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Bioaccumulation and translocation of heavy metals mercury and lead in mangroves *Rhizophora apiculata* and *Sonneratia* sp. in the estuarine waters of Malili River

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ABSTRACT

The presence of various industrial activities is not far from negative impacts such as heavy metal waste. This study examined the ability of *R. apiculata* and *Sonneratia sp.* mangroves to translocate and accumulate mercury (Hg) and lead (Pb) in the Malili River estuary, East Luwu regency. The methodology used involved sediment sampling as well as mangrove tissue to analyze heavy metal concentrations. The parameters measured included Hg and Pb concentrations in sediments and tissues of *R. apiculata* and *Sonneratia sp.*, by calculating the bioconcentration factor (BCF) and translocation factor (TF). The results showed that the concentration of Hg metal in sediments ranged from 2.0–2.9 mg/kg, while in *R. apiculata* and *Sonneratia sp*. ranged from 0.48–1.14 mg/kg and 0.55–1.05 mg/kg, respectively. For Pb, sediment concentrations ranged from 3.50–8.20 mg/kg, while those of *R. apiculata* and *Sonneratia sp*. ranged from 0.22–0.52 mg/kg and 0.35–0.66 mg/kg, respectively. BCF of both mangrove species showed a range of values of 0.03–0.82 which means the value of BCF < 1 (excluder category) while the value of TF showed a range of values of 0.05–0.92 which means the value of TF < 1 (phytostabilization). These results indicate that these mangroves effectively retain heavy metals in the roots without translocating them to other tissues. This study confirmed the role of mangroves as a natural solution in phytoremediation of heavy metal polluted waters.

Keywords: bioaccumulation, translocation, heavy metals, mangrove.

INTRODUCTION

The rapid development of industrial activities in Southeast Asia, including Indonesia, has improved people's quality of life in various aspects over the past decade (Isventina et al., 2018). However, this progress also brings negative impacts, especially for the coastal environment. One of the main threats is the pollution of waters by heavy metal waste generated from industrial, agricultural, residential and mining activities. These wastes tend to undergo precipitation and adsorption in aquatic sediments (Indrawati et al., 2022). The Malili River in East Luwu regency, south Sulawesi, is one of the areas affected by the development of activities along the watershed. Previous research by (Nurhasmiati et al., 2023) revealed that the concentrations of mercury (Hg) and lead (Pb) in sediments upstream and downstream of the Malili River have exceeded the established quality standard threshold. This condition demands an effective solution to reduce the heavy metal concentrations in the waters. Mangroves, a typical coastal plant, are known for their ability to accumulate heavy metals and tolerate them at high levels. This makes mangroves a potential candidate for phytoremediation technology, which utilizes plants to reduce pollutants in the environment (Hamzah & Pancawati, 2013). Previous studies have shown that mangrove ecosystems, such as *R. apiculata* and *Sonneratia* sp., act as bioaccumulators of harmful heavy metals by mechanisms such as rhizofiltration (Yusuf et al., 2017; Mentari et al., 2022)

This study aimed to evaluate the ability of *R. apiculata* and *Sonneratia sp.* to translocate and accumulate Hg and Pb in the waters of the Malili River estuary. By assessing the bioconcentration (BCF) and translocation factor (TF), this study is expected to provide scientific contributions in the development of ecosystem-based strategies to address heavy metal pollution in coastal areas.

MATERIALS AND METHODS

Research area

The study was conducted in the Malili River estuary, Malili District, East Luwu regency, which is an area with significant industrial and harbor activities. This location was chosen based on previous research that showed high concentrations of heavy metals in the area. Three sampling station points were strategically determined based on distance from the harbor and human activities that affect the aquatic ecosystem.

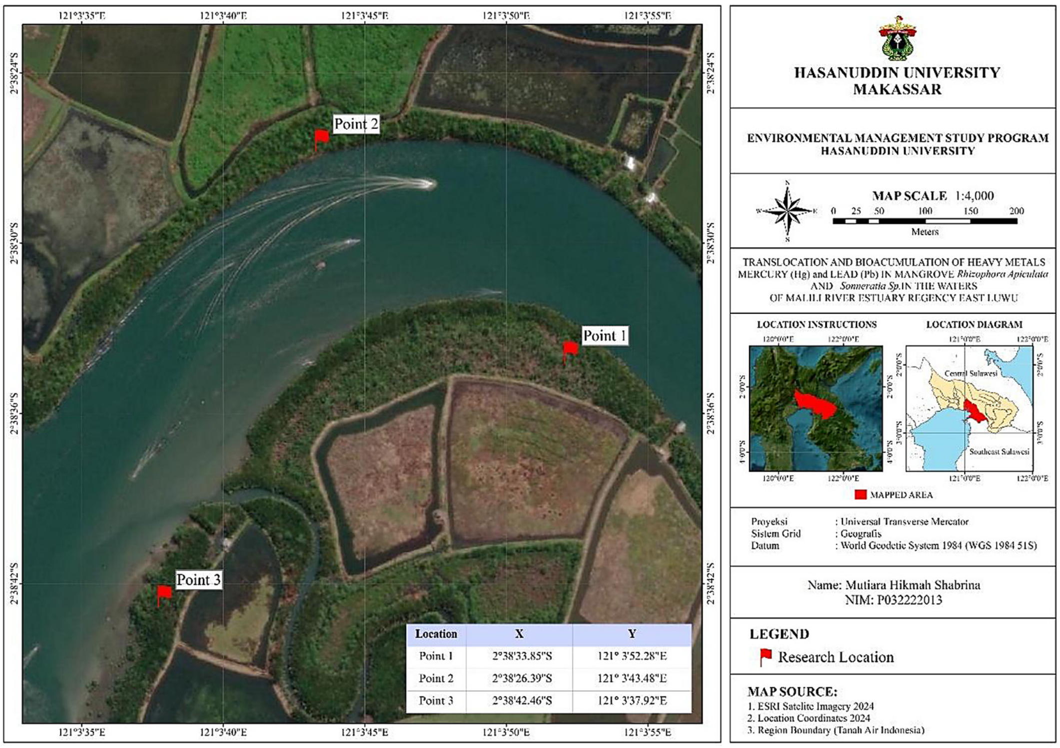
Sampling was conducted using a *purposive sampling* method to ensure that the selected sites represented the variation in heavy metal pollution levels in the region. This process consists of:

- sediment sampling – was conducted using PVC pipes to a depth of 0-10 cm. This depth was chosen because heavy metals generally accumulate in the upper layers of sediment. Each station was repeated three times to increase the validity of the data.
- mangrove sampling – the roots, stems, and leaves of *R. apiculata* and *Sonneratia sp.* mangroves were taken at each station. These samples were cleaned and cut into small pieces to ensure homogeneity. Mangrove species were selected based on their dominance in the area and their proven ability in phytoremediation.

Methods of analysis

The levels of heavy metals Hg and Pb in sediments and mangrove tissues were analyzed using the inductively coupled plasma optical emission spectroscopy (ICP-OES) method. ICP-OES was chosen due to its high accuracy in detecting heavy metals at low concentrations.

Temperature, salinity, pH, and Eh were measured directly in the field using digital sensors to obtain supporting data that affect heavy metal



Location	X	Y
Point 1	2°38'33.85"S	121° 3'52.28"E
Point 2	2°38'26.39"S	121° 3'43.48"E
Point 3	2°38'42.46"S	121° 3'37.92"E

Figure 1. Map of research points

distribution. These parameters were chosen because they affect the mobility of heavy metals in the water. Data analysis used the bioconcentration factor and translocation factor calculation methods to calculate the ability of *R. apiculata* and *Sonneratia sp.* toabsorb heavy metals and the ability of mangroves to transfer metals from roots to leaves.

$$BCF\ (\text{l/kg}) = \frac{\textit{Heavy metal Hg in mangroves}\ (\text{mg/kg})}{\textit{Heavy metal Hg in sediment}\ (\text{mg/l})} \quad (1)$$

A BCF value of <1 defines that mangroves belong to the excluder category, BCF=1 defines that mangroves belong to the indicator category, and BCF>1 defines that mangroves belong to the accumulator category.

$$TF\ Hg = \frac{\textit{Heavy metal Hg in leaves/stems}\ (\text{mg/kg})}{\textit{Heavy metal Hg in roots}\ (\text{mg/kg})} \quad (2)$$

Translocation factor is a calculation of the ratio of heavy metal concentrations in leaves and roots. TF>1 indicates phytoextraction, while TF<1 indicates phytostabilisation.

In addition, *Spearman analysis* management was used to see the influence of environmental parameters on sediment concentration in waters.

RESULTS AND DISCUSSION

Heavy metal concentrations in sediments

This study used 2 heavy metal parameters, namely mercury and lead. Hg concentration ranged from 2.0–2.9 mg/kg and Pb concentration ranged from 3.5–8.2 mg/kg (Table 1). The average concentration at the three stations showed that Pb was found to have the highest average concentration of 6.57 mg/kg but did not exceed the established quality standards. The results of Hg concentrations are 2.47 mg/kg and exceed the quality standard limits that have been set.

The difference in the amount of Hg heavy metal concentration at each station is most likely based on the activities that dominate around the sampling station area. Station 1 has a higher concentration of Hg, because this station is located in an area closer to the port and the loading and unloading activities of mining company ships. In vicinity of a harbor, the anchoring activities of industrial ships are likely to discharge water and waste will flow into the river. The process of industrialization cannot escape the negative effects it will cause, the presence of industrial waste materials both in solid and liquid form will affect the surrounding environment. If the waste is released into free waters, it will cause changes in the value of the waters, both quality and quantity so that the waters can be considered polluted (Rochyatun & Rozak, 2010). As for lead (Pb), the highest concentration was found in the station 2 area, the difference in concentration at each location is also thought to be influenced by currents and tidal processes (Putra, 2022). The different concentrations are due to the lead (Pb) dissolved under tidal conditions showing the effect of different heavy metal concentration results in each water area or sediment collection area.

The concentration of metals in the sediment is also influenced by the quality or parameters in the aquatic environment. In this study, environmental parameters such as water temperature, pH, and salinity were measured. The results showed that there was an influence of environmental parameters on sediment concentrations at each sampling station. Increasing temperature and decreasing pH values result in increased accumulation ability so that the concentration of metals in the sediment increases (Król et al., 2020). In addition, the salinity of the waters also has an effect, where the higher the salinity of the waters, the higher the concentration of heavy metals (Musie & Gonfa, 2023). The redox potential of sediments is also measured to see the size of the tendency of a chemical species to obtain electrons to be reduced, the Eh results obtained in sediment measurements, which produce low values at each station -37, -45, and -48 (Table 2). In this study, the Eh results obtained were low. The lower the Eh, the higher the concentration of metals in the

Table 1. Heavy metal concentrations in sediments

Location (N)	Concentration (mg/kg)		Standard quality (mg/kg) (OSPAR, 2004)	
	Hg	Pb	Hg	Pb
1	2.9	8.0	1.0	25
2	2.0	3.5		
3	2.5	8.2		

Table 2. Environmental parameter measurement results

Station	Parameter			
	Temperature (°C)	pH	Salinity (ppt)	Redox potential (mV)
I	31	7.35	24.28	-37
II	30	8.16	18.54	-45
III	30	7.45	22.90	-48
Standard quality (PP No.22 , 2021)	28±32	6±9	21.28±26.28	-100±100

sediment, thus reducing the availability of metals in mangroves (Dendievel et al., 2022). Reduced Eh conditions can cause heavy metals to associate with Fe and Mn oxides (Mitra et al., 2022).

The results of calculations using Spearman analysis to see the effect of environmental parameters on heavy metal concentrations in aquatic sediments show that the correlation value and significant value that produces a value (sig.) <0.05, which means that there is a significant correlation between environmental parameters as well sa concentrations of Hg and Pb in sediments.

Heavy metal concentrations in mangroves

On the basis of the research results, both types of mangroves are able to absorb Hg and Pb in the waters (Table 3). Heavy metals are found in the mangrove section in all locations, namely in the *R. apiculata* mangrove, the content of Hg varies between 0.48 and 1.14 mg/kg, while in the case of Pb – between 0.22 and 0.52 mg/kg. In turn, in *Sonneratia* sp. mangrove, the content of Hg ranges between 0.55 and 1.05 mg/kg, and in the case of Pb – between 0.35 and 0.61 mg/kg. The differences in the results of measuring the concentration of heavy metals, both Hg and Pb in each mangrove organ are due to factors such as differences in the age of the mangrove plants at the time of sampling (Setyaningrum et al., 2018). The highest concentrations of Hg and Pb were found in mangrove roots, according to Table 3 indicating the ability of mangroves to absorb heavy metals naturally, which is also known as biosorption. To prevent poisoning and damage to plant cells, plants accumulate heavy metals in the roots, due to exposure to inorganic substances, such as heavy metals (El-sappah et al., 2024).

Direct interaction between mangrove roots and sediment and water contaminated with heavy metals causes higher concentrations of heavy metals in mangrove roots than other mangrove tissues and deposition of these metals into other tissues (Retnosari et al., 2024). The penetration process of these inorganic elements can occur through three mechanisms: diffusion, water flow in sediment solution diffusion, passive transport by water flow in sediment, and roots in direct contact with metals in the sediment matrix Several studies on the accumulation and distribution of heavy metals in mangrove forests show that the concentration of heavy metals is found both in sediment and in plant roots (Kumar et al., 2019) and the concentration of these metals increases drastically with age. The ability to withstand heavy metals also depends on plant age and biomass production (Bishnu et al., 2024).

Bioconcentration factors and mangrove translocation

The results of BCF and TF on mangrove species *R. apiculata* and *Sonneratia* sp. at the three stations showed BCF values <1 and TF values <1 (Table 4). The results of the BCF and TF values in the mangrove species *R. apiculata* and sp., at all sampling stations showed a BCF value <1, which means that both types of mangroves are included in the excluder category. The results of the bioaccumulation analysis (BCF) on these two types of mangrove trees showed an average value of 0.93–0.04 mg/kg and less than 1 (<1), which can be interpreted that this type of mangrove tree functions as an exclusion plant, namely a plant that is more effective in preventing the entry of heavy metals into the upper plant organs, but the concentration of metals in the roots remains high (Thakur et al., 2022).

Heavy metals, such as Hg and Pb, can accumulate in mangrove roots through two main pathways, namely the symplast and apoplast pathways (Shetty et al., 2025). The symplast pathway involves the transport of solutes through the cytoplasm, while the apoplast pathway uses the intercellular space as a transport medium. This is in line with the view that metals can be absorbed

Table 3. Heavy metal concentrations in mangroves

Species	Location	Root	Stem	Leaf	Total
Mercury (Hg)					
R. apiculata	1	0.18	0.15	0.15	0.48
	2	0.20	0.19	0.14	0.67
	3	0.67	0.27	0.20	1.14
Sonneratia sp.	1	0.43	0.35	0.27	1.05
	2	0.44	0.34	0.02	0.80
	3	0.22	0.20	0.13	0.55
Lead (Pb)					
R. apiculata	1	0.21	0.07	0.07	0.35
	2	0.09	0.08	0.05	0.22
	3	0.20	0.18	0.14	0.52
Sonneratia sp.	1	0.14	0.08	0.13	0.35
	2	0.46	0.13	0.07	0.66
	3	0.27	0.16	0.18	0.61

Species	Location	Root	Stem	Leaf	Total
Mercury (Hg)					
R. apiculata	1	0.18	0.15	0.15	0.48
	2	0.20	0.19	0.14	0.67
	3	0.67	0.27	0.20	1.14
Sonneratia sp.	1	0.43	0.35	0.27	1.05
	2	0.44	0.34	0.02	0.80
	3	0.22	0.20	0.13	0.55
Lead (Pb)					
R. apiculata	1	0.21	0.07	0.07	0.35
	2	0.09	0.08	0.05	0.22
	3	0.20	0.18	0.14	0.52
Sonneratia sp.	1	0.14	0.08	0.13	0.35
	2	0.46	0.13	0.07	0.66
	3	0.27	0.16	0.18	0.61

by plants either through the intercellular space (apoplast pathway) or by penetrating the plasma membrane (symplast pathway) (Widyasari, 2021). The process of absorption and transport of metals through the plasma membrane in root cells takes place in three stages, namely metal retention in root cells, transport through the symplast pathway to the stele, and release into the xylem assisted by organic compounds (Kadarwati, 2022)

On the basis of the BCF value obtained, namely BCF <1, which is mangroves included in the excluder category. The leaf organs of both types of mangroves at each station have low BCF values for the ability to accumulate heavy metals, while the roots have a higher accumulation capacity. The BCF values of all mangrove organs at the three stations are included in the low accumulation category. From the average calculation of the BCF value between the two mangroves, the average BCF value of the *R. apiculata* mangrove type was 0.185 while the BCF value of the *Sonneratia sp.* mangrove type was 0.211. This means that the highest BCF value is the mangrove type *Sonneratia* sp.

The obtained TF value <1, in other words, the mangrove plants *R. apiculata* and *Sonneratia* sp. used in this study have undergone phytostabilization. Phytostabilization is one of the phytoremediation mechanisms. The way phytostabilization works is by utilizing the ability of the roots to change environmental conditions (Kafle et al., 2022). Plants stop the movement of absorbed metals which then accumulate in the roots and are absorbed in the rhizosphere (Thakur et al., 2022). Phytostabilization also allows plants to accumulate pollutants in the root zone, absorb pollutants

Table 4. BCF and TF values of mangroves

Species	Station	BCF		TF	
		Hg	Pb	Hg	Pb
R. apiculata	1	0.82	0.05	0.82	0.33
Sonneratia sp.	1	0.34	0.03	0.62	0.92
R. apiculata	2	0.28	0.09	0.68	0.05
Sonneratia sp.	2	0.37	0.14	0.06	0.16
R. apiculata	3	0.63	0.11	2.43	0.69
Sonneratia sp.	3	0.18	0.05	0.60	0.68

on the root surface, and store them in transport/immobilization by precipitating the pollutants (Bakshe & Jugade, 2023). This is consistent with the fact that the concentration of heavy metals is higher in the roots than in the bark and leaves. From the average calculation of TF values between mangrove types *R. apiculata* and *Sonneratia* sp., the average value obtained is that the mangrove type *R. apiculata* is 0.57 and the mangrove type *Sonneratia* sp. is 0.50. The comparison of TF values between the two types of mangroves does not differ significantly.

The presence of heavy metal concentrations in sediments will certainly accumulate in organisms, for example mangrove plants (Mohajane & Manjoro, 2022). Mangroves are aquatic plants that can absorb heavy metals in water. Each mangrove species has a different capacity and ability to absorb metals, depending on the size and diameter of the root system and stems (Sudhir et al., 2022). In this study, the concentration of Hg and Pb was detected in the roots of mangrove trees. The root part interacts directly with water and sediment, so that it is likely to cause the highest accumulation in the roots compared to the stems and leaves (Tardieu et al., 2017).

Mangroves can also accumulate and translocate heavy metals to other organs such as stems and leaves (Hossain et al., 2022). Mangrove plants can reduce heavy metal pollution in water and sediment by absorbing and accumulating heavy metals in mangrove body tissue (Sari et al., 2024). The calculated BCF and TF values for the mangrove species *R. apiculata* and *Sonneratia* sp. have BCF values of less than 1 and TF values of less than 1. The calculated BCF and TF values for the mangrove species *R. apiculata* and *Sonneratia* sp. have BCF values greater than 1, both mangroves are included in the excluder and phytostabilization categories. These two types of mangroves are mangroves that are morphologically different, especially in the roots, where *R. apiculata* has root modifications in the form of supporting roots (Shamin-Shazwan et al., 2021), and the *Sonneratia* sp. mangrove type has root modifications in the form of respiratory roots (Sudhir et al., 2022), but in this study the results showed that both mangroves have the same ability to collect and transfer heavy metals to other tissues and organs. However, each mangrove species certainly has different metal absorption capacities or abilities depending on the root system

Table 5. Previous research

Species	BCF	TF	Location	Reference
R. mucronata	Hg (0.22;0.042; 0.035)	Hg (0.237; 0.233; 0,217)	Teluk Kayeli, Kabupaten Buru	(Ismail et al., 2020)
Sonneratia apetala	Cu (1,93; 1,8) Mn (0,11; 013) Fe (0,57; 0,49); Zn (0,58; 0,58) Sr (0,68; 0,58)	Cu (3.38; 3.64) Mn (0.18; 0.25) Fe (1; 1) Zn (1.018; 1.17) Sr (1.19; 1.17)	Bangladesh, Indian	(Hossain et al., 2022)
Avicennia sp.	Pb (0,42; 0,35; 0,18) Cu (1,29; 0,25; 0,10) Zn (0,23; 0,29; 0,23)	Pb (0,83; 0,89; 0,11) Cu (0,88; 1,24; 2,30)	Blanakan Fish Farm	(Takarina & Pin, 2017)
Avicennia marina	Cd (0,37); Pb (0,04); Zn (0,63)	Cd (0.81); Pb (0.41); Zn (0,79)	Wonorejo Mangrpve Ecosystem, East Surabaya	(Hikmah et al., 2023)
Rhizopora sp.	Cu (1.36; 1.64; 1.35) Cr (2.26; 2.87; 1.65)	Cu (0.61; 0.74; 0.74)	PLTD, Pinrang	(Aras et al., 2024)

and the size or diameter of the stem (Yang et al., 2024). Low metal translocation factors indicate that mangroves are likely to utilize these metals to support their metabolic activities and growth (Pachura et al., 2016). However, non-essential metals show relatively higher mobility from roots to leaves (Samosir et al., 2023). In leaves, metals such as Pb and Hg are toxic, especially for photosynthesis, chlorophyll synthesis, and antioxidant enzymes (Singh et al., 2016). Roots have a mechanism to inhibit the transport of non-essential metals, so these metals accumulate in roots to a greater degree (Skuza et al., 2022).

CONCLUSIONS

On the basis of the results of the research conducted, the average concentration of heavy metal Hg in the bottom sediment was 2.47 mg/kg, in the mangrove type *R. apiculata* it was 0.76 mg/kg and the mangrove type *Sonneratia* sp. it was 0.80 mg/kg. While the concentration of Pb in the sediment was 6.57 mg/kg, in the mangrove type *R.apiculata* it was 0.37 mg/kg and in the mangrove type *Sonneratia* sp. it was 0.54 mg/kg. The results of the BCF value of the mangrove types *R. apiculata* and *Sonneratia* sp. were BCF<1 (excluder) and the results of the TF value of the mangrove types *R. apiculata* and *Sonneratia* sp. were TF<1 (phytostabilization). Both types of mangroves are effective in accumulating heavy metals in their roots with low translocation ability, making them more suitable for phytostabilization compared to other phytoremediation methods. On the basis of their low BCF and TF values, these two types of mangroves play a significant role in mitigating heavy metals in coastal environments, particularly by controlling pollutants in the root zone.

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