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Original article

Bioconcentration Factor (BCF) of Lead (Pb) and Copper (Cu) in Mangrove Roots as an Indicator of Heavy Metal Accumulation

Dina Deartha Vansari Damanik[1]*, I Ketut Ginantra[1], I Made Sara Wijana[1], Made Ria Defiani[1], Luh Putu Eswaryanti Kusuma Yuni[1], Ni Luh Watiniasi[1]

[1] Udayana University, Denpasar 80234, Indonesia

Abstract

Mangrove ecosystems play a crucial role in trapping, storing, and accumulating heavy metals from surrounding waters and sediments, making them important bioindicators for environmental monitoring and conservation in coastal areas. Heavy metals such as Lead (Pb) and Copper (Cu) can accumulate in mangrove tissues, and their distribution between plant organs and sediments can be evaluated through the Bioconcentration Factor (BCF). This study aimed to assess the BCF values of Pb and Cu in mangrove roots and sediments in the Mangrove Tahura Ngurah Rai, Bali. Sampling was conducted using a purposive random sampling method at several stations representing different mangrove zones. Sediment and root samples from four mangrove species*Rhizophoraapiculata*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, and *Sonneratia alba*were collected during low tide. Heavy metal concentrations were measured using *Atomic Absorption Spectrophotometry* (AAS). The BCF values were calculated as the ratio between the concentration of heavy metals in roots and those in sediments. The results showed that all species had BCF values < 1, classifying them as excluders. The highest Pb BCF value was 1.00 in *Rhizophora mucronata* and the highest Cu BCF value was 1.13 in *Rhizophoraapiculata*. Mean Pb BCF values were higher than Cu in all species, with *Rhizophora apiculata* (0.65±0.22) and *Rhizophora mucronata* (0.64±0.33) exhibiting greater accumulation potential than *Bruguiera gymnorrhiza* and *Sonneratia alba*. Variations in BCF values were influenced by root morphology, zonation, and ion uptake ability. These findings highlight the superior potential of *Rhizophoraapiculata* and *Rhizophora mucronata* for heavy metal uptake, underscoring their role in mangrove-based phytoremediation and coastal environmental conservation.

Keywords: bioconcentration factor, Cu, heavy metal, mangrove Tahura Ngurah Rai, Pb

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Introduction

Heavy metals are one of the most hazardous pollutants in aquatic environments due to their toxic nature, persistence, and tendency to accumulate through the food chain (Zhao *et al.*, 2013). As the trophic level of organisms increases, the concentration of heavy metals in their bodies also increases, a process known as biomagnification (Suryono & Indardjo, 2023). Heavy metals entering aquatic systems may settle in sediments, becoming a major source of exposure for benthic organisms. Anthropogenic activities such as industry, transportation, households, and shipping are the main contributors to the increasing concentration of heavy metals in aquatic environments (Aljahdali & Alhassan, 2020).

Lead (Pb) and Copper (Cu) are among the most commonly detected heavy metals in polluted aquatic environments. Pb commonly originates from transportation activities and fuel emissions, while Cu is frequently associated with boating, industrial discharges, and coastal anthropogenic inputs (Indrawan & Putra, 2021, Mbaba *et al.*, 2024). Both metals can disrupt physiology, growth, and the abundance of aquatic organisms (Suryono & Indardjo, 2023).

Mangrove ecosystems play an important role in absorbing, retaining, and stabilizing pollutants, including heavy metals. Mangroves can take up heavy metals through their root system and accumulate them within their tissues. Heavy metal accumulation such as Cu and Zn in mangroves reduces chlorophyll-a and chlorophyll-b. This also lowers carbon assimilation. These changes show that photosynthesis is disrupted. Antiradical activity also decreases, which indicates higher oxidative stress and possible tissue damage (D'Addazio *et al.*, 2023). For this reason, mangroves are often used both as bioindicators and natural biofilters for heavy metal contamination in coastal environments (Marissa, 2020).

One of the key parameters to evaluate the ability of organisms or plants to absorb heavy metals from their environment is the Bio-Concentration Factor (BCF). BCF is defined as the ratio of the heavy metal concentration in the organism's tissue to its concentration in the surrounding medium (water or sediment). A high BCF value indicates that the organism has a strong bioaccumulation capacity, which can be used to assess both the potential ecological risks of contamination and the effectiveness of the organism as an agent for phytoremediation.

Ngurah Rai Grand Forest Park (Tahura Ngurah Rai) in Bali is one of the most important mangrove ecosystems, located in an area with high anthropogenic pressure. The site receives pollutant inputs from various activities, including household waste, industrial discharge, transportation, and river flows discharging into the mangrove area (Febriyanto *et al.*, 2022). Studies on heavy metals in Tahura Ngurah Rai have been conducted before. Mbaba *et al.* (2024) examined the phytoremediation

* Corresponding Author:
Dina Deartha Vansari Damanik
Udayana University, Denpasar 80234, Indonesia
Phone: 085270752239
E-mail: dinadeartha@gmail.com

ability of *Rhizophora apiculata* and *Sonneratia alba* for Pb and Cu. Indrawan and Putra (2021) also studied heavy metal concentrations in water and sediment in the Serangan waters. However, research on the relationship between heavy metal concentrations in sediments and their accumulation in mangrove vegetation in the context of BCF remains very limited. Therefore, investigating the Bio-Concentration Factor (BCF) of heavy metals in mangrove ecosystems at Tahura Ngurah Rai is essential to understand the extent to which mangroves accumulate heavy metals from their environment. The findings of such research are expected to provide scientific insights into the level of heavy metal pollution in the coastal area while reinforcing the ecological function of mangroves as natural biofilters that safeguard the stability of Bali's coastal ecosystems.

Methods

Time and Location

The research was carried out for four months, from March 17th to June 29th, in the mangrove ecosystem in Tahura Ngurah Rai, Bali (Figure 1). The sample testing and analysis of the research results were performed at the Balai Pengujian Standar Instrumen Lingkungan Pertanian, West Java.

Sampling Method

This research was conducted in the mangrove ecosystem of Tahura Ngurah Rai, Bali. The sampling points were determined using a purposive sampling method (Razi *et al.*, 2023). Samples of mangrove roots and sediments were collected from eight stations distributed across the mangrove ecosystem of Tahura Ngurah Rai, namely Nusa Dua, Kampung Kepiting, Jimbaran, Pemogan, Serangan, and Suwung (as shown in Figure 1). Each station represented one sampling point. The selection of these eight stations was based on their vicinity to potential pollution sources. Nusa Dua was chosen due to its adjacency to tourism and industrial activities, while Jimbaran was selected for its spatial relation to household activities. Kampung Kepiting and Pemogan were located near fishing and community activities. Serangan was adjacent to the harbor and situated opposite the landfill site, while Suwung was influenced by shipping activities. The last sampling point was located near Jl. By-pass Ngurah Rai, which is directly adjacent to the highway and close to the downstream areas of Tukad Mati and Tukad Badung rivers (as shown in Figure 2).

Sample Preparation for AAS Analysis

Sediment

Sediment samples were collected beneath mangrove species where root samples were taken. Sampling was carried out using a PVC pipe (50–100 cm length, ±10 cm diameter) inserted vertically to a depth of 50 cm. Approximately 300 g of wet sediment was obtained in a single collection and stored in labeled plastic bags before being transported to the laboratory. Root samples were collected from tree-level mangroves (diameter >4 cm, height >2 m). Sampling followed the root type of each


Sites 1 (-8.7905, 115.2199)


Sites 2 (-8.7789, 115.1797)


Sites 3 (-8.7439, 115.1835)


Sites 4 (-8.7208, 115.2019)


Sites 5 (-8.7154, 115.2231)


Sites 6 (-8.7116, 115.2350)


Sites 7 (-8.7219, 115.2241)


Sites 8 (-8.7184, 115.2335)

Fig. 1. Eight sampling points distributed across the Tahura Ngurah Rai area

species: stilt roots for Rhizophora (basal part 3–5 cm above sediment), pneumatophores for Sonneratia and Avicennia (from within sediment to just above the surface), and knee roots for *Bruguiera gymnorrhiza* (bent section extending into sediment). Root fragments (1–10 cm) were cut with a cutter and stored in labeled plastic.

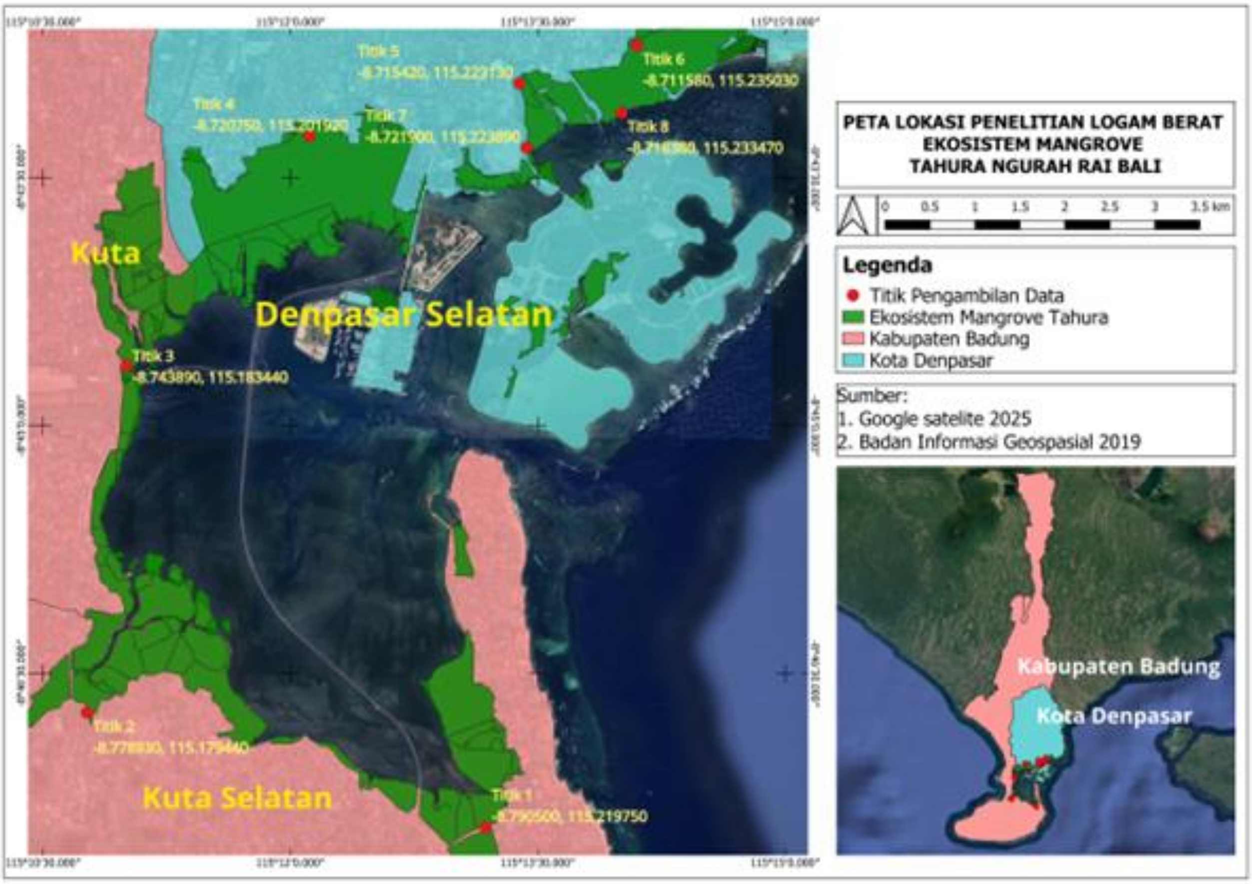

Fig. 2. Research Map of Heavy Metals in the Mangrove Area of Tahura Ngurah Rai

Roots

Root samples were cut into small pieces, oven-dried at 60°C for 3–4 days, and ground into powder. A total of 5 g of root powder was ashed in a furnace at 550°C for 4 h, then digested in 30 ml of demineralized water and 10 ml HNO_3. The solution was boiled for 10 min, cooled, filtered, and diluted to 50 ml with demineralized water before being vortexed and transferred into sample bottles. Sediment samples (30 ml wet sediment) were mixed with 10 ml demineralized water and 10 ml HNO_3, boiled for 10 min, cooled, filtered, and diluted to 50 ml with demineralized water. The solutions were vortexed for 1 min, stored in sample bottles, and analyzed using Atomic Absorption Spectrophotometry (AAS).

Data Analysis

The bioconcentration factor is an indicator used to determine the ability of mangroves to accumulate heavy metals from sediments, calculated using the following formula, (Purnamawat *et al.*, 2015).

$$\text{BCF} : C_{roots}/C_{sediment}$$

Description:
BCF : Bio-concentration Factor
Croots : Heavy metal concentrations in roots
Csediment: Heavy metal concentrations in sediment

BCF values are grouped into four categories (Purnamawat *et al.*, 2015).

a. BCF ≥ 1000 is hyperaccumulator
b. BCF > 1 is accumulator
c. BCF < 1 is excluder
d. BCF = 1 is indicator

Results

Heavy metal concentrations in Sediments and Roots

The laboratory analysis revealed that Pb concentrations in sediments ranged from 8.55 to 18.88 mg/kg, while Cu concentrations ranged from 18.07 to 50.18 mg/kg. In mangrove roots, Pb concentrations ranged between 5.84 and 8.97 mg/kg, whereas Cu concentrations ranged from 8.68 to 20.96 mg/kg (Table 1). The highest concentration of Pb in sediments was recorded at station 8, dominated by *Rhizophora apiculata*, with a value of 18.88 mg/kg. At this site, Pb concentrations in roots were 7.84 mg/kg for *Rhizophora apiculata* and 5.84 mg/kg for *Sonneratia alba*. The lowest sediment Pb concentration (8.55 mg/kg) was observed at station 7, where both *Rhizophora apiculata* and *Rhizophora mucronata* were present. At this location, Pb concentrations in roots were 8.97 mg/kg in *Rhizophora apiculata* and 8.59 mg/kg in *Rhizophora mucronate* (Table 2).

For Cu, the highest sediment concentration (50.18 mg/kg) occurred at station 2, where *Bruguiera gymnorrhiza* was found, with a root Cu concentration of 18.77 mg/kg. The lowest Cu concentration in sediments (18.07

Table 1. Measurement of BCF of Lead (Pb) and Copper (Cu) (Values are presented as mean ± SD.)

Species of Mangrove	BCF		Category
	Pb	Cu	
Sonneratia alba	0,42±0,03	0,34±0,04	ekskluder
Rhizophora mucronata	0,64±0,33	0,40±0,209	ekskluder
Rhizophora apiculata	0,65±0,22	0,58±0,38	ekskluder
Bruguiera gymnorrhiza	0,52±0,08	0,34±0,15	ekskluder

Table 2. Water Temperature, pH, and Salinity Values at the Study Sites

No	Parameter	Unit	Sampling Points								Water Quality Standard*
			1	2	3	4	5	6	7	8	
1	Temperature	°C	29	27.6	25	25.3	28.3	25.8	28.1	28.1	28-32
2	pH	-	7.97	7.35	7.40	7.59	6.96	7.73	7.03	7.78	7 – 8,5
3	Salinity	ppt	28.9	32.2	31	28	28.6	28.9	28	31.2	s/d 34

(*= Seawater quality standards based on the Indonesian Minister of Environment Decree No. 51 of 2004)

mg/kg) was observed at station 3, which supported three species: *Rhizophora apiculata*, *Sonneratia alba*, and *Rhizophora mucronata*. Root Cu concentrations at this site were 20.39 mg/kg in *Rhizophora apiculata*, 12.75 mg/kg in *Sonneratia alba*, and 8.68 mg/kg in *Rhizophora mucronate*.

Bioconcentration Factor (BCF) of Pb and Cu

The bioconcentration factor (BCF) values for heavy metals varied among the mangrove species. The highest BCF for Pb (1.00) was recorded in *Rhizophora mucronata*, while the highest BCF for Cu (1.13) was observed in *Rhizophora apiculata*. Overall, Pb showed higher maximum BCF values than Cu across species.

For mean BCF values, *Rhizophora apiculata* exhibited the highest mean Pb BCF (0.65 ± 0.22), followed closely by *Rhizophora mucronata* (0.64 ± 0.33). Lower mean Pb BCF values were observed in *Sonneratia alba* (0.42 ± 0.03) and *Bruguiera gymnorrhiza* (0.52 ± 0.08). A similar pattern was observed for Cu, in which *Rhizophora apiculata* had the highest mean Cu BCF (0.58 ± 0.38), followed by *Rhizophora mucronata* (0.40 ± 0.21), whereas *Sonneratia alba* and *Bruguiera gymnorrhiza* both showed mean values of 0.34 ± 0.15.

Discussion

Heavy metal concentrations in Sediments and Roots

The results show that Pb and Cu were detected in both roots and sediments at all sampling stations, with Cu consistently higher than Pb. Spatial variation was strongly influenced by local pollution sources. Station 1 in Nusa Dua was affected by tourism and water-sport activities, where engine-powered vessels release Cu and Pb from antifouling paints and engine lubricants (Selvinia, 2015, Tang *et al.*, 2022). Station 2 in Jimbaran received input from restaurant wastewater and the flow of Tukad Sema, where liquid waste contains Cu from cooking equipment and Pb from food packaging (Callano, 2014, Faiz *et al.*, 2024, Ozbay *et al.*, 2017). Station 3 in Kampung Kepiting was located deeper inside the mangrove forest, reducing direct interaction with Tukad Mati and enhancing metal deposition within the sediment (Suta *et al.*, 2025). Station 4 in Pemogan was influenced by domestic effluents, household activities, and workshops that contribute heavy-metal contamination (Kardana *et al.*, 2023). Station 5 in Serangan was affected by inputs from the Suwung landfill, shipping activities, and several river mouths (Dimyati *et al.*, 2022, Bighui *et al.*, 2016). Station 6 near the Bypass Ngurah Rai received inputs from furniture industries, plastic recycling centers, hotels, and runoff from Tukad Punggawa (Miranji *et al.*, 2024, Harahap *et al.*, 2020). Station 7, located opposite the Suwung landfill, was influenced by shipyard activities that release Cu and Pb during coating, sanding, and oil disposal (Singh & Turner, 2009). Station 8 at Site Surga in Serangan was affected by intensive boating activities and river discharges from Tukad Ayung, Tukad Punggawa, and Tukad Ranga, where antifouling paints containing Cu and Pb are widely used (Samosir *et al.*, 2023).

Cu in sediments reached its highest value at Station 2 and lowest at Station 3 and was higher than reported in Pekalongan and Madura (Mentari *et al.*, 2022, Ilhami *et al.*, 2024). Elevated Cu at Station 2 reflected domestic wastewater inputs and restaurant activities (Syahminan *et al.*, 2015 in Sari & Purnomo, 2024, Prasetio *et al.*, 2016). The lowest value at Station 3 was associated with its inner-forest position, which promotes stronger filtration and deposition processes (Ma *et al.*, 2021). Pb was highest at Station 8 and lowest at Station 7, with values exceeding those reported by Syafira *et al.* (2023). Higher Pb concentrations at Station 8 were linked to boat activities that release Pb from engine oil and antifouling paints (Hanifah, 2024, Permana *et al.*, 2022). Pb is also widely used globally and ranks among the most common xenobiotic metals (Malekirad *et al.*, 2010, Tuahatu *et al.*, 2022). Sediment Pb is influenced by anthropogenic sources such as domestic waste, fisheries, industry, and agricultural runoff (Matitapuy *et al.*, 2024). Differences between Cu and Pb concentrations were also related to their affinity for sediment organic matter, with Pb showing a lower affinity due to its larger ionic radius and higher polarizability (Hung *et al.*, 2024).

Pb concentrations in roots ranged from 8.54 to 8.97 mg/kg and Cu from 8.68 to 20.96 mg/kg. The highest Pb concentration occurred at Station 7 and the lowest at Station 8 in *Sonneratia alba*, which has a lower metal-uptake capacity due to root structure and limited metalbinding compounds (Mariwy *et al.*, 2024). The proximity of Station 8 to open-ocean boat traffic increased Pb input, consistent with findings that mooring areas often contain elevated Pb from fuel additives and paint particles (Anisyah *et al.*, 2016, Nurfadillah *et al.*, 2020). Cu in roots was highest at Station 4 in *Bruguiera gymnorrhiza*, a known accumulator species (Elfrida *et al.*, 2020), and lowest at Station 3, where exposure to marine inputs was minimal

Overall, sediment contained higher metal concentrations than roots, consistent with Setiawan & Hamzah (2010) and Li *et al.* (2016), indicating that sediments act as the primary sink for heavy metals. Increases in sediment metals were associated with increased concentrations in roots (Hossain *et al.*, 2022), as sediments serve as the main source of dissolved ions absorbed through rhizosphere processes (Nguyen *et al.*, 2020, Ubong & Obunwo, 2018).

Environmental parameters such as pH, salinity, and temperature also influenced Pb and Cu accumulation. Cu remained higher than Pb across all stations because it is more soluble, more mobile, and more efficiently absorbed by plant tissues (Hladun *et al.*, 2015). Cu inputs are further amplified by natural mineral erosion and anthropogenic activities such as wood-processing industries, boating, and vehicle-related pollution (Fonseca *et al.*, 2011, Samosir *et al.*, 2023).

Bio-concentration Factor (BCF) of Pb and Cu

Mangroves possess the capacity to absorb and/or accumulate pollutants such as heavy metals (Aljahdali & Alhassan, 2020). The bioconcentration factor (BCF) is commonly used to indicate a mangrove's ability to accumulate heavy metals (Mahmiah *et al.*, 2023). In this study, BCF was calculated by comparing the concentration of heavy metals in mangrove root tissues to their concentrations in sediments. Following Purnamawat *et al.*, 2015, BCF values are grouped into four categories: BCF $\geq$ 1000 indicates a hyperaccumulator; BCF > 1 indicates an accumulator; BCF < 1 indicates an excluder; and BCF = 1 indicates an indicator species.

In this study, BCF values for each heavy metal varied among mangrove species. Consistent with the observed patterns of metal accumulation in sediments and roots, the BCF values also varied among mangrove species. The highest mean BCF for Pb was recorded in *Rhizophora apiculata* (0.65 ± 0.22), while the lowest mean BCF was observed in *Sonneratia alba* (0.42 ± 0.33). However, although the mean values differed among species, the difference between *Rhizophora apiculata* and *Sonneratia alba* was not statistically significant ($t = 2.03$, $p \approx 0.08$). The high variability within *Rhizophora apiculata* and the small sample size contributed to the lack of statistical significance. Other species showed intermediate Pb BCF values, including *Rhizophora mucronata* (0.64 ± 0.33) and *Bruguiera gymnorrhiza* (0.52 ± 0.87). For Cu, the highest mean BCF was also found in *Rhizophora apiculata* (0.58 ± 0.38), followed by *Rhizophora mucronata* (0.40 ± 0.21), whereas *Sonneratia alba* and *Bruguiera gymnorrhiza* both showed mean Cu BCF values of 0.34 ± 0.15.

According to Purnamawat *et al.*, 2015, BCF values < 1 indicate excluder species plants that limit uptake of heavy metals from their environment. The mean Pb BCF patterns observed here are consistent with Mbaba (Mbaba, 2024), who reported higher mean Pb BCF in *Rhizophora apiculata* than in *Sonneratia alba*. In our results, *Rhizophora apiculata* exhibited the highest mean BCF, whereas *Sonneratia alba* showed the lowest. This pattern can be attributed to several factors, including root architecture, habitat position, and species-specific ion uptake mechanisms.

Rhizophora apiculata develops stilt roots that grow from the stem into the substrate, providing a relatively concentrated rooting zone with greater sediment contact that can enhance heavy-metal uptake. In contrast, *Sonneratia alba* produces conical pneumatophores that facilitate gas exchange through lenticels and oxygenate anaerobic sediments, reducing sulfide precipitation and lowering metal bioavailability at the root interface (Marissa, 2020, Nguyen *et al.*, 2023). Heavy metals in sediments often occur in sulfide-bound forms, and the oxidation caused by *Sonneratia alba* pneumatophores can promote precipitation of these metals, further limiting uptake.

Additionally, *Sonneratia alba* possesses cable-like subsurface roots and widely spreading pneumatophores, which differ from the more narrowly distributed and deeper-penetrating stilt roots of *Rhizophora apiculata*. These structural differences result in a smaller effective contact area with sediments for *Sonneratia alba*, contributing to its lower accumulation capacity (Razi *et al.*, 2023).

Beyond root structure, species' positional zonation further influences BCF. *Rhizophora apiculata* typically occupies inner mangrove zones (farther from the open sea). As noted by Hilmi *et al.*, 2015 *Rhizophora apiculata* and *Rhizophora mucronata* are often found closer to the mainland, in wetter substrates with relatively deep mud, influenced by tidal waters and riverine inflows; Noor in Wakano *et al.*, 2022, Likewise, freshwater inflows can transport heavy metals into mangrove ecosystems. To support this explanation, local environmental parameters were included. The measured temperature ranged from 25–29°C, which falls within the normal threshold for mangrove habitats. The pH values ranged from 6.96 to 7.9, also within the acceptable range, while salinity ranged from 28 to 32.2 ppt, indicating conditions that remain suitable for mangrove systems. These environmental measurements strengthen the argument that habitat-specific factors influence metal dynamics within the study area. n the context of this study area, the Ngurah Rai Grand Forest Park is surrounded by dense human activity residential areas, restaurants, hotels, and malls and functions as a receiving environment for their effluents (Wakano & Ukaratalo, 2022). By contrast, *Sonneratia alba* commonly occupies the seaward fringe (Prihandana *et al.*, 2021), where higher marine dilution may lower heavy-metal exposure. *Sonneratia alba* also exhibits a toxicity-mitigation strategy via dilution storing water to reduce internal heavy-metal concentrations and thus toxicity (Utami *et al.*, 2018).

Inter-specific differences in BCF are therefore governed not only by habitat and root morphology but also by variability in ion uptake activities. As shown by Sazon & Migo (Sazon & Migo, 2019), BCF depends on species, tissue type, and the specific ion. Uptake is typically greatest in roots compared with stems, leaves, or fruits, because roots directly absorb ions from water and sediments including both essential nutrients and non-essential (potentially toxic) ions. Kamaruzzaman reported that *Rhizophora apiculata* exhibits exclusion mechanisms and can still accumulate heavy metals, making it effective for bioremediation. *Rhizophora apiculata* also synthesizes metal-chelating compounds such as phytochelatins (Mariwy *et al.*, 2024).

Phytochelatins further influence mangrove metal accumulation capacity. These peptides composed of cysteine, glycine, and glutamate—are induced under metal stress (Triwardana & Junaidi, 2023). They are synthesized from the glutathione (GSH) precursor by phytochelatin synthase (PCS) (Inouhe, 2005). Located in the cytoplasm and vacuoles, phytochelatins bind heavy-metal ions, forming stable complexes that reduce toxicity and enable intracellular transport and storage without cellular damage. While *Sonneratia alba* also produces phytochelatins, their levels are generally lower than in *Rhizophora apiculata* (Sazon & Migo, 2019). Reduced PCS production in *Sonneratia alba* may represent a physiological adaptation prioritizing osmoregulation and antioxidant functions rather than a direct response to heavy-metal exposure (Feng *et al.*, 2020).

Conclusion

The findings of this study demonstrate that mangrove species have different capacities to accumulate heavy metals, particularly Pb and Cu, as reflected by their bioconcentration factor (BCF) values. The highest BCF value for Pb was recorded in *Rhizophora mucronata*, whereas *Rhizophora apiculata* showed the highest BCF value for Cu, reaching 1.13. These results indicate that both *Rhizophora apiculata* and *Rhizophora mucronata* possess superior abilities to accumulate heavy metals compared to other species such as *Sonneratia alba* and *Bruguiera gymnorrhiza*. The variation in accumulation capacity among species highlights the influence of species-specific characteristics, such as root morphology and ecological zonation, on heavy metal uptake. Overall, the study emphasizes the important role of *Rhizophora apiculata* and *Rhizophora mucronata* in mangrove ecosystems, particularly their potential contribution to phytoremediation and environmental conservation in areas impacted by heavy metal pollution.

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