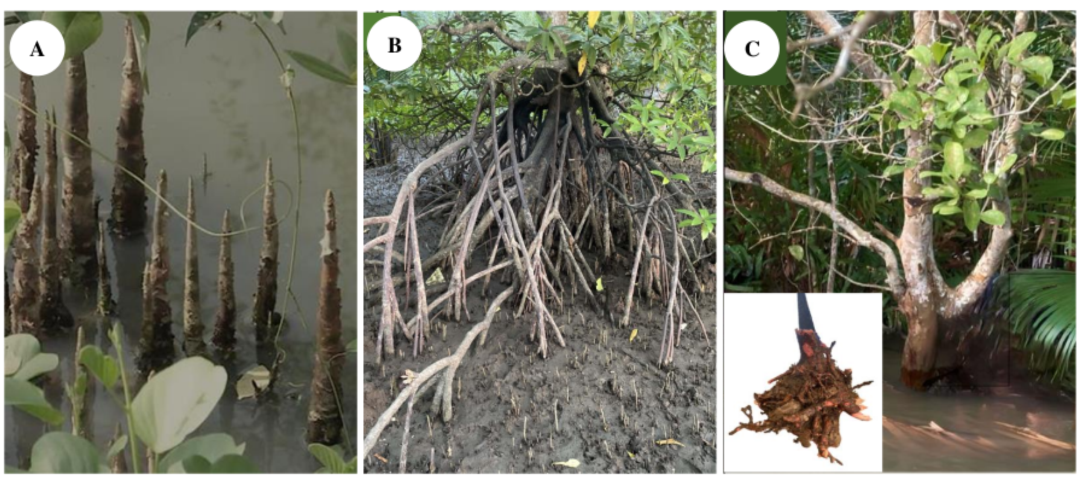

Figure 2. Morphology of mangrove roots. A. *Sonneratia caseolaris*, B. *Rhizopora apiculata*, C. *Xylocarpus granatum*

Table 3. Variation of average heavy metal concentrations (mg/kg) in mangrove sediments and roots

	Pb	Cu	Zn	Cd
Sediments				
St.1	7.344±0.20*	6.747±0.012*	40.533±0.13*	nd
St.2	8.912±0.08*	7.705±0.008*	38.256±0.03*	nd
St.3	12.786±0.26*	10.405±0.011*	42.752±0.05*	nd
ERL	46.7	34	150	1.2
ERM	218	270	410	9.6
TEL	30.2	18.7	124	0.68
PEL	112	108.2	271	4.2
Mangrove roots				
S. caseolaris (St.1)	2.596±0.002*	5.459±0.030*	11.881±0.015*	nd
R. apiculata (St.2)	1.340±0.075*	1.532±0.016*	5.428±0.004*	nd
X. granatum (St.3)	0.514±0.129*	8.850±0.011*	3.933±0.010*	0.160±0.020
F Table	19,33	19.33	19.33	
F Value	444.114	94856.92	496580.302	

Note: nd: Not detected, *The mean difference is significant at the 0.05 level

Table 4. Comparison of heavy metal concentrations associated with various mangrove roots

Species	Heavy metals	Reference
R. apiculata	Cr (0.26 - 11.69 mg/kg), Cu (0.21-8.17 mg/kg), Ni (0.11 - 854 mg/kg)	(Nguyen et al. 2020b)
Sonneratia apetala & *Avicennia officinalis*	Cu (25.89 mg/kg), Fe (1376.7 mg/kg), Cr (2.85 mg/kg)	(Chowdhury et al. 2017)
Lumnitzera racemosa	Cu (83.85μgg^{-1}) and Hg (0.52μgg^{-1})	(Analuddin et al. 2017)
Bruguiera gymnorrhiza	Cd (10.81μgg^{-1})	
Bruguiera parviflora	Zn (70.41μgg^{-1})	
Ceriops tagal	Pb (1.36μgg^{-1})	
E.agallocha > A.officinalis > S.apetala	Fe (737.37±153.06) > Mn (151.13±34.26) > Sr (20.98±6.97) > Cu (16.12±4.34) > Zn (11.3±2.39) mg/kg	(Hossain et al. 2022)
Phoenix paludosa	Cu, Mn, Zn, Ni, Fe, Cr, Cd and Pb (162.2, 563.3, 289.1, 228.8, 31,524.3, 475.5, 8.5 and 256.8 mg/kg)	(Kumar et al. 2021)
Avicennia marina	Cd, Ca, Zn, Cr, Al (0.24, 18234, 14.4, 7.24 and 1982 μg/g)	(Salimi et al. 2019)
Avicennia marina	Cu (200 μg/g)	(MacFarlane et al. 2003)
A.marina, R. mucronata, S. caseolaris	Zn (18.08-54.64 mg/kg, 9.75-54.75 mg/kg, and 19.58-33.33 mg/kg) Cu (0.33-0.89 mg/kg, 0.2-54.75 mg/kg and 0.4-0.99 mg/kg)	(Takarina 2020)
Rhizophora racemosa	Pb (1.34 mg/g), Cu (0.08 mg/g), and Cd (0.04 mg/g)	(Eribo et al. 2021)
Avicennia marina	Cu (153 mg/kg), Pb (189 mg/kg), Zn (378 mg/kg), Ar (16 mg/kg), Cr (21 mg/kg), Ni (11 mg/kg)	(Chaudhuri et al. 2014)

Discussion

The habitat of the three mangrove species *S. caseolaris, R. apiculata*, and *X. granatum,* are found on characteristic muddy substrates that are influenced by environmental factors. For example, physicochemical factors: temperature, salinity, DO, pH, currents, tides, and waves (Rozirwan et al. 2023d). According to Saputra et al. (2021), the substrate tends to be muddy in the leading zone of the mangrove ecosystem. Mangrove roots closely associated with sediment to bind and retain heavy metals from their surrounding environment. Differences in the morphology of roots can influence the plant's ability to absorb and accumulate heavy metals in its tissues (Hu et al. 2023). Roots that are broader or deeper may have a greater capacity to absorb heavy metals (DalCorso et al. 2019). Longer or more branched roots can reach a wider soil area and penetrate deeper layers where heavy metals may be concentrated (Audah et al. 2022). *Sonneratia caseolaris* is a pioneer species in mangrove ecosystem found in the leading zone. The roots are cone-like vertical breath (up to 1 m high) that are numerous and very strong. *Sonneratia caseolaris* has four types of roots: cable, pneumatophores, feeding, and anchor. In addition, the roots of *S. caseolaris* also have root periderms that play an important role in salt exclusion, and the appearance of tanniferous cells is related to salt elimination (Tatongjai et al. 2021).

Rhizopora apiculata has characteristic rooting that reaches up to 5 meters in height and sometimes has aerial roots from the branches. Prop roots and stilt roots (lateral roots from the base of the stem often curving downward to meet the substrate) are mainly seen in *R. apiculata* (Shamin-Shazwan et al. 2021). One of the characteristics of *R. apiculata* is that it has structures that protrude in various directions around its trunk to the ground, which are specialized branches with positive geotropism that form a large number of roots when in contact with the soil (De

Oliveira et al. 2021). *Xylocarpus granatum* has plank roots that extend laterally, twisting and forming cleavages. The stem has buttresses and above-ground roots extending far on either side. Buttress or buttress roots (laterally or vertically compressed and flattened board-like roots near the trunk) (Dey et al. 2021).

Concentrations of heavy metals Pb, Cu, Zn, and Cd (detected in *X. granatum* roots) in sediment were higher than in mangrove roots. This shows that mangrove roots are effective in preventing the entry of heavy metals into the upper parts of the plant (Guo et al. 2023), even though the metal concentration in the roots exceeds the threshold specified in *S. caseolaris* for Pb >2 mg/kg, Zn in each species >0.60 mg/kg, Cd in *X. granatum* >0.02 mg/kg, and for Cu each species does not exceed the specified threshold. Mangrove sediments have great potential to absorb heavy metals in the long term, with the characteristics of being anaerobic, reduced, rich in organic matter, and a fine substrate. The finer the sediment, the higher its strength in binding heavy metals, so roots do not absorb more heavy metal concentrations (Briffa et al. 2020). In addition, mangrove roots are able to release oxygen to avoid the toxic effects of anaerobic conditions on sediments (Castro et al. 2022). In line with the opinion of Lin et al. (2021), submerged roots in the sediment will differ from some types of roots that grow outside the sediment surface. Differences in root types will also affect the concentration of heavy metals in mangrove tissue (Rezaei et al. 2021; Hossain et al. 2022). The plank root of *X. granatum* has the lowest heavy metal concentration compared to the breath root of *S. caseolaris* and the aerial root of *R. apiculata*. Plank roots under the surface sediment are able to store a lot of water to dilute the concentration of heavy metals in their body tissues, thereby reducing the toxicity of these metals (Dhalaria et al. 2020; Huang et al. 2020). In this study, *X. granatum* was found in the upper zone, periodically submerged by coastal tides. Mangrove efficiently retain heavy metals within the root system and may significantly reduce their translocation to other parts (Yan et al. 2017). According to Mathivanan et al. (2021), possible coping mechanisms include localization, excretion, and dilution to weaken the toxic effects of these heavy metals. These mangrove root's ability to defend themselves againts environmental pressure can reduce negative impacts on the ecosystem (Sunkur et al. 2023). Variations in the accumulation of specific metals depend on their respective physiological rhythms and the ecological conditions of the environment they inhabit (Kumar et al. 2021). Since roots are the first tissue to be exposed to excess heavy metal content excess in the soil, toxic symptoms due to excessive heavy metal exposure are more common in roots than in other tissues (Zhang et al. 2019).

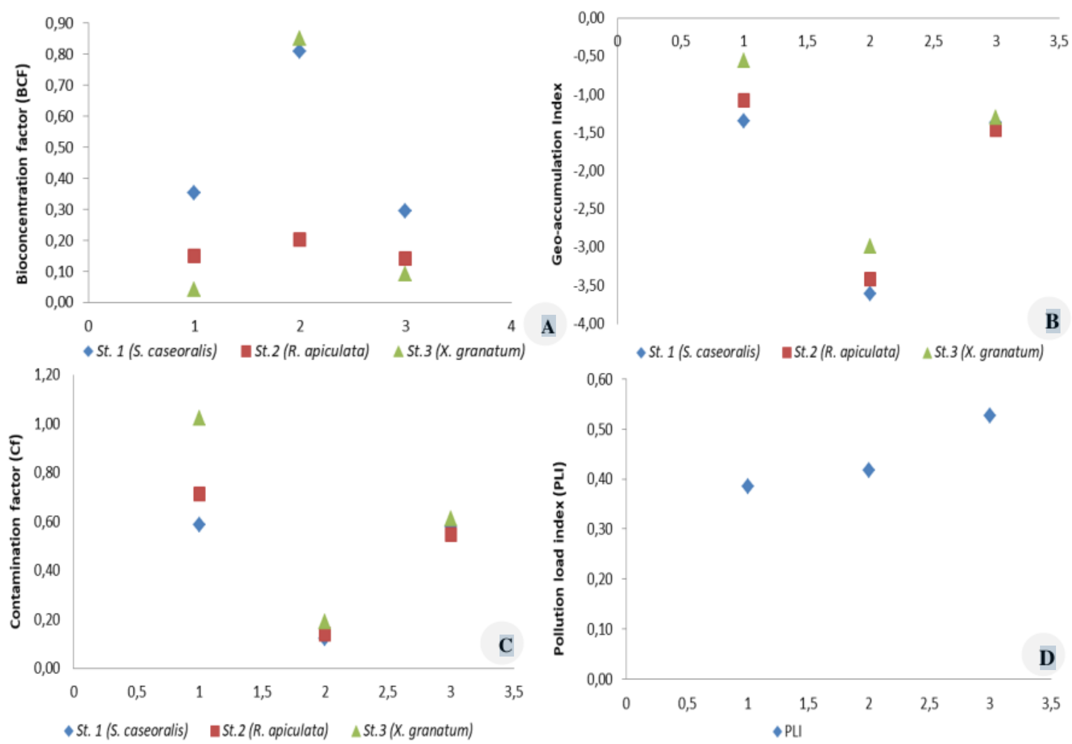

Figure 3. (A-D) Pollution indices. A. Bioconcentration Factor (BCF), B. Geo-accumulation Index (Igeo), C. Contamination Factor (Cf), and D. Pollution Load Index (PLI)

Mangrove ecosystems located in coastal areas have the potential to be exposed to pollutants, especially heavy metals, because of their function both ecologically and socio-economically for the community. Based on Figure 3 for bioconcentration factor (Bcf) <1 for all heavy metals caused by the ability of mangrove roots to detoxify metals by exclusion mechanism (Aljahdali and Alhassan 2020). In line with the opinion of Bakshi et al. (2017), the ability of plants to bioaccumulate metals and other pollutants from sediments can be evaluated using the bioconcentration factor between the total concentration of metals in plants and the concentration in sediments. The Igeo values observed in this study indicate that the Payung Island mangrove ecosystem sediments are not contaminated (Igeo <0). Geo-accumulation Index values can be efficiently applied to determine sediment quality (Singh et al. 2020). Different metals in sediments may be due to the increased particulate water with relatively unpolluted sediments combinations (Li et al. 2022; Shi et al. 2022). The study's Contamination factor (Cf) shows that each metal causes low contamination, except for the heavy metal Pb, which is included in moderate contamination. In line with the findings of Rezaei et al. (2021) contamination showed of heavy metal accumulation in sediments in the north of the Persian Gulf, but this is associated with gas and petrochemical activities, which can be considered a potential source of heavy metal release into the aquatic environment. PLI can be used to characterize or establish conclusions about the pollution status of the ecosystem (Jiang et al. 2020; Hummel et al. 2021). PLI values of sediments collected from mangrove ecosystems are classified as unpolluted to slightly polluted (PLI = 0-2). The highest Pollution Load Index (PLI) value is at station 3 (*X. granatum*), which is higher because this station is directly opposite Sungsang Village, which is an area filled with fishing activities and household waste such as detergent, soap, and organic/inorganic waste (Rozirwan et al. 2022). Apart from that, station 3 is located in the estuary area of a consequent river (the flow is in the same direction as the slope). In contrast, stations 1 and 2 are located in the open river estuary, which is directly connected to the Bangka Strait, which has an inconsistent nature (irregular flow) caused by high currents and waves, so the heavy metals concentrations in both the water and sediment is dynamic (Rozirwan et al. 2021). This factor have a significant impact on the water content of various environments (Rozirwan et al. 2019; Ramses et al. 2020). This could be a result of the dense activities around the area, ranging from fisheries, boat transportation, and household waste (Rozirwan et al. 2024). These findings are align by Pejman et al. (2015) study conducted in Northwest sediments from the Persian Gulf. The results showed sediment contamination (PLI<1) associated with wastewater discharge activities from the area's petrochemical industry and tanker leachate.

In conclusion, the total concentrations of Pb, Cu, Zn, and Cd (only detected in *X. granatum* roots) evaluated statistically had significant differences (p<0) at each sediment station and mangrove root species. Furthermore, Pb, Cu, Zn, and Cd (not detected) concentrations in soil were still below the quality standards. While for *S. caseolaris* Pb >2 mg/kg, Zn for each species >0.60 mg/kg, Cd for *X. granatum* >0.02 mg/kg, and Cu for each species do not exceed the specified threshold. The environmental risk assessment of Pb, Cu, and Zn metals in mangrove sediments and roots was also assessed based on bioconcentration factors, geoaccumulation index, pollution factors, and ecological risk assessment. Except for Cd, because it was only detected in the roots of *X. granatum*, whereas the ecological risk assessment found a link between sediment as a growth medium and the plant. The heavy metals Pb, Cu, and Zn were observed not to accumulate in mangrove roots due to their low concentrations in the sediment, so they do not pose a significant ecological risk.

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