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The potential of *Avicennia alba* blume in phytoremediation of heavy metal Pb and Cu in the area east coast mangrove forest Reserve Jambi, Indonesia

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Abstract

The Batanghari River is the fourth longest river in Indonesia, and along the course of the river, there are many community activities, such as fishing, coal-carrying, and industrial activities. These various activities can cause contamination of heavy metals lead (Pb) and copper (Cu). This pollution can be overcome by using phytoremediation techniques using *Avicennia alba* Blume, which grows in the East Coast Mangrove Forest Reserve Area (CAHBPT), Jambi. This study aims to determine the potential and mechanism of phytoremediation of heavy metals Pb and Cu by *A. alba* at CAHBPT, Tanjung Solok, Tanjung Jabung Timur, Jambi. Sampling was done by a purposive sampling method. This study showed that the accumulation level of Pb metal in sediments was 10.08-13.42 mg/kg, and Cu metal was 8.61-22.92 mg/kg. The potential of *A. alba* in reducing the impact of Pb and Cu metal pollution is classified as an excluder marked BCF <1, even though the concentration of heavy metals in sediments is still below the EPA quality standard threshold for sediments. *A. alba* that grows in CAHBPT, Jambi, has a Pb metal translocation mechanism in the form of phytoextraction which is characterized by a TF value >1, and for Cu metal with a phytostabilization mechanism which is characterized by a TF <1.

Keywords: *Avicennia alba* Blume; Mangrove; Phytoremediation; Heavy Metals; East Coast Mangrove Forest Reserve Area Jambi

1. Introduction

Indonesia, Indonesian waters occupy a large part of the total area of Indonesia, which makes it a coastal country. The coastal area has many natural resources, so this area is widely used by the community as a source of livelihood, industry, and sea transportation. These various activities contribute to heavy metals that can pollute waters, especially coastal areas and river estuaries. Pollution occurs in the form of organic and inorganic pollution. There are several types of inorganic pollution, such as heavy metals, radioactive materials, and so on [1].

Heavy metals that enter the waters will accumulate to form sediment and be carried by the current toward the river estuary area. River estuaries are places where river water meets sea water [2]. The estuary of the Batanghari River, which is located in the Kuala Jambi District, East Tanjung Jabung Regency, is often used as a transportation route for fishermen and coal-carrying ships. Not only that, but many household activities, palm oil, coconut plantations, animal husbandry, and industry are also found along the Batanghari River.

Heavy metals are toxic pollutants that cannot be destroyed and can cause bioaccumulation or accumulation of heavy metals in the body of organisms [3]. Before accumulating in the bodies of organisms, heavy metals in the waters will

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first spread and settle to the bottom of the waters. This has a great opportunity to enter the bodies of marine biota that look for food at the bottom of the waters, thus allowing for the transfer of heavy metals from the environment to organisms and between organisms through the food chain [4]. This can increase the threat of heavy metal exposure to human health.

Based on the 2015 environmental status data for Jambi Province, it is known that the Batanghari River receives a lot of input waste, especially the effluent from the palm oil industry and the pulp and paper industry, which includes heavy metals, such as Pb, Zn, Cd, and Cu. Furthermore, there is previous research conducted by [5], concerning the distribution of heavy metals in sediments in the estuary and sea waters of Jambi Province, which shows that the Jambi River estuary is polluted by medium-level cobalt (Co), copper (Cu) with a high level of pollution, nickel (Ni), lead (Pb), and chromium (Cr) with a slight degree of contamination.

Control of heavy metals in water can be done using phytoremediation techniques, which have received a lot of attention because of their advantages, such as simple technology, low cost, and environmental friendliness. This technique is very important considering that heavy metals have properties that cannot be degraded, so certain plant species that can accumulate heavy metals in their roots are expected to reduce the concentration of heavy metals in the environment [6]. One type of plant that can be used in the phytoremediation of heavy metals is mangrove plants.

Tanjung Jabung Timur Regency, Jambi Province, precisely in Tanjung Solok Village, Kuala Jambi District, there is a mangrove area that is included in the Jambi East Coast Mangrove Forest Nature Reserve (CAHBPT). The Tanjung Solok mangrove area can act as a controller for heavy metals that pollute the waters of the Batanghari Estuary. A mangrove that has the potential to absorb heavy metals is *Avicennia alba* Blume, which is mostly found in CAHBPT, Tanjung Solok, Tanjung Jabung Timur, Jambi. Based on this basis, it is necessary to carry out research aimed at determining the ability and mechanism of Pb and Cu phytoremediation in *A. alba* in the East Coast Mangrove Forest Nature Reserve (CAHBPT), Tanjung Solok, Tanjung Jabung Timur, Jambi.

2. Material and methods

This research was conducted from November 2022 to January 2023. Sampling in this study was spread over three station points (Figure 1) using the purposive sampling method which will represent the study area based on characteristics.

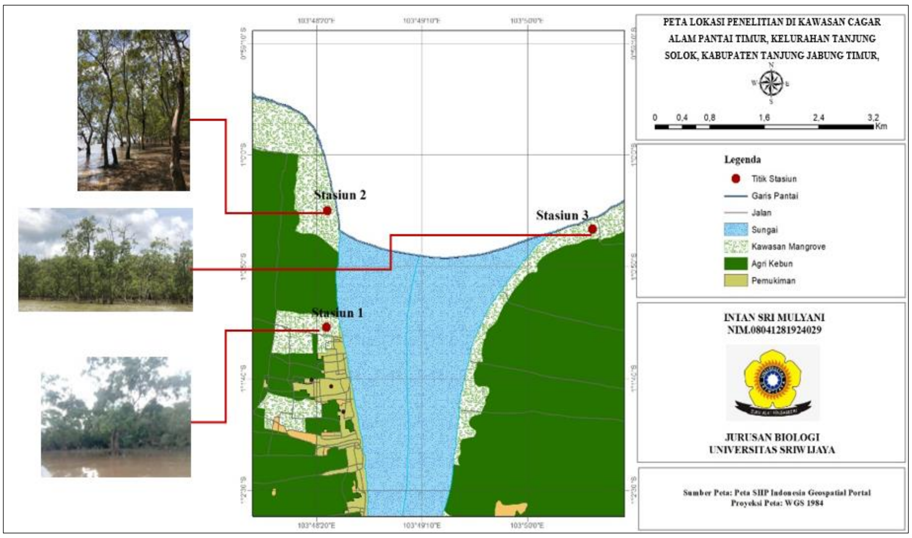

Figure 1 Map of the research location in the East Coast Mangrove Forest Nature Reserve (CAHBPT), Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province

2.1. Sampling

Sediments were taken at each station point using a pipe to a depth of ±30 cm for 500 g each. The root samples used were the pencil roots of *A. alba* and roots that were in sediment or nutrient roots. Leaf samples used dark green mature leaves.

2.2. Sample Preparation

Sample preparation of both sediment and roots and leaves was carried out based on SNI No. 06-6992.5-2004 to determine Cu levels and SNI No. 06-6992.3-2004 to determine Pb levels by acid destruction using nitric acid (HNO3) and perchloric acid (HClO4).

2.3. Measurement and Calculation of Pb and Cu contents

Measuring the content of Pb, and Cu using an Atomic Absorption Spectrophotometer (AAS) and then calculating the levels of heavy metals Pb, and Cu using the following formula:

$$Content\ of\ metal\ Cu\ or\ Pb = \frac{C \times V \times fp}{B}$$

Notes:

- Content of metal Cu or Pb in the sample (⌠g/g eq. mg/kg)
- C: Pb or Cu levels obtained from the calibration curve (μg/ml)
- V: Final volume (ml)
- Fp: Dilution factor if no dilution is done, then fp = 1.
- B: Sample weight (g)

2.4. Data analysis

2.4.1. Bioconcentration Factor (BCF)

BCF calculation is used to determine the level of heavy metal accumulation in roots and leaves originating from the environment. BCF is calculated by the formula:

$$BCF = \frac{heavy\ metal\ content\ in\ organs}{heavy\ metal\ content\ in\ sediments}$$

Notes:

If the BCF value > 1 belongs to the accumulator category, if the BCF value <1 belongs to the excluder category, and if the BCF value = 1 belongs to the Indicator category.

2.4.2. Translocation Factor (TF)

Calculation of TF is used to determine the process of transferring heavy metals (Pb and Cu) from roots to leaves. TF is calculated by the formula:

$$TF = \frac{heavy\ metal\ content\ in\ leaves}{heavy\ metal\ content\ in\ roots}$$

Notes:

The TF value has a category, namely, if TF > 1, then it is included in the phytoextraction mechanism, whereas if TF <1, then it is included in the phytostabilization mechanism.

2.5. Environmental Parameters

Environmental factor data on measurements of temperature, salinity, and pH of the water were analyzed by analysis of averages and standard deviations.

3. Results and discussion

3.1. Accumulation of Heavy Metals Pb and Cu in Sediments

The levels of accumulation of Pb and Cu metals in sediments at station 1, station 2, and station 3 are presented in Figure 2.

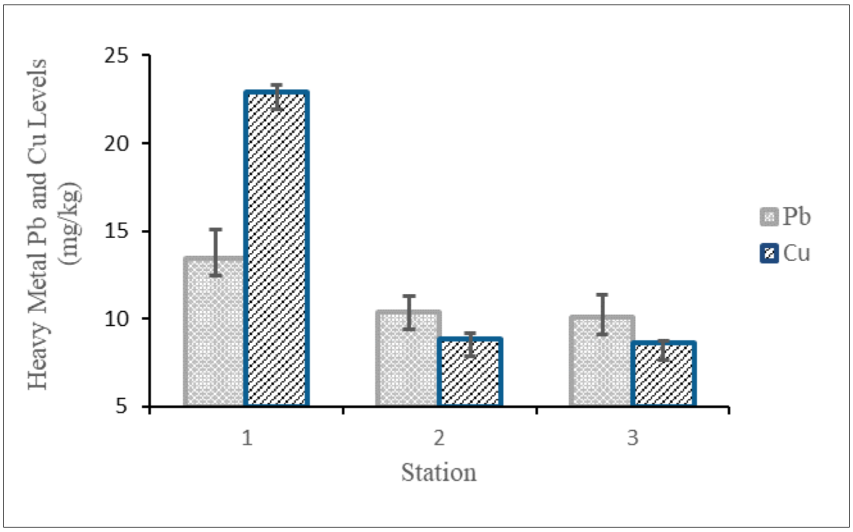

Figure 2 Heavy Metal Pb and Cu Levels in Sediments from Each Research Station in the Waters of the Batanghari Estuary in the CAHBPT Tanjung Solok area, Tanjung Jabung Timur, Jambi

The levels of accumulation of heavy metals Pb and Cu in sediments have the same pattern of distribution and accumulation of Pb and Cu. The accumulation of Pb metal in sediments was more abundant at station 1 (13.42 ± 1.68 mg/kg), followed by station 2 (10.38 ± 0.89 mg/kg) and station 3 (10.08 ± 1, 25mg/kg). The difference in the accumulation of Pb metal at each station is due to the different sources of Pb pollution at each station. Accumulation of more Pb at station 1 is thought to be due to the location of the research station which is closer to residential areas and industrial activities from upstream, so the bodies of water at the station receive a lot of domestic waste input, such as spilled paint, batteries, and pipes. Then, station 1 is also close to the fishing boat dock where there are petrol and diesel refueling activities. Based on research by [7], which shows the concentration of Pb accumulation in sediments in the waters of Loli Beach, Donggala Regency is quite high (1.78 mg/kg–7.73 mg/kg) due to shipping activities, the use of fuel oil and lubricants on ships.

The level of accumulation of Cu metal was higher at station 1 (22.92 ± 6.37 mg/kg), followed by station 2 (8.86 ± 0.19 mg/kg) and station 3 (8.61 ± 0.71 mg /kg) (Figure 1). The concentrated concentration of Cu accumulation in sediments at station 1 was caused by the dense activity of the fishing boat docks, as well as the dense activity of the population. [8] research result, showed that the level of accumulation of Cu metal in sediments along the West Coast of the Bali Strait, Banyuwangi, was higher at the Ketapang Port station (7.8 mg/kg), where this station has port, shipping, and fishing activities. Similar results were found by [9], that increased concentrations of Zn and Cu metal accumulation were found at research stations close to port activities and ferry terminals in Oman.

The contents of Pb and Cu metals in the sediments at each station showed the same distribution pattern. That is, the more toward the sea, the levels of Pb and Cu decreased (Figure 1). It is suspected that this is happening because the further it is towards the sea, the farther it is from the source of pollution, so before arriving at the station near the sea (stations 2 and 3), some of the heavy metals have already been deposited in the sediments. Based on research conducted by [10], the pattern of distribution of Pb and Cd metals in the waters of the Babon and Seringin Rivers, Semarang, looks increasingly towards the sea and away from sources of pollution, so the heavy metals carried by river currents will be deposited first while still on their way towards the sea.

The difference in the accumulation of heavy metals Pb and Cu at each station is thought to be influenced by the texture of the sediment. Sediments at Station 1 are estimated to have a relatively fine texture compared to sediments at other stations. According to [11], sediments with a fine texture (in this study there are concentrations of Pb and Cu in mud sediments) have a large surface area and stable ion density to binding heavy metals, resulting in the number of heavy metals in fine-textured sediments. there will be more.

The concentration of heavy metals Pb and Cu in the sediments of the Batanghari Estuary in the CAHBPT Area, Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province can be used to determine the environmental status of the area by comparing the results of heavy metal measurements with quality standards. This study used the EPA (Environmental Protection Authority) quality standard which has a threshold value of 50 mg/kg of Pb for sediment and 65 mg/kg of Cu for sediment. The concentrations of Pb and Cu in the waters of the Batanghari Muara River in the

CAHBPT area are 10.08-13.42 mg/kg and 8.61-22.92 mg/kg, so it can be seen that both Pb and Cu concentrations have not exceeded the quality standard threshold. EPA (2017), which means it is still in good condition and safe for biota life.

3.2. Accumulation of Heavy Metals Pb and Cu in the Roots and Leaves of *Avicennia alba*

The accumulation of Pb and Cu metals in the roots and leaves at each station is presented in Figure 3. Based on Figure 3. it can be seen that the level of accumulation of Pb metal in the roots of *A. alba* at station 1 (1.93 ± 0.41 mg/kg) is less than that of Cu metal (2.45 ± 0.47 mg/kg). Whereas at station 2 and station 3, it was the opposite where the accumulation of Pb metal in the roots of *A. alba* at station 2 (2.30 ± 0.31 mg/kg) and station 3 (2.88 ± 0.12 mg/kg) was higher compared to Cu metal at station 2 (2.17 ± 0.74 mg/kg), and station 3 (2.00 ± 0.56 mg/kg). This could be due to the fact that the accumulation of Pb in sediments at station 1 was indeed less than that of Cu, while the levels of accumulation of Pb in sediments at stations 2 and 3 were more than Cu metal (Figure 1). According to [12], the level of accumulation of heavy metals in roots is directly proportional to the level of accumulation of heavy metals in sediments. [13], added that the concentration of heavy metal accumulation in mangrove roots is due to the root organs interacting directly with sediment and water containing these heavy metals.

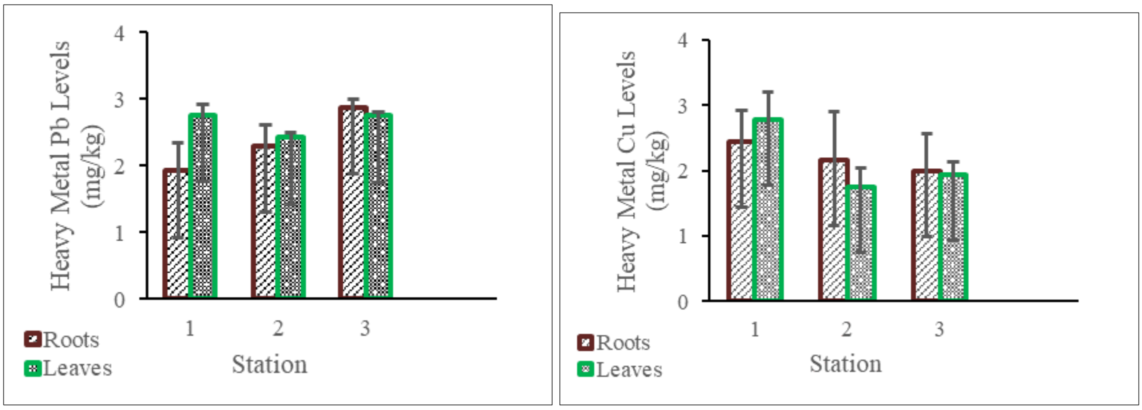

Figure 3 Levels of Pb (3a) and Cu (3b) in Roots and Leaves of *Avicennia alba* from Each Research Station in the Waters of the Batanghari Estuary in the CAHBPT area of Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province

The concentration of Pb accumulation in *A. alba* leaves was mostly at station 1 (2.76 ± 0.16 mg/kg), followed by station 3 (2.75 ± 0.06 mg/kg) and station 2 (2.75 ± 0.06 mg/kg). 43 ± 0.06 mg/kg). Furthermore, the levels of Cu metal in *A. alba* leaves were more abundant at station 1 (2.78 ± 0.42 mg/kg), followed by station 3 (1.93 ± 0.21 mg/kg) and station 2 (1, 75 ± 0.29 mg/kg). The results of these measurements indicated that the average concentration of Pb accumulation in *A. alba* leaves was higher than that of Cu metal. This can be caused by the mobility of Pb from roots to leaves, which is quite high and also related to localization efforts by *A. alba* for Pb metal, which is non-essential for plants and other organs, such as leaves which are localized in the vacuole. According to [14], the high accumulation of Pb in the leaves is a localization effort by mangroves by hoarding it in one organ.

In Figure 2.b. it can be seen that the average accumulation of Cu in the roots is more than in the leaves. Root organs have direct interactions with sediment and water, so they can be a factor for high Cu content in roots. In addition, the level of accumulation of Cu in the roots was higher than in the leaves, which could also be caused by *A. alba* using Cu metal to meet metabolic needs. Based on research by [12], showed that the low translocation of essential metals (in this study using Cu metal) in mangroves was due to the use of these metals by mangroves for metabolic and growth activities. Further added by [15], Cu metal is needed for plants in mitochondrial and chloroplast reactions, cell wall lignification processes, carbohydrate metabolism, and protein synthesis, and is needed in enzyme systems related to photosystem II electron transport.

The average levels of Pb accumulation were in contrast to Cu, where Pb accumulation was more in the leaves than in the roots. Pb metal is a non-essential metal which means it is not needed by organisms, such as plants because it is toxic. [16] stated that Pb is toxic to plants because it is known to interfere with plant growth, root elongation, seed germination, transpiration, and interfere with chlorophyll production. This causes *A. alba* to localize Pb to other parts of the plant body, such as leaves, which can then be released through leaf aborting. According to [12], non-essential metals have high mobility from roots to leaves because these metals are not used by mangroves, which includes efforts to localize heavy metals from mangroves to certain parts. Further added by [17], the metal will enter the plant through the roots, then be distributed and accumulated in the tissues in the leaf organs, and then released along with leaf fall (abscission).

3.3. Bioconcentration Factor (BCF) and Translocation Factor (TF) of Heavy Metals Pb and Cu in *Avicennia alba*

Based on Table 2, it can be seen that the BCF values of Pb and Cu metals in the roots were 0.21 and 0.16, respectively, while the BCF values of Pb and Cu metals in the leaves were 0.23 and 0.15, respectively. The BCF values of Pb and Cu metals in both roots and leaves show a value of less than one (<1). This shows that the ability of *A. alba* in the Muara Sungai Batanghari waters in the CAHBPT area of Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province is categorized as an excluder plant for Pb and Cu metals. Similar results were found in a study by [12], that the BCF value for *A. alba* in Wonorejo Waters, Surabaya City for Pb and Cu metals is <1, which means that *A. alba* is categorized as an excluder plant.

Table 1 Biological Concentration Factor (BCF) and Translocation Factor (TF). in *Avicennia alba*. at the estuary of the Batanghari River in the Tanjung Solok CAHBPT Area, Tanjung Jabung Timur, Jambi

Heavy Metals	BCF		TF
	Roots	**Leaves**	
Pb	0.21	0.23	1.12
Cu	0.16	0.15	0.97

Excluding plants can limit the absorption and movement of heavy metals entering their bodies. [18] added that the avoidance strategy refers to the ability of plants to limit the absorption and movement of heavy metals in the plant body through various mechanisms such as metal immobilization using root exudates (organic acids released by roots) in the root area. The BCF value < 1 can be caused by the concentration of accumulated Pb and Cu metals in sediments, which is more than the accumulation in plant organs, both roots and leaves. According to [19], the BCF value for Mercury accumulation is low (BCF < 1) because the concentration of Mercury accumulation in plant body parts is less than in sediments.

The translocation factor (TF) of *A. alba* for Pb metal was 1.12 (Table 2). The TF value of Pb metal shows a value of > 1 which means that *A. alba* in the waters of the Batanghari Estuary in the CAHBPT Area, Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province uses a phytoextraction mechanism for Pb metal. Similar results were found in a study by [12], that *A. alba* in Wonorejo Waters, Surabaya has a TF value> 1 for Pb metal, so the *A. alba* translocation mechanism there is classified as phytoextraction. According to [20], the mechanism of phytoextraction is a process of absorption of heavy metals through plant roots which will then be transferred or translocated to other parts of the body. The translocation of Pb metal includes efforts to localize Pb as a non-essential metal by plants.

Phytoextraction of heavy metals can be carried out by plants by absorbing metals from the environment through the roots in the form of metal ions, then translocated to the top of the plant, such as leaves through the xylem vessels with chelating substances, then when it reaches the leaf organs it will be stored in several tissues. According to [18], the mechanism of absorption and translocation of heavy metals in plants includes several steps, namely mobilization of metals that are still bound to sediments with the help of root exudates (organic acids, or metal-binding peptides), then absorption of metal complexes with organic ligands by root symplastically, then the metal complex is translocated from the root to the leaf through the xylem vessels, after arriving at the leaf, the metal will enter into several tissues in the leaf organs and can be stored in cell vacuoles in the leaf organs so as not to disturb the physiology of the plant itself.

Based on Table 1, shows that the type of *A. alba* phytoremediation mechanism used for Cu metal is in the form of phytostabilization because the TF value <1. According to [21], the phytostabilization mechanism is a remediation strategy carried out by plants, to immobilize heavy metals in the rhizosphere and when absorbed, the metals will be retained in the roots. Further added by [22], that heavy metals in roots can be retained because they are bound by root cell walls composed of pectin, besides that there are also vacuoles in the cell walls which act as storage for heavy metals carried by chelating substances in the form of metal-binding peptides and organic acids, which where these chelating substances bind heavy metals in the cytosol.

When compared, the TF value of Pb metal is higher than Cu metal (Table 1). This can be caused by differences in the types of metals in the two, where Pb metal is included in non-essential metals which are toxic both in small and large amounts, so that the mobility of Pb from roots to leaves is higher as an effort to localize toxic metals by plants to other parts of the body. By the opinion of [14], the high concentration of Pb accumulation in other plant parts (in this study on the leaves) is a localization effort by plants. As for Cu metal as an essential metal, the presence of this metal is needed by plants for metabolic processes.

4. Conclusion

Based on research on Lead (Pb) and Copper (Cu) Heavy Metal Phytoremediation by *Avicennia alba* Blume. In the area of the East Coast Mangrove Forest Nature Reserve (CAHBPT), Tanjung Solok Village, East Tanjung Jabung Regency, Jambi Province, which has been carried out, it can be concluded that the ability of *A. alba* to reduce the impact of Pb and Cu metal pollution is classified as an excluder marked BCF < 1, although the concentration of heavy metals in sediments is still below the Environmental Protection Authority (EPA) quality standards for sediments. *A. alba* at CAHBPT, Tanjung Solok, Tanjung Jabung Timur, Jambi has a Pb metal translocation mechanism in the form of phytoextraction which is characterized by a TF value> 1, and for Cu metal using a phytostabilization mechanism which is characterized by a TF <1.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Mohan, A. Saraswat, Y. S. Ok, and C. U. Pittman, "Organic and Inorganic Contaminants Removal From Water with Biochar, A Renewable, Low Cost and Sustainable Adsorbent - A Critical Review," Bioresour. Technol., vol. 160, pp. 191–202, 2014, doi: 10.1016/j.biortech.2014.01.120.

[2] A. Pamuji, M. R. Muskananfola, and C. A'in, "The Effect of Sedimentation on Macrozoobenthos Abundance in the Betahwalang River Estuary, Demak Regency," J. Saintek Perikan., vol. 10, no. 2, pp. 129–135, 2015.

[3] S. Yudo, "Conditions of Heavy Metal Pollution in DKI Jakarta River Waters," JAI, vol. 2, no. 1, pp. 1–15, 2006.

[4] H. Setiawan, "Accumulation and Distribution of Heavy Metals in Mangrove Vegetation in Coastal Waters of South Sulawesi," J. Ilmu Kehutan., vol. 7, no. 1, pp. 12–24, 2013.

[5] T. M. Susantoro, D. Sunarjanto, and A. Andayani, "Distribution of Heavy Metals in Sediments in the Muara and Sea Waters of Jambi Province," J. Kelaut. Nas., vol. 10, no. 1, pp. 1–11, 2015.

[6] V. C. Pandey and O. Bajpai, "Phytoremediation: From Theory Toward Practice," in Phytomanagement of Polluted Sites: Market Opportunities in Sustainable Phytoremediation, V. C. Pandey and K. Bauddh, *Eds*. Elsevier Inc., 2018, pp. 1–49.

[7] S. Santi, V. M. A. Tiwow, and S. T. Gonggo, "Analysis of Copper (Cu) and Lead (Pb) in Seawater and Sediments in Loli Beach Waters, Banawa District, Donggala Regency," J. Akad. Kim., vol. 6, no. 4, pp. 241–246, Jan. 2018, doi: 10.22487/j24775185.2017.v6.i4.9456.

[8] D. Yona, S. H. J. Sari, A. Kretarta, C. R. P. Effendy, M. N. Aini, and M. A. A. Adi, "Distribution and Status of Heavy Metal Contamination in Sediments Along the West Coast of the Bali Strait, Banyuwangi," TORANI J. Fish. Mar. Sci., vol. 1, no. 2, pp. 21–30, 2018, doi: 10.35911/torani.v1i2.4439.

[9] B. P. Jupp, S. W. Fowler, S. Dobretsov, H. van der Wiele, and A. Al-Ghafri, "Assessment of Heavy Metal and Petroleum Hydrocarbon Contamination in The Sultanate of Oman with Emphasis on Harbours, Marinas, Terminals and Ports," Mar. Pollut. Bull., vol. 121, no. 1–2, pp. 260–273, Aug. 2017, doi: 10.1016/j.marpolbul.2017.05.015.

[10] S. Y. Wulandari, B. Yulianto, and Sukristiyo, "Distribution Pattern of Pb and Cd Heavy Metals in the Babon and Seringin River Estuaries, Semarang," J. Ilmu Kelaut., vol. 13, no. 4, pp. 203–208, 2008.

[11] E. Supriyantini and N. Soenardjo, "Lead (Pb) and Copper (Cu) Heavy Metal Content in *Avicennia marina* Mangrove Roots and Fruits in Tanjung Emas Waters, Semarang," J. Kelaut. Trop., vol. 18, no. 2, pp. 98–106, 2015.

[12] R. Rachmawati, D. Yona, and R. D. Kasitowati, "The Potential of Avicennia alba Mangrove As a Phytoremediation Agent for Heavy Metals Lead (Pb) and Copper (Cu) in Wonorejo Waters, Surabaya City," J. Kelaut. Indones. J. Mar. Sci. Technol., vol. 11, no. 1, pp. 80–87, Nov. 2018, doi: 10.21107/jk.v11i1.3341.

[13] P. K. Dewi, E. D. Hastuti, and R. Budihastuti, “Accumulation Ability of Heavy Metal Copper (Cu) in Mangrove Roots of *Avicennia marina* (Forsk.) and *Rhizophora mucronata* (Lamk.) Types in Ponds,” J. Akad. Biol., vol. 7, no. 4, pp. 14–19, 2018.

[14] N. M. Heriyanto and E. Subiandono, “Absorption of Heavy Metal Pollutants (Hg, Pb and Cu) by Mangrove Types,” J. Penelit. Hutan dan Konserv. Alam, vol. 8, no. 2, pp. 177–188, 2011, doi: 10.20886/jphka.2011.8.2.177-188.

[15] J. A. C. Verkleij and H. Schat, “Mechanisms of Metal Tolerance in Higher Plants,” in Heavy Metal Tolerance in Plants: Evolutionary Aspects, Boca Raton, Florida: CRC Press Inc, 1990, pp. 179–193.

[16] B. Pourrut, M. Shahid, C. Dumat, P. Winterton, and E. Pinelli, “Lead Uptake, Toxicity, and Detoxification in Plants,” in Reviews of Environmental Contamination and Toxicology, vol. 213, Castanet-Tolosan, France: EcoLab (Laboratoire d’écologie fonctionnelle), 2011, pp. 113–136.

[17] R. L. Chaney, S. L. Brown, and J. S. Angle, “Soil – Root Interface : Ecosystem Health and Human Food-Chain Protection,” no. 52, pp. 279–311, 1998.

[18] A. A. Dalvi and S. A. Bhalerao, “Response of Plants towards Heavy Metal Toxicity: An overview of Avoidance, Tolerance and Uptake Mechanism,” Ann. Plant Sci., pp. 362–368, 2013, [Online]. Available: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d2fc85a59f9d797395f982304a87edaf5a063036.

[19] I. Ismail, R. Mangesa, and I. Irsan, “Bioaccumulation of Heavy Metal Mercury (Hg) in Rhizophora Mucronata Mangrove in Kayeli Bay, Buru Regency,” Biosel Biol. Sci. Educ., vol. 9, no. 2, pp. 139–152, Dec. 2020, doi: 10.33477/bs.v9i2.1637.

[20] A. J. M. Baker, “Accumulators and Excluders - Strategies in the Response of Plants to Heavy Metals,” J. Plant Nutr., vol. 3, no. 1–4, pp. 643–654, 1981, doi: 10.1080/01904168109362867.

[21] N. S. Bolan, J. H. Park, B. Robinson, R. Naidu, and K. Y. Huh, “Phytostabilization: A Green Approach to Contaminant Containment,” in Advances in Agronomy, vol. 112, Elsevier Inc., 2011, pp. 145–204.

[22] W. H. O. Ernst, J. A. C. Verkleij, and H. Schat, “Metal Tolerance in Plants,” Acta Bot. Neerl., vol. 41, no. 3, pp. 229–248, Sep. 1992, doi: 10.1111/j.1438-8677.1992.tb01332.x