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Heavy Metal Concentrations in *Avicennia alba* from the Western Coast of Dumai City, Riau Province

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ABSTRACT

Coastal ecosystems play a crucial role in supporting biodiversity, but are increasingly threatened by heavy metal pollution from industrial and domestic activities. The mangrove species *Avicennia alba* can absorb heavy metals through phytoremediation processes, making it a promising bioindicator of environmental contamination. This study aimed to analyze the concentrations and variations in the accumulation of lead (Pb) and copper (Cu) in *A. alba* roots, stems, and leaves along the western coast of Dumai City, Riau Province. Fieldwork was conducted from January to February 2025 at two sampling sites: Pangkalan Sesai Village (Station 1) and Purnama Village (Station 2). Heavy metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS) following wet digestion. Environmental parameters were also measured, including temperature, salinity, and pH. Data analysis involved descriptive statistics, non-parametric tests, and independent t-tests. The results indicated that Pb and Cu were present in all plant parts. The highest concentration of Pb was found in the stems (7.05 µg/g), while Cu was most concentrated in the roots (5.38 µg/g). No statistically significant differences were observed among plant parts ($p > 0.05$); however, a significant spatial difference in Pb concentrations between the two stations was detected ($p < 0.05$). These findings suggest that anthropogenic activities and local water quality conditions likely Influence the observed variations. Overall, *A. alba* demonstrates strong potential as a bioindicator species for monitoring heavy metal contamination in coastal environments.

Keywords: *Avicennia alba,* Phytoremediation, Heavy metals, Coastal West Dumai

1. INTRODUCTION

Coastal ecosystems play a strategic role in maintaining the environmental balance, protecting against coastal erosion, providing habitat for various species, and improving water quality. As a transition zone between land and ocean, coastal areas host meaningful ecological interactions that support biodiversity. However, these areas are increasingly threatened by anthropogenic activities such as industrial, agricultural, and residential growth, which leads to increased pollution, including heavy metal pollution (Mulyadi et al., 2021).

Heavy metals such as lead (Pb) and copper (Cu) are major toxic, persistent contaminants and can accumulate in organisms' tissues. Pb generally comes from industrial activities such as painting and metal processing, while Cu can come from agricultural and domestic waste. Both metals can degrade water quality, harm aquatic organisms, and negatively impact human health. Pb is known to damage the kidneys, liver, nervous system, and photosynthetic function of plants (Palar, 1994; Handayanto et al., 2017), while Cu in high levels can interfere with the growth and reproduction of marine biota (Irianti et al., 2017). The level of toxicity can increase in conditions of low salinity and extreme pH, such as in estuary areas (Utami et al., 2018).

Mangroves have an important ecological function as natural filters that absorb heavy metals through phytoremediation mechanisms. *Avicennia alba* is a mangrove species that effectively accumulates heavy metals from water and sediment, especially in the roots. This species grows in the front zone of mangrove forests directly exposed to seawater, so it has excellent potential to retain pollutants before they spread more widely (Hogarth, 2007). Previous research shows that *A. alba* can accumulate Pb, Cu, and Zn with high Bio-Concentration Factor (BCF) values, making it a potential bioindicator of heavy metal pollution (Mulyadi et al., 2021).

On the West Dumai coast, the presence of

A. alba is quite dominant, including in the Bandar Bakau and Purnama urban village areas. In addition to absorbing pollutants, *A. alba* also provides important habitat for various marine species and supports the productivity of coastal community fisheries (Karimah, 2017). The phytoremediation process in the mangrove rhizosphere also supports the activity of decomposing microorganisms that accelerate detoxification (Utami et al., 2018).

However, heavy metal accumulation still has the potential to enter the food chain and endanger ecosystems and humans. The purpose of this study is to analyze the differences in the concentrations of heavy metals Pb and Cu in the roots, stems, and leaves of *A. alba* mangroves, to determine the concentrations of heavy metals in each part of the plant, and to compare the concentrations of heavy metals between observation stations. Therefore, research on heavy metal concentrations in *A. alba* in the coastal area of West Dumai is important to evaluate pollution levels and formulate appropriate mitigation strategies to maintain the sustainability of coastal ecosystems.

2. RESEARCH METHOD

Time and Place

This research was conducted from January to February 2025. The mangrove species *A. alba* was sampled along the coast of West Dumai, specifically at two stations located in Pangkalan Sesai Village and Purnama Village.

Figure 1. Research location

Method

The study used a survey method, with the coast of West Dumai serving as the sampling area. Sampling stations were determined using purposive sampling, and stations were selected based on observations and environmental conditions in the study area. The map of the research stations is presented in Figure 1.

Procedures

The determination of sampling locations was based on representing areas close to industrial areas and relatively far from the city center. The study was conducted at two stations, with three replicates at each station. Station 1 was located on the coast of Pangkalan Sesai, which is close to industrial areas, dense settlements, and shipping activities, making it susceptible to pollution with heavy metals. Station 2 is located in Purnama, West Dumai Subdistrict, which is relatively far from the city center and is expected to have lower levels of heavy metal pollution. This station was chosen to illustrate the condition of the coastal environment with minimal influence from industrial activities.

Sampling Collection and Preparation

The *A. alba* mangrove sampling procedure for heavy metal analysis refers to the method of Rachmawati et al. (2018); Tampubolon & Utomo (2020), which includes roots, stems, and leaves. Sampling starts from the root systems buried in the sediment by selecting healthy trees. Roots were cut into 10-20 cm lengths, weighing about 50 g, and randomly taken from three trees to obtain various data. Samples were then cleaned of soil and dirt and stored in clean plastic bags.

Furthermore, stem sampling was conducted on trees with a 15-30 cm diameter and 3-5 meters in height. Stem samples were obtained by cutting the surface of the stem 5 cm deep and 10 cm long at a height of 1-1.5 meters from the ground using a sharp machete. Cutting was done on the healthy part of the stem to maintain sample quality. Wounds on the stem were covered with mangrove mud to prevent infection and accelerate healing. At the same time, samples were stored in labeled containers for analysis.

The last stage was leaf sampling by selecting dark green leaves at the base of the twigs, as leaves in this position are considered the most representative of heavy metal content analysis. Leaves are taken randomly from several trees with uniform stem diameters, weighing about 50 g. The picked leaves must be in good condition and free from contamination. They are then stored in a clean plastic bag and placed in an ice box to maintain sample quality before being analyzed in the laboratory.

Heavy Metal Analysis

The analysis of heavy metals in the roots, stems, and leaves of *A. alba* was conducted using the modified method of Yulaeni et al. (2022); Kahula et al. (2024). The samples were cleaned using distilled water and then dried in an oven at 105°C until the moisture content disappeared. After that, the dried sample was crushed into powder, 1 g was weighed, and 10 mL of concentrated HNO_3 was added. This mixture was heated at 150°C for 1 hour in a fume hood, then three drops of 10% H_2O_2 were cooled and added to help dissolve metals and oxidize organic compounds.

The digested solution was filtered using Whatman filter paper to obtain a clear filtrate. Distilled water was added to adjust the volume to 50 mL, neutralize the acidity, and align the heavy metal concentrations with the standards required for atomic absorption Spectrophotometer (AAS) analysis. For calibration, standard solutions were prepared from stock solutions of $PbNO_3$ and $CuSO_4$ with an initial concentration of 1000 ppm. These were diluted to 0.1, 0.3, 0.5, and 1.5 ppm concentrations to produce a linear calibration curve between concentration and absorbance.

The analysis used an AAS equipped with a concave cathode lamp according to the analyzed metal element. Metal concentrations were obtained based on the standard curve and then calculated using the formula from Supriatno & Lelifajri (2009):

$$K(\mu g/g) = \frac{a\ (\mu g/l) \times b(l)}{c\ (g)}$$

Description:

K = Actual concentration (µ g/g)
a = AAS calculated concentration (µ g/l)
b = Solvent volume (l)
c = Sample Weight (g)

Data Analysis

Analysis of differences in heavy metal concentrations in *A. alba* was conducted to determine whether there were significant variations in the levels of heavy metals among the roots, stems, and leaves. Since the data did not meet the assumption of homogeneity, analysis of variance (ANOVA) was not applicable. Therefore, non-parametric tests assessed the differences in heavy metal concentrations among the plant parts.

An independent t-test was used to compare heavy metal concentrations between Station 1 and Station 2. The t-test is a widely used statistical method for comparing two groups, and it provides a clearer understanding of significant differences in heavy metal concentrations between the two stations

3. RESULT AND DISCUSSION

Water Quality

The results of water quality parameter measurements conducted along the coast of West Dumai, specifically in Pangkalan Sesai and Purnama Villages, are presented in Table 1.

Table 1. Average results of water quality parameter measurements

Station	Parameters		
	Temperature (^{0}C)	pH	Salinity (‰)
1	30 ± 0.57	7 ± 0.57	23±0.57
2	26 ± 2.13	7 ± 0.81	16±3.66

Comparison of Heavy Metals Pb and Cu between Plant Parts of *A. Alba*

Comparison of the average concentrations of heavy Pb and Cu in each part of the *A. alba* plant found in the coastal area of West Dumai Beach is presented in detail in Table 2.

Table 2. Comparison of average concentrations of Pb and Cu in *A.alba*

Plant Parts	Concentration (µg/g)	
	Pb	Cu
Roots	6.89 ± 0.43	5.38 ± 0.40
Stem	7.05 ± 0.59	4.81 ± 1.46
Leaves	6.55 ± .10	4.64 ± 0.28

Based on plant parts, the concentration of Pb was higher in the stems compared to the roots and leaves. In contrast, Cu was more concentrated in the roots than in the stems and leaves. According to the results of the non-parametric test used to compare metal concentrations among plant parts, the p-values for Pb ($p = 0.721$) and Cu ($p = 0.224$) > 0.05. These findings indicate no statistically significant differences in Pb and Cu concentrations among the roots, stems, and leaves of *A. alba*.

Measurements of Pb heavy concentrations in the roots, stems, and leaves of *A. alba* showed that the highest accumulation was in the stem at 7.05 µg/g, followed by the roots at 6.89 µg/g, and the Lowest in the leaves at 6.55 µg/g. The high concentration of Pb in the stem is thought to be due to the longer residence time of the metal in the stem tissue, allowing for higher accumulation than in roots and leaves (Barutu et al., 2014). Roots also showed high concentrations due to direct contact with heavy metal-contaminated sediments in mangrove habitats.

The primary source of Pb in the study area is thought to come from anthropogenic activities, especially the shipyard industry and the people's harbor in Dumai. Wastes such as ballast water used batteries, and ship hull paint contribute to Pb pollution in the waters. In addition, the flow of the Dumai River through residential areas also carries domestic waste containing Pb. Pb can enter plant tissues through two main pathways: the xylem system that spreads it to all parts of the plant, or through particles attached to the leaves and enters through the stomata (Heriyanto & Subiandono, 2011).

Meanwhile, the highest Cu concentration was detected in the roots (5.38 µg/g), then the stem (4.81 µg/g), and the lowest in the leaves (4.64 µg/g). This is due to the ability of the roots to absorb or adsorb metals from sediments and water and retain metals that cannot be translocated to other parts of the plant (Soenardjo & Mentari, 2023). Cu is an essential metal used in plant metabolic processes, so its amount in stems and leaves is relatively lower due to distribution for plant physiological needs (Amin, 2001). Therefore, Cu accumulation is more dominant in the roots as the central filter part of the surrounding environment.

Concentration of Heavy Pb and Cu in *A. alba* Roots

The average concentration of Pb and Cu in *A. alba* roots between research stations on the West Dumai coast is presented in Table 3.

Table 3. Average concentrations of Pb and Cu in *A. alba* roots

Station	Concentration (µg/g)	
	Pb	Cu
1	6.54 ± 0.24	5.03 ± 0.19
2	7.25 ± 0.18	5.73 ± 0.08

The results show that *A. alba* can accumulate heavy metals, especially lead (Pb) and copper (Cu), in the roots. The concentration of Pb in the roots was higher in Station 2 at 7.25 µg/g compared to Station 1 at 6.54 µg/g. Similarly, Cu concentration in the roots at Station 2 was recorded as higher at 5.70 µg/g. At the same time, at Station 1, it was 5.03 µg/g. The high concentration of metals in Station 2 is thought to be influenced by the interaction of various environmental factors such as wind, temperature, and the movement of water currents, as well as anthropogenic activities such as the use of ship paints containing Cu. Mangrove roots tend to accumulate higher amounts of heavy metals because they are the part that interacts directly with polluted sediments before being translocated to other plant parts (Arisandy et al., 2012).

Concentration of Pb and Cu in *A. alba* stem

The average concentration of Pb and Cu in *A. alba* leaves at each research station on the West Dumai coast is presented in Table 4.

Table 4. Average concentrations of Pb and Cu in the *A. alba* stem

Station	Concentration (µg/g)	
	Pb	Cu
1	6.55 ± 0.34	6.14±0.16
2	7.55 ± 0.14	3.48±0.19

Higher concentrations of Pb metal in the stem of *A. alba* were found at Station 2 at 7.55 µg/g, which is thought to be due to the ability of the stem to store heavy metals longer than leaves or fruit. Roots also showed high concentrations because they interact directly with polluted sediments, allowing heavy metals to be absorbed and translocated to other plant parts.

Meanwhile, higher concentrations of Cu in the bars were recorded at Station 1 at 6.14 µg/g, which may be influenced by the high marine transportation activities, including fishing boats that use Cu-based anti-rust paint and loading and unloading activities at the port. In addition, ocean currents influenced by tides, wind, and other environmental factors also play a role in the distribution of heavy metals in the coastal waters of West Dumai.

Research by Barutu et al. (2014) shows that the concentration of heavy metal Cu in mangrove stems is higher than that found in this study. This is thought to be influenced by high water transportation activity and the use of copper-based anti-rust paint by fishing boats, which contributes to increased Cu content in the water. These metal contents are then absorbed by mangrove tissues, particularly in the stem, indicating that anthropogenic factors play a significant role in the accumulation of heavy metals in mangrove ecosystems.

Concentration of Pb and Cu in *A. alba* Leaves

The average concentration of Pb and Cu metals in *A. alba* leaves at each research station on the West Dumai coast is presented in Table 5.

Table 5. Average concentrations of Pb and Cu in *A. alba* leaves

Station	Concentration (µg/g)	
	Pb	Cu
1	5.56 ± 0.36	4.85 ± 0.17
2	7.54 ± 0.12	4.43 ± 0.19

The higher concentration of Pb in *A. alba* leaves was found in Station 2 at 7.54 µg/g, While the higher concentration of Cu metal was found in Station 1 at 4.85 µg/g, this difference reflects the variation of pollutant sources in each location, which are thought to come from anthropogenic activities, such as the shipyard industry, agricultural activities, and motor vehicle emissions in the West Dumai Coastal area. Waste from these activities enters the aquatic environment. It is absorbed by mangrove plants, including the leaves that play an active role in the metabolic process and accumulation of heavy metals. The content of heavy metals in the leaves, which is close to the value in the roots and stems, indicates the effectiveness of the translocation process from the roots to the leaves. Heavy metal accumulation occurs through absorption by the roots and its distribution through the xylem network to all parts of the plant, as well as through metal particles attached to the leaf surface and entering through the stomata.

This is in line with MacFarlane & Burchett's (2002) findings, which suggest that *A. alba* mangroves absorb heavy metals through their roots, which interact directly with water and sediment. These heavy metals are then translocated through the xylem transport system to the trunk and leaves, moving along with water and nutrients. The roots are the primary site of accumulation due to their intensive contact with water and sediment. At the same time, some heavy metals also accumulate in the leaves.

Comparison of Heavy Metal Concentrations Between Stations

The comparison of the average Pb and Cu levels at each station on the west coast of Dumai is presented in Table 6.

Table 6. Comparison of average concentrations of Pb and Cu between stations

Station	Concentration (µg/g)	
	Pb	Cu
Pangkalan Sesai	6.22 ± 0.56	5.34 ± 0.62
Purnama	7.44 ± 0.19	4.54 ± 0.98

Based on the t-test results presented in Table 6, the concentration of Pb showed a significant difference between stations ($p = 0.000 < 0.05$), while the concentration of Cu did not show a significant difference ($p = 0.058 > 0.05$).

The concentration of Pb at Station 2 (Purnama) was higher than at Station 1 (Pangkalan Sesai). This increase is strongly suspected to be influenced by industrial activities around the location, such as cement factories, palm oil processing, agricultural activities, and emissions from motorized vehicles. In addition, the flow of water from the Masjid River also carries polluting materials from upstream areas, while oil loading and unloading activities and significant ship traffic at the mouth of the river increase the risk of heavy metal pollution. The low salinity of 16‰ recorded at this location is also thought to exacerbate the accumulation of heavy metals, in line with the opinion of Natadisastra et al. (2018), who stated that decreasing salinity can increase toxicity and accumulation of heavy metals.

In contrast, Cu concentrations were higher at Station 1 (Pangkalan Sesai) than at Station 2 (Purnama). This location is at the mouth of the Dumai River, which receives waste runoff from various city activities, including shipyards, ship repair, and loading and unloading of industrial materials. The presence of small fishing boats that use copper-based anti-rust paint also contributes to the accumulation of Cu. The dynamics of tidal currents and the influence of wind and other oceanographic factors cause the spread of heavy metals and pollutants to occur more quickly and evenly in this region (Soenardjo & Mentari, 2023).

Based on the t-test, Pb concentrations

between stations showed significant differences ($p < 0.05$), while Cu concentrations were not significantly different ($p > 0.05$). This indicates that anthropogenic activities and current patterns influence the distribution of heavy metals in the waters. Kennedy (2014) explained that ocean currents play an important role in the spread of heavy metals because they can distribute them horizontally throughout the waters, so that the concentration of metals becomes more evenly distributed and does not accumulate in one location only.

4. CONCLUSION

Research on heavy metals in *A. alba* shows the concentration of Pb in the roots (6.90 µg/g), stems (7.05 µg/g), and leaves (6.55 µg/g). While Cu in the roots is (5.38 µg/g), stems (4.81 µg/g), and leaves (4.64 µg/g). There was no significant difference between roots, stems, and leaves. Meanwhile, the two research stations showed that Pb concentration was significantly different, while Cu concentration was not significantly different between stations. Anthropogenic activities and water quality around the station affect the accumulation of Pb and Cu in *A. alba* at both stations.

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