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Bioconcentration and Translocation of Heavy Metals in *Mangrove Avicennia* sp. and *Rhizophora* sp. in Diesel Powel Plant

Siti Aras Ainun Basri[1*], Muhammad Farid Samawi[2], Fahruddin[3]

[1] Environmental Management Study Program, Graduate School, Hasanuddin University, Makassar 90245, Indonesia
[2] Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar 90245, Indonesia
[3] Department of Biology, Faculty of Mathematics and Natural Sciences, Hasanuddin University, Makassar 90245, Indonesia
* Corresponding author's e-mail: sitiarasainun@gmail.com

ABSTRACT

Diesel power plants produce wastewater containing heavy metals. This study focused on analyzing the role of mangroves around the site. The results showed that Cu metal concentrations in sediments ranged from 10.01–17.76 mg/kg and Cr ranged from 13.06–20.34 mg/kg, and Cu and Cr metal concentrations in *Avicennia* sp. mangrove were 25.04–42.05 mg/kg; 11.78–28.21 mg/kg, respectively, and showed bioaccumulation and translocation abilities of Cu and Cr of 2.34–2.5 (BCF > 1) and 0.6–0.69 (TF < 1); 0.9–1.39 (BCF < 1) and 0.4–0.53 (TF < 1), while in mangrove *Rhizophora* sp., namely 13.51–29.24 mg/kg; 21.52–58.38 mg/kg, and showed bioaccumulation and translocation abilities of Cu and Cr, respectively, 1.35–1.64 (BCF > 1) and 0.61–0.74 (TF < 1); 1.65–2.87 (BCF > 1) and 0.62–0.84 (TF < 1). BCF > 1 indicates that mangroves are accumulators, and BCF < 1 is an excluder. TF value < 1 indicates that mangroves are phytostabilisers. This research can be a reference for diesel power plant companies to plant mangroves *Avicennia* sp. and *Rhizophora* sp. around the source of wastewater outlets. In addition to absorbing CO_2 emissions in the environment, they can also absorb heavy metals derived from diesel processing.

Keywords: diesel power plant, copper, chromium, mangrove.

INTRODUCTION

A diesel power plant (PLTD) is a power plant that usually uses diesel engines to meet small-scale electricity needs. The operation of PLTD can generate waste due to the use of fuel (gasoline and diesel) and lubricating oil, which can pollute the environment when directly disposed of. Heavy metals (Cu, Cr-total, Fe, Cd, and Ni), phenol, oil, and fat are believed to be present in this waste (Susanto et al., 2019; Coufalík et al., 2019; Rumaropen et al., 2021). Heavy metals are toxic, difficult to break down, and easily bond with other substances. If heavy metals such as Cu, Pb, Mn, and Cr enter water bodies, they can harm aquatic organisms, including humans, through the food chain (Rahman et al., 2022). Heavy metals can be concentrated in fuels through refining, distillation, and breakdown processes present in crude oil, which are retained and concentrated in the resulting fuel. Different concentrations of heavy metal contaminants in crude oil cause heavy metals to be concentrated in the resulting fuel. The release of metals into the environment and atmosphere as oxides during their combustion can harm ecosystems and humans (Pulles et al., 2012; Akpoveta and Osakwe, 2014).

Previous research has discussed the utilisation of plants such as mangroves to help absorb heavy metals in the aquatic environment (MacFarlane et al., 2007; Analuddin et al., 2023; Yap and Al-Mutairi, 2023). Mangrove species such as *Avicennia* sp. and *Rhizophora* sp. are found in PLTD waters, but their area is decreasing due to conversion to seaweed cultivation (Bibin and Ardian, 2020). The ability of mangroves to store large amounts of water can help reduce heavy metal concentrations in their tissues. Mangroves also serve as biological indicators and collect pollutants in polluted environments (Supriyantini and Soenardjo, 2016).

Bioconcentration and translocation mechanisms find heavy metals in various mangrove tissues (roots, stems, and leaves) and sediments. Bioconcentration refers to the concentration of metals in plant tissues and sediments and the ability of plants to remove metal compounds from the soil or substrate. Translocation refers to the movement of metals between plant tissues and refers to the ability of heavy metals to move from plant roots to other organs. Plants with bioconcentration and translocation values (BCF and TF) >1 are considered bioaccumulators (Wang et al., 2019; Mahmudi et al., 2021; Li et al., 2023). Human activities such as industry, agriculture, and aquaculture affect the stability of Mangroves and rivers and may contribute to the transfer of heavy metals to seawater. To determine the role of Mangroves in mitigating heavy metal pollution, this study analysed the bioconcentration and translocation of heavy metals in mangrove ecosystems around the coastal areas of power plants.

MATERIALS AND METHODS

Study area

Three different locations (Figure 1) were selected for the study in the waters of the Diesel Power Plant (PLTD): ponds (station 1), PLTD IPAL (station 2), and Jetty (station 3). These areas are characterised by different field conditions, where most of them are surrounded by seaweed farming ponds conducted by local residents, and there are two types of mangrove species to be studied, namely *Avicennia* sp. and *Rhizophora* sp.

Sediment and mangrove sampling

Sampling techniques in this study involve direct measurement in the field with the purposive sampling method. Sediment samples were collected (three replicates in each location) from Mangroves using PVC pipes at a depth of 0–30 cm from the surface and put into plastic samples that have been labeled. Next, mangrove samples (roots, stem bark, and leaves) of both species, *Avicennia* sp. and *Rhizophora* sp., were taken, cleaned, and cut into small pieces. Each sample of roots, stem bark, and old leaves was taken for about 500 grams. All samples were brought to the laboratory to be dried in an oven, HNO_3 and $HClO_4$ added, and then heated and measured

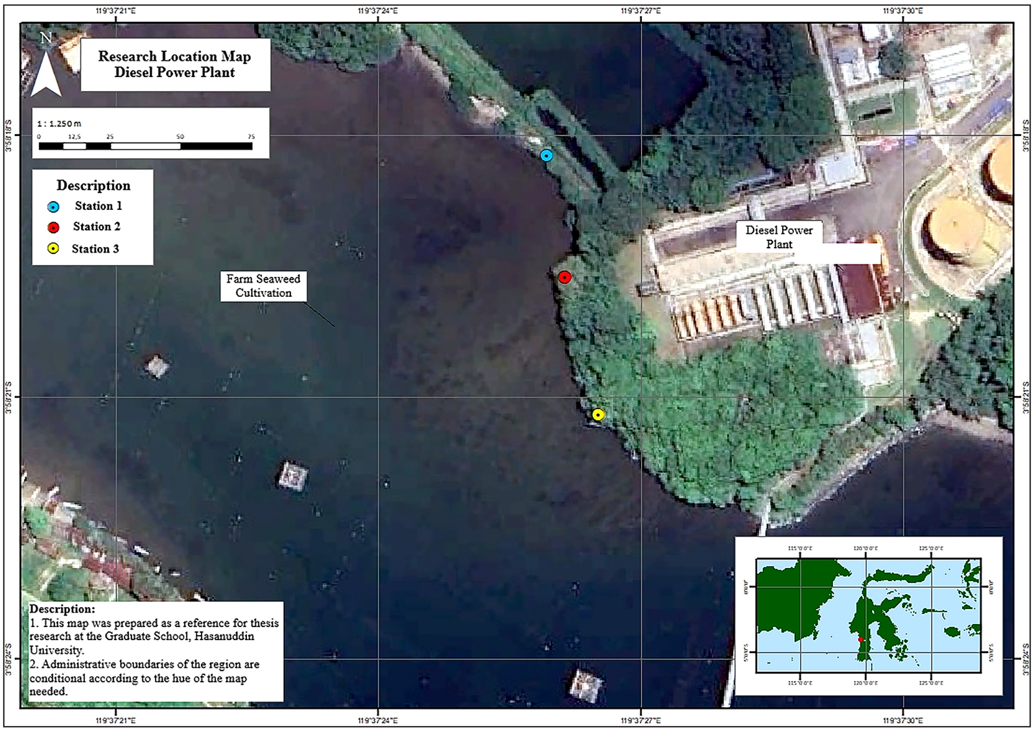

Figure 1. Study location

using an acitylene air flame and analysed using an atomic absorption spectrophotometer (AAS) (Dudani et al., 2017; Mahmudi et al., 2021). All samples were stored in a cool box and brought to the laboratory. The study area was subjected to tides using three environmental parameters namely temperature (31–32 °C), salinity (24–25 psu) and pH (7.7–7.8).

Data analysis

The laboratory analysed the data and used the calculation methods of bioconcentration factor (BCF) and translocation factor (TF) to analyse the absorption of sediment, roots, stem bark, and leaves of mangrove *Avicennia* sp. and *Rhizophora* sp. The bioconcentration factor describes the phytoaccumulation ability of plants as the ratio of total metal content in root plant tissue (C_p, mg/kg) to total metal content in root soil (C_s, mg/kg). The calculation of plant BCF value is listed in the Equation (1) (Dan et al., 2017; Hallare et al., 2015; Mngongo et al., 2023):

$$\text{BCF} = \frac{C_p}{C_s} \quad (1)$$

A BCF value of < 1 means that the mangrove is an exception category; BCF = 1 means that the mangrove is an indicator category; and BCF > 1 means that the mangrove is an accumulator category. Meanwhile, the translocation factor was used to calculate the ratio between heavy metal concentrations in leaves and roots. TF values > 1 indicate phytoextraction, and TF values < 1 indicate phytostabilization. The following equation Ayujawi and Takarina (2020) lists the calculations for the TF value of plants (mg/kg):

$$\text{TF} = \frac{C_a}{C_s} \quad (2)$$

This study also employed one-way ANOVA statistical analysis to identify variations in metal concentrations in sediments at each station, as well as variations in metal concentrations in sediments containing plant tissue. Additionally, correlation person analysis was employed to determine the relationship between environmental parameters and mangrove metals.

RESULTS AND DISCUSSION

Heavy metal concentration in sediments

This study analysed two types of metals (Cu and Cr) from mangrove sediments. Heavy metal concentrations of Cu ranged from 10.01–17.76 mg/kg and Cr ranged from 13.06–20.34 mg/kg (Table 1). The average concentrations at the three stations showed the order of Cr (13.05 ± 0.48; 15.14 ± 0.61; 20.34 ± 0.55) > Cu (10.01 ± 0.46; 13.10 ± 0.38; 17.76 ± 0.30), which means the amount of Cu and Cr metals measured varied significantly between sampling locations at each observation station with a value of (Sig.) < 0,05.

This is similar to the research of Dudani et al. (2017), Mao et al. (2022) and Tang et al. (2022), which showed the concentration level of Cr > Cu in sediment. The absorption of Cr > Cu metals in sediments in the PLTD coastal water area suggests that the PLTD industrial pollution source directly contributes to metal absorption. Cr is more easily bound to sediments compared to Cu metal, so the accumulation of Cr is higher in mangroves. Moreover, Cr metal typically exists as Cr(III), a more stable form that tends to settle in the sediment, whereas Cu is more soluble and travels through water. The corrosion and wear of engine components, the combustion of diesel fuel, and the use of lubricants containing metal additives allow the PLTD to release Cu and Cr metals. Diesel engine operation releases these metal particles into the environment, with plants typically producing more Cr than Cu due to the higher content of chrome-based additives in fuels and lubricants, as well as the higher stability and reactivity of Cr(VI).

The coastal water area around PLTD has a sandy mud beach that functions as a substrate where vegetation grows. Organisms living in the water deposit heavy metals on the substrate and then absorb them. Pollutants continuously deposit metals into sediments, causing groundwater pollution (Mahmudi et al., 2021). At all research stations, Cu and Cr metal levels ranged from 10.01 to 20.34 mg/kg. Based on the ANZECC and ARMCANZ (2000) sediment quality standards in Batley et al. (2003), Cu metal content is 65–270 mg/kg and Cr is 80–370 mg/kg. Therefore, the levels of Cu and Cr metals did not exceed the quality standard limits. Remediation is required if the concentration of heavy metals in the sediment exceeds the quality standard.

Table 1. Cu and Cr metal levels in sediments

Location	Metal type (mg/kg)	
	Cu	Cr
1	13.16	15.15
2	17.76	20.34
3	10.01	13.06

Heavy metal concentration in mangrove

Based on the results of the study, *Avicennia* sp. and *Rhizophora* sp. were able to absorb Cu and Cr metals in the waters of PLTD (Table 2). Heavy metals in plant parts in all mangrove locations, namely *Avicennia* sp. in Cu metal, ranged from 25.04–42.05 mg/kg; Cr ranged from 11.78–28.21 mg/kg; and *Rhizophora* sp. in Cu metal, ranged from 13.51–29.04 mg/kg; Cr ranged from 21.52–58.38 mg/kg.

Table 2 displays the amounts of copper (Cu) found in *Avicennia* sp. and *Rhizophora* sp. mangroves in three different locations. The amounts of Cu in *Avicennia* sp. ranged from 25.04 mg/kg to 42.05 mg/kg, and the amounts of Cu in *Rhizophora* sp. ranged from 13.51 mg/kg to 29.04 mg/kg. The amounts of Cr in *Avicennia* sp. ranged from 11.78 mg/kg to 28.21 mg/kg, and the amounts of Cr in *Rhizophora* sp. ranged from 21.52 mg/kg to 58.38 mg/kg. The ANOVA test showed that the concentration of Cu and Cr metals had a significant difference in the effect on roots, stem bark, and leaves, with a value of P 0.043 and P 0.013, respectively. Overall, research by Hossain et al. (2022), Sari et al. (2023), and Yap and Al-Mutairi (2023) indicates that *Avicennia* sp. tends to accumulate higher concentrations of metals like Cu compared to *Rhizophora* sp., albeit not as effectively as *Rhizophora* sp. Furthermore, Aboulsoud and Elkhouly (2023) and Aken et al. (2023), have noted that *Rhizophora* sp. excels at absorbing Cr metal in its roots, stem bark, and leaves due to its physiological characteristics and adaptation to thrive in saline environments.

According to Dudani et al. (2017), Maharani et al. (2019), and Sari et al. (2023), compared to other plant parts, root tissue has the highest metal content in the order of roots > stem bark > leaves. The ability of each mangrove species to absorb metals varies depending on the species and the metals absorbed; an extensive root system will affect the absorption of metals by the roots (Yan et al., 2017). The amount of metal accumulated is determined by differences in stem diameter, but when compared to leaves and fruits, stems store metals in tissues longer (Yunasfi et al., 2022). Metal will enter the plant through its roots and reach its leaves. The old leaves will store the metal until they eventually die and fall, thereby lowering the concentration on the plant (Anjaini et al., 2023). *Avicennia* sp. absorbs copper better because its body has systems that help with movement and storage. *Rhizophora* sp., on the other hand, absorbs copper more because it has an apoplastic barrier system, which includes suberin in the endodermis, that lets metals enter directly. Studies by Thanh–Nho et al. (2019), Chang et al. (2023), and Titah et al. (2021) say that *Avicennia* sp. is better at absorbing Cu because it has physiological mechanisms that help with transportation and accumulation. On the other hand, *Rhizophora* sp. is better at absorbing Cr because it has an apoplastic barrier system that includes suberin in the endodermis. Due to the direct dumping of industrial waste into the water pipes, the concentration of heavy metals in the mangrove is believed to be very high.

Bioconcentration factor and translocation factors

Results of BCF and TF in mangroves *Avicennia* sp. and *Rhizophora* sp. are shown in Table 3. *Avicennia* sp. and *Rhizophora* sp. at stations 1 and 2 are accumulators > 1 for Cu

Table 2. Concentration of Cu and Cr metals in mangrove roots, stem bark, leaves

Spesies	Location	Roots	Stem bark	Leaves	Total
Copper (Cu)					
Avicennia sp.	1	13.32	8.38	9.14	30.84
	2	18.43	11.16	12.46	42.05
	3	11.46	6.35	7.23	25.04
Rhizophora sp.	1	8.53	4.23	5.17	17.93
	2	12.54	7.18	9.32	29.04
	3	5.74	3.53	4.24	13.51
Chromium (Cr)					
Avicennia sp.	1	8.74	3.25	4.64	16.63
	2	12.24	7.36	8.61	28.21
	3	6.53	2.67	2.58	11.78
Rhizophora sp.	1	13.59	9.21	11.48	34.28
	2	23.98	18.62	15.78	58.38
	3	9.32	6.42	5.78	21.52

Table 3. BCF and TF Cu and Cr on mangrove *Avicennia* sp. and *Rhizophora* sp.

Mangrove	Location	BCF		TF	
		Cu	Cr	Cu	Cr
Avicennia sp.	1	2.34	1.1	0.69	0.53
Rhizophora sp.	1	1.36	2.26	0.61	0.84
Avicennia sp.	2	2.37	1.39	0.68	0.70
Rhizophora sp.	2	1.64	2.87	0.74	0.66
Avicennia sp.	3	2.5	0.9	0.63	0.40
Rhizophora sp.	3	1.35	1.65	0.74	0.62

(BCF 1.36–2.37) and Cr (1.1–2.87), indicating that they can accumulate high concentrations of metals in their plant tissue, even surpassing their soil concentrations with phytostabilization for both Cu (TF 0.61–0.68) and Cr (0.53–0.84). At station 3, *Avicennia* sp. and *Rhizophora* sp. are accumulators of more than one to Cu (BCF 1.35–2.5), except for *Avicenna* sp., which is an excluder of less than one for Cr metals (BCF 0.9). This indicates that these plants effectively prevent heavy metals from entering the top areas of the plants. However, the concentration of metal around the incinerator remains high due to phytoestabilization for both Cu (TF 0.63–0.74) and Cr (0.40–0.62).

In their research, Takarina and Pin (2017) and Usman et al. (2013), found that the *Avicennia* sp. plant, with a value of BCF > 1, was highly efficient in separating the metals Cu and Cr. Furthermore, according to Wu et al. (2023) and Yap and Al-Mutairi (2023), BCF Cr *Rhizophora* sp. is much more effective in reducing the mobility of Cr through the roots. On the other hand, *Avicennia* sp. is less able to absorb Cr and more consistently shows phytostabilizing properties (TF < 1) for Cu and CR. This is the process that plants use to change pollutants in the soil into non-toxic compounds without taking the pollutants into their own bodies.

Chen et al. (2005), Haque et al. (2008) and Kaewtubtim et al. (2016), concluded that different types of plants also have different physiology and different translocation potential. High concentrations of metals in the roots combined with TF values < 1 indicate the plant's potential for balanced metal translocation. Researchers have identified species like *Rhizophora apiculata* and *Rhizofora mucronata*

Table 4. Comparison of heavy metal concentrations in mangrove areas around the world

Mangrove species	BCF	TF	Location	Reference
Rhizophora apiculata	Cd (0.10; 0.01; 0.123); Zn (0.53; 0.39; 0.71)	Cd (0.85; 0.11); Zn (0.75; 0.55)	Segara Anakan Lagoon, Indonesia	[Hilmi et al., 2023]
Rhizophora mucronata	Pb (29.92; 33.27; 38.65; 59.31); Cr (24.66; 25.64; 42.93; 28.45)	Pb (leaf 0.59; 0.80; 0.87; 0.82; steam 0.83; 0.94; 0.89; 0.80); Cr (leaf 0.69; 0.60; 0.43; 0.67; steam 0.90; 0.77; 0.84)	Sei Carang, Wacopek, dan Senggarang, Indonesia	[Azizah et al., 2021]
Rhizophora stylosa	Co (0.01; 0.06; 0.20); Cu (0.52; 0.86; 1.51); Fe (0.01; 0.09; 0.06); Mn (0.20; 0.05; 0.04); Ni (0.02; 0.12; 0.25); Zn (0.16; 0.48; 0.58)	Co (0.03); Cu (0.56); Fe (0.06); Mn (4.08); Ni (0.13); Zn (0.34)	New Caledonia	[Marchand et al., 2016]
Avicennia sp.	Cu (0.261; 0.877; 0.231; 0.529); Zn (0.57; 0.482; 0.296; 0.275)	Cu (3.356; 2.291); Zn (0.846; 0.930)	Blanakan Riparian, Subang	[Ayujawi and Takarina, 2020]
Avicennia marina	Cd (0.71; 1.1; 1.19; 1.9; 0.77); Pb (1.09; 1.06; 1.25; 1.19; 1.24); Cu (0.36; 0.35; 0.3; 0.28; 0.45); Zn (0.3; 0.68; 0.35; 0.37; 0.73)	Cd (0.92; 1.42; 1.54; 2.46); Pb (1.01; 0.88;0.86; 0.96); Cu (0.8; 0.77; 0.67; 0.62); Zn (0.41; 0.93; 0.48; 0.51)	Southeast coast of India	[Arumugam et al., 2018]
Avicennia alba	Pb (0.746; 0.926; 0.914; 0.768; 0.735); Cr (0.83; 0.32)	Pb (0.773; 0.797; 0.838; 0.783; 0.756; 0.730)	Bee Jay Bakau Resort, Indonesia	[Mahmudi et al., 2021; Titah et al., 2021]

as efficient metal accumulators of Cu, Pb, Ni, Mo, Cr, and others in their roots, stem brak, and leaves, indicating their potential for phitoremediation and metal biomonitoring (Yap and Al-Mutairi, 2023). In addition, the distribution and grouping of heavy metal accumulations in Mangroves indicate variations between different species. We highlighted *Rhizophora mucronata*, *Avicennia marina*, and *Sonneratia alba* due to their specific heavy-metal accumulation capabilities (Yunasfi et al., 2022).

CONCLUSIONS

The results of the calculation of the bioconcentration factor and translocation factor values of Cu and Cr on mangroves *Avicennia* sp. and *Rhizophora* sp. at the three stations are in the accumulator category (BCF > 1), meaning that plants can hoard high concentrations of metals in their plant tissues even exceeding concentrations in the soil, except in Avicennia sp. for Cr metal as an excluder < 1 (BCF 0.9) which means that plants effectively prevent heavy metals from entering the upper area of the plant, but metal concentrations around the roots are still high and with phytostabilization values (TF < 1) for *Avicennia* sp. and *Rhizophora* sp. on Cu and Cr means that the process carried out by plants to transform pollutants in the soil into non-toxic compounds without absorbing the pollutants into the plant body. The results of the transformation of these pollutants remain in the soil of the plant to stabilize pollutants in the soil, thus making heavy metals harmless.

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