



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] Submission Acknowledgement

1 pesan

Ahmad Dwi Setyawan via SMUJO <support@smujo.com>

13 November 2023 pukul 10.44

Balas Ke: Ahmad Dwi Setyawan <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

Thank you for submitting the manuscript, "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment" to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: <https://smujo.id/biodiv/authorDashboard/submission/16424>

Username: rozirwanb

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ahmad Dwi Setyawan

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com>

10 Desember 2023 pukul 16.01

Balas Ke: Smujo Editors <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>, Nadila Nur Khotimah <nadilakhotimah1142@gmail.com>, Wike Ayu Eka Putri <wike_ayu_ep@unsri.ac.id>, Fauziyah <siti_fauziyah@yahoo.com>, Riris Aryawati <riris.aryawati@unsri.ac.id>, Nurhayati Damiri <nurhayati@fp.unsri.ac.id>, Isnaini <isnainimawardi22@gmail.com>, Redho Yoga Nugroho <redhoyn.29@gmail.com>

Rozirwan Rozirwan, Nadila Nur Khotimah, Wike Ayu Eka Putri, Fauziyah, Riris Aryawati, Nurhayati Damiri, Isnaini, Redho Yoga Nugroho, Redho Yoga Nugroho:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment". Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) or enable Track Changes.

Our decision is: Revisions Required

Reviewer C:Recommendation: See Comments

Reviewer J:

This study investigates the environmental risk of heavy metal pollution in the mangrove ecosystem of Payung Island, South Sumatra, Indonesia. Focusing on three mangrove species (*Sonneratia caseoralis*, *Rhizophora apiculata*, *Xylocarpus granatum*), the research analyzes heavy metal concentrations in both mangrove roots and surrounding sediments using atomic absorption spectrometry. Employing ecological risk assessment parameters such as Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI), the study finds that although heavy metal concentrations in sediments are notably higher than in mangrove roots, the ecosystem remains classified as safe based on the established indices. The investigation highlights the role of mangrove roots in preventing heavy metal translocation to the upper parts of the plants and emphasizes the significance of root types in influencing metal concentrations. Additionally, the study underscores the importance of considering human activities, such as fisheries and household waste, in understanding contamination factors at different observation stations. Overall, the findings contribute valuable insights into the resilience of mangrove ecosystems to heavy metal pollution and provide a basis for environmental risk assessment in coastal areas.

Strengths:

The paper has several strengths. First, the authors used a variety of materials and methods, including data collection, interviews, and surveys, to conduct their environmental risk assessment. Second, they used statistical analysis to analyze the data collected and make recommendations for risk reduction and management. Third, they used the geoaccumulation index to assess the environmental risks of the metals. Fourth, they considered the potential for contamination of the environment, the presence of vulnerable populations, and the need for risk reduction. Finally, they evaluated the effectiveness of the risk reduction measures.

Weaknesses:

The paper has some weaknesses. First, the authors did not consider other potential sources of environmental risk, such as air pollution or water contamination. Second, the study area and sampling sites were limited in scope and may not have been representative of the entire region. Third, the data analysis techniques used to evaluate the environmental risks were limited in scope and may not have been comprehensive. Finally, the authors did not consider the long-term impacts of their recommendations for risk reduction and management.

There is some questions:

1. How do the concentrations of heavy metals (Pb, Cu, Zn, Cd) in mangrove roots compare with those in the surrounding sediments, and what implications does this have for the ecological risk assessment?
2. The paper mentions various root structures of mangrove species. How might the different root structures of *Sonneratia caseoralis*, *Rhizophora apiculata*, and *Xylocarpus granatum* contribute to variations in heavy metal concentrations in their roots?
3. According to the paper, mangrove roots are efficient at retaining heavy metals within the root system. How does this efficiency contribute to the overall safety of the mangrove ecosystem in the context of heavy metal pollution?
4. The study suggests that variations in heavy metal concentrations depend on root types. How does the concentration of heavy metals differ between the cone-like vertical breath roots of *Sonneratia caseoralis*, aerial roots of *Rhizophora apiculata*, and plank roots of *Xylocarpus granatum*?
5. How do the characteristics of mangrove sediments, such as being anaerobic, reduced, and rich in organic matter, contribute to their potential to absorb heavy metals over the long term?
6. The paper mentions that mangrove roots prevent heavy metals from entering the upper parts of the plant. How does the translocation of heavy metals within mangrove roots impact the overall health of the mangrove ecosystem?
7. The study uses Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI) for ecological risk assessment. How do these parameters collectively provide a comprehensive understanding of heavy metal pollution in the mangrove ecosystem?
8. The Igeo values suggest that sediments in the Payung Island mangrove ecosystem are not contaminated. How reliable is the Geo-accumulation Index (Igeo) in determining sediment quality, and what are its limitations?
9. The Contamination Factor (Cf) results indicate low pollution except for Pb, which shows moderate contamination. How do human activities, such as fisheries, boat transportation, and household waste, contribute to the variation in contamination factors at different observation stations?
10. The highest Pollution Load Index (PLI) value was found at station 3 (*X. granatum*). How do the concentrations of heavy metals at this station compare to the others, and what specific human activities around this area might contribute to the elevated PLI?

Recommendation: Revisions Required

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



C-16424-Article Text-1100222--24Nov2023b_Review.pdf

695K

Table of Responses

No.	Questions	Answers
1	How do the concentrations of heavy metals (Pb, Cu, Zn, Cd) in mangrove roots compare with those in the surrounding sediments, and what implications does this have for the ecological risk assessment?	<p>The concentrations of heavy metals (Pb, Cu, Zn, and Cd) in mangrove roots are lower than in sediments, indicating that mangrove roots are able to effectively prevent heavy metals from entering the upper area of the plant, even though the concentration of metals in the surrounding sediments is higher, it still does not exceed the predetermined threshold.</p> <p>The direct impact of the ecological risk assessment of heavy metal contamination of sediments and roots is of course to evaluate the possibility of adverse negative impacts due to pollutants on the environment and the environment.</p>
2	The paper mentions various root structures of mangrove species. How might the different root structures of <i>Sonneratia caseoralis</i> , <i>Rhizophora apiculata</i> , and <i>Xylocarpus granatum</i> contribute to variations in heavy metal concentrations in their roots?	<p>The board root of <i>X. granatum</i> is a type of root that is below the sediment surface, in contrast to <i>S. caseoralis</i> breath roots and <i>R. apiculata</i> aerial roots which are included in the type of roots that are outside the sediment surface. The concentration of heavy metals in <i>X. granatum</i> roots is the lowest compared to the others because of the plank root under sediment surface is able to store a lot of water to dilute the concentration of heavy metals in its body tissues, thereby reducing the toxicity of these metals. <i>X. granatum</i> in this study was found in the upper zone where the area is periodically submerged, including plants in the area that are also periodically submerged by tides in coastal areas.</p>
3	According to the paper, mangrove roots are efficient at retaining heavy metals within the root system. How does this efficiency contribute to the overall safety of the mangrove ecosystem in the context of heavy metal pollution?	<p>Based on the results of the Bioconcentration Factor (BCF), the roots are classified in the exclusion, namely plants that effectively prevent heavy metals from entering the upper part of the plant, but the metal concentration around the root area is still high. This may contribute to mangrove safety due to heavy metal pollution that has exceeded the threshold can affect the process of development and growth of mangroves due to excessive and</p>

		uncontrolled oxidative stress that causes chlorosis and decay in the leaves and ends at the end of the mangrove mortality.
4	The study suggests that variations in heavy metal concentrations depend on root types. How does the concentration of heavy metals differ between the cone-like vertical breath roots of <i>Sonneratia caseoralis</i> , aerial roots of <i>Rhizophora apiculata</i> , and plank roots of <i>Xylocarpus granatum</i> ?	<p>The vertical breath root of <i>S. caseoralis</i> and aerial root of <i>R. apiculata</i> are surface or dry roots that have lower water content compared to the board root of <i>X. granatum</i> in the sediment (wet root). In addition, it is suspected that the plank root has other toxic coping abilities, including by weakening the toxic effect through dilution, which is by storing a lot of water to dilute the concentration of heavy metals in its body tissue so as to reduce the toxicity of the metal. Another factor is that the roots of <i>S. caseoralis</i> and <i>R. apiculata</i> are of the same type, but the accumulation of heavy metals is different.</p> <p><i>The reason S. caseoralis is higher than R. apiculata is that S. caseoralis is a frontzone mangrove species that can accumulate more heavy metals because it is in direct contact with the water than the mangrove zone in the front zone (R. apiculata).</i></p>
5	How do the characteristics of mangrove sediments, such as being anaerobic, reduced, and rich in organic matter, contribute to their potential to absorb heavy metals over the long term?	Anaerobic, reduced, and rich sediments are characterized by clay or fine-grained sediments. Finer substrates have a stronger ability to bind organic matter than coarser substrates. The finer the sediment size, the higher its strength to bind heavy metals so that they are not absorbed by plants. That may jeopardize growth and their development. In the long term, sediments with these characteristics can help reduce concentrations in the plants (mangroves)
6	The paper mentions that mangrove roots prevent heavy metals from entering the upper parts of the plant. How does the translocation of heavy metals within mangrove roots impact the overall health of the mangrove ecosystem?	The impact of heavy metal translocation in the roots on the overall health of the mangrove ecosystem is that heavy metals that enter the roots will experience various responses to cope with toxic material in the tubunhta. Possible coping mechanisms are localization, excretion, dilution to weaken the toxic effects of heavy metals through dilution, and chemical inactivation. With the ability of mangroves to defend

		themselves against environmental pressures, it can reduce the negative effects that will occur, such as death in mangrove ecosystems.
7	The study uses Bioconcentration Factor (BCF), Geoaccumulation Index (I_{geo}), Contamination Factor (Cf), and Pollution Load Index (PLI) for ecological risk assessment. How do these parameters collectively provide a comprehensive understanding of heavy metal pollution in the mangrove ecosystem?	Ecological risk assessment uses indicators of bioconcentration factor (bcf), geoaccumulation index (i_{geo}), contamination factor (cf), and pollution load index (pli) as important components in the process of estimating the probability of pollutant pollution that negatively affects the environment, because BCF is used to determine the bioaccumulation of metals from mangroves in water and sediment. I_{geo} quantitatively evaluates the extent of heavy metal contamination and assigns pollution levels according to classification criteria. The contamination factor is used to quantify the level of contamination and also the possible influence caused by anthropogenic activities on sediments. The pollution load index is used to determine the quality of pollution. Thus, the overall heavy metal pollution of an ecosystem within a certain classification can be determined by the presence of indicators.
8	The I_{geo} values suggest that sediments in the Payung Island mangrove ecosystem are not contaminated. How reliable is the Geo-accumulation Index (I_{geo}) in determining sediment quality, and what are its limitations?	The index of geo accumulation (I_{geo}) is a method used to evaluate the level of heavy metal contamination in sediments. The method is designed to help identify whether a site is polluted or not, as well as to assess the level of sediment pollution in an area. I_{geo} is mainly used to assess heavy metal contamination in sediments, such as mercury, cadmium, lead and others. Therefore, I_{geo} may not provide complete information on contamination by these substances non-metallic or other pollutants.
9	The Contamination Factor (Cf) results indicate low pollution except for Pb, which shows moderate contamination. How do human activities, such as fisheries, boat transportation, and household waste, contribute to the variation in contamination factors at different observation stations?	Payung Island is a river estuary area that is influenced by various anthropogenic activities such as the transportation rate of coal transport ships, fishing boats, household waste from the Sungsang Village community, Tanjung Api-api port, and other industrial activities around the river estuary.

		<p>Heavy metal groups such as Pb and Cd are non-essential heavy metals which means that they have no biological relevance and are harmful to plants and animals at higher concentrations. The source of Pb and Cd can come from ballast water waste from transportation of cargo ships, fishing boats, and passenger ships, because the fuel used in the form of gasoline and diesel is one of the main sources of Pb and Cd pollution that can enter the waters. While metals such as Cu and Zn known as micronutrients play an important role in the metabolic and physiological activities of humans, plants and microorganisms depending on their concentration, if they exceed the threshold they can also adversely affect the growth and development process. Ships that are generally made of wood must be coated with paint that contains Cuprum Chrome Arsenic (CCA) as anti-fouling agent. These paints will dissolve into the water column as the vessel activities and can therefore be a source of Cu pollution in waters.</p>
10	<p>The highest Pollution Load Index (PLI) value was found at station 3 (<i>X. granatum</i>). How do the concentrations of heavy metals at this station compare to the others, and what specific human activities around this area might contribute to the elevated PLI?</p>	<p>The highest Pollution Load Index (PLI) value at station 3 (<i>X. granatum</i>) is higher because this station is directly opposite Sungsang Village, which is an area crowded with fishing activities and household waste such as detergents, soaps, and organic/inorganic waste. In addition, station 3 is located in a consequent river estuary area (the flow is in the same direction as the slope). In contrast, stations 1 and 2 are located in the estuary of an open river that is directly connected to the Bangka Strait which is inconsistent (irregular flow) caused by high currents and waves, so that the concentration of heavy metals in both waters and sediments is high dynamic.</p>



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com>

23 Desember 2023 pukul 13.30

Balas Ke: Smujo Editors <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>, Nadila Nur Khotimah <nadilakhotimah1142@gmail.com>, Wike Ayu Eka Putri <wike_ayu_ep@unsri.ac.id>, Fauziyah <siti_fauziyah@yahoo.com>, Riris Aryawati <riris.aryawati@unsri.ac.id>, Nurhayati Damiri <nurhayati@fp.unsri.ac.id>, Isnaini <isnainimawardi22@gmail.com>, Redho Yoga Nugroho <redhoyn.29@gmail.com>


Rozirwan Rozirwan, Nadila Nur Khotimah, Wike Ayu Eka Putri, Fauziyah, Riris Aryawati, Nurhayati Damiri, Isnaini, Redho Yoga Nugroho, Redho Yoga Nugroho:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment". Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) or enable Track Changes.

Our decision is: Revisions Required

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.

2 lampiran **A-16424-Article Text-1103724-1-4-20231220 REV.doc**
6879K **A-16424-Article Text-1103724-1-4-20231220.xlsx**
72K



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] New notification from Biodiversitas Journal of Biological Diversity

1 pesan

Aditya Triyanto via SMUJO <support@smujo.com>

28 Desember 2023 pukul 19.22

Balas Ke: Aditya Triyanto <aditya@smujo.id>, Ahmad Dwi Setyawan <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

You have been added to a discussion titled "Uncorrected proof" regarding the submission "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment".

Link: <https://smujo.id/biodiv/authorDashboard/submission/16424>

Ahmad Dwi Setyawan

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] New notification from Biodiversitas Journal of Biological Diversity

1 pesan

DEWI NUR PRATIWI via SMUJO <support@smujo.com>

29 Desember 2023 pukul 04.32

Balas Ke: DEWI NUR PRATIWI <biodiv07@gmail.com>, Ahmad Dwi Setyawan <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

You have been added to a discussion titled "BILLING" regarding the submission "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment".

Link: <https://smujo.id/biodiv/authorDashboard/submission/16424>

Ahmad Dwi Setyawan

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] New notification from Biodiversitas Journal of Biological Diversity

1 pesan

DEWI NUR PRATIWI via SMUJO <support@smujo.com>

3 Januari 2024 pukul 06.32

Balas Ke: DEWI NUR PRATIWI <biodiv07@gmail.com>, Ahmad Dwi Setyawan <editors@smujo.id>

Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

There is new activity in the discussion titled "BILLING" regarding the submission "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment".

Link: <https://smujo.id/biodiv/authorDashboard/submission/16424>

Ahmad Dwi Setyawan

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



Biodiversitas & Nusantara Biosci.

Society for Indonesian Biodiversity

Jl. Ir. Sutami 36 A Surakarta 57126
Tel./Fax. 0271-663375, email: unsjournals@gmail.com
http://biodiversitas.mipa.uns.ac.id/
http://biosains.mipa.uns.ac.id/nusbioscience.htm

INVOICE

for AUTHOR

DATE	29/12/2023
CUSTOMER ID	688
DUE DATE	05/01/2024

BILL TO

ROZIRWAN

Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya
Jl. Raya Palembang-Prabumulih Km. 32, Indralaya, Ogan Ilir 30862, South Sumatra, Indonesia
Tel. +62-711-580056, Fax. +62-711-580268
email: rozirwan@unsri.ac.id

Title:

Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment

DESCRIPTION	TAXED	AMOUNT (IDR)
Payment for manuscript publication		6.000.000,00
Payment for English improvement		-
Cost reduction for manuscript presented in the SIB Meeting		-

Subtotal	6.000.000,00
Taxable	-
Tax rate	0,000%
Tax due	-
Other	-
TOTAL IDR	6.000.000,00

OTHER COMMENTS

1. Currency exchange: USD 1 = IDR 14,000
2. Total bill: IDR 6,000,000,-
3. Transfer to BNI (BNINIDJA), Acc. no. 0356986994 (Dewi Nur Pratiwi)
4. Send the proof of payment to finance@smujo.id and a carbon copy (CC) to unsjournals@gmail.com

If you have any questions about this invoice, please contact
Dewi NP. HP +62-812-9165-0588, email: dewinp11@gmail.com

Terimakasih atas partisipasi anda



Transaksi Berhasil

Rekening Tujuan 356986994

Nama Penerima Ibu DEWI NUR PRATIWI

Tanggal Transaksi 29-12-2023

Waktu Transaksi 09:29:47 WIB

Email Penerima

Bank Tujuan BNI

Nama Pengirim ROZIRWAN

Nominal 6.000.000

Fee 0

Total 6.000.000

Keterangan Publication Fee Rozirwan et al 2023



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] New notification from Biodiversitas Journal of Biological Diversity

1 pesan

Smujo Editors via SMUJO <support@smujo.com>
Balas Ke: Ahmad Dwi Setyawan <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

18 Januari 2024 pukul 07.21

You have a new notification from Biodiversitas Journal of Biological Diversity:

There is new activity in the discussion titled "Uncorrected proof" regarding the submission "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment".

Link: <https://smujo.id/biodiv/authorDashboard/submission/16424>

Ahmad Dwi Setyawan

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.



Rozirwan unsri <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Managers via SMUJO <support@smujo.com>

22 Januari 2024 pukul 17.34

Balas Ke: Managers <managers@smujo.id>

Kepada: ROZIRWAN <rozirwan@unsri.ac.id>, NADILA NUR KHOTIMAH <nadilakhotimah1142@gmail.com>, WIKE AYU EKA PUTRI <wike_ayu_ep@unsri.ac.id>, FAUZIYAH <siti_fauziah@yahoo.com>, RIRIS ARYAWATI <riris.aryawati@unsri.ac.id>, NURHAYATI <nurhayati@fp.unsri.ac.id>, ISNAINI <isnainimawardi22@gmail.com>, REDHO YOGA NUGROHO <redhoyn.29@gmail.com>

ROZIRWAN, NADILA NUR KHOTIMAH, WIKE AYU EKA PUTRI, FAUZIYAH, RIRIS ARYAWATI, NURHAYATI, ISNAINI, REDHO YOGA NUGROHO:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment".

Our decision is to: Accept Submission

[Biodiversitas Journal of Biological Diversity](#)

Caution: This e-mail (including attachments, if any) is sent by system and only intended for the recipients listed above. If you are not the intended recipient, then you are not permitted to use, distribute, distribute, or duplicate this e-mail and all its attachments. Please cooperate to immediately notify Smujo International and delete this e-mail and all attachments. This email was sent due to, your email is listed as participant on Biodiversitas Journal of Biological Diversity.

Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment

ROZIRWAN¹✉, NADILA NUR KHOTIMAH², WIKE AYU EKA PUTRI¹, FAUZIYAH¹, RIRIS ARYAWATI¹,
NURHAYATI DAMIRI³, ISNAINI¹, REDHO YOGA NUGROHO²

¹Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. Jl. Raya Palembang-Prabumulih Km. 32, Ogan Ilir 30862, South Sumatra, Indonesia. Tel.: +62-711-580056, Fax.: +62-711-580268, ✉email: rozirwan@unsri.ac.id

²Program of Environmental Management, Graduate Program, Universitas Sriwijaya. Jl. Padang Selasa No.524, Palembang 30139, South Sumatra, Indonesia

³Department of Plant Protection, Faculty of Agriculture, Universitas Sriwijaya. Jl. Raya Indralaya, Ogan Ilir 30662, South Sumatra, Indonesia

Manuscript received: 13 November 2023. Revision accepted: 25 December 2023.

Abstract. Rozirwan, Khotimah NN, Putri WAE, Fauziyah, Aryawati R, Damiri N, Isnaini, Nugroho RY. 2023. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. *Biodiversitas* 24: 6733-6742. Mangroves as the largest coastal ecosystem can accumulate heavy metals from their environment. This study aimed to evaluate the environmental risk associated with heavy metal pollution accumulated in the roots of mangroves and the surrounding sediments. The mangrove roots consisted of three species *Sonneratia caseolaris*, *Rhizophora apiculata*, and *Xylocarpus granatum*, collected from three observation stations within the Payung Island mangrove ecosystem in South Sumatra, Indonesia. The concentrations of heavy metals were determined using atomic absorption spectrometry. Statistical analysis employed one-way Analysis of Variance (ANOVA). At the same time, ecological risk assessment utilized the Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination factor (Cf), and Pollution Load Index (PLI). The highest sediment concentrations of heavy metals at station 3 were 12.786±0.26 mg/kg for Pb, 10.413±0.011 mg/kg for Cu, 42.752±0.053 mg/kg for Zn, and Cd was not detected. In mangrove roots, the highest concentrations were found in *S. caseolaris*, with 2.596±0.002 mg/kg for Pb and 11.881±0.015 mg/kg for Zn, while *X. granatum* exhibited 8.850±0.011 mg/kg for Cu and 0.160±0.020 mg/kg for Cd. BCF values <1 were categorized as exclusion, Igeo<0 indicated non-contamination, Cf<1 signified low pollution, and PLI<0 denoted an unpolluted status. Based on the results, the quality of the mangrove ecosystems affected by heavy metal pollution is currently considered safe regarding environmental risk assessment.

Keywords: Environmental risk assessment, heavy metals, mangrove roots, sediment

INTRODUCTION

Mangroves have important ecological functions in coastal ecosystems. In addition to playing a role in biodiversity conservation, it also provides a stable environment for the surrounding coastal landscape (Henriques et al. 2021; Cahyaningsih et al. 2022). Mangroves with a complete network system can adapt to tidal changes and reduce coastal erosion (Montgomery et al. 2018; Nizam et al. 2022; Amos and Akib 2023). In coastal areas, mangroves are very vulnerable to the spread of heavy metals due to anthropogenic activities (Rozirwan et al. 2023a). Oil discharges from ships, pesticides, and other types of pollutants, both carried by river flow and directly discharged into the waters, greatly affect the preservation of mangrove functions (Almaniar et al. 2021; Fitria et al. 2023).

Pollutants emitted by anthropogenic activities such as As, Cu, Zn, Co, Ni, Fe, Cr, Mn, I, and Se play an important role in the metabolic and physiological activities of mangroves depending on their concentration (Bhardwaj et al. 2017; Mariam and Alamgir 2020). On the other hand, heavy metals such as As, Ag, Hg, Cd, and Pb do not have biological relevance and are harmful at concentrations

exceeding the threshold (Almahasheer et al. 2018). Concentrations of heavy metals that exceed standards can poison the aquatic environment and inhibit the growth and development of mangroves (Rezaei et al. 2021). Naturally, mangroves have the ability to store metals, remove them from sediments, and translocate them in roots, stems, and leaves (Thanh-Nho et al. 2019; Khan and Aljahdali 2022). Mangroves remove metals through sorption, cation exchange, filtration, and chemical changes through root accumulation processes (Razif and Farhan 2017; Yap and Al-Mutairi 2023). Mangrove roots have a function in attenuating toxic effects through dilution by storing water to dilute the concentration of heavy metals in their body tissues to reduce toxicity in heavy metals (Hanarisanty and Titah 2019; Purwaningdyah and Takarina 2020). Moreover, mangrove roots also have major and trace elements, which are part of the natural biogeochemical cycle (Ray et al. 2021). The major elements as macro nutrients such as Ca, Mg, N, P, and K are important for plant development and growth (Savarino et al. 2021). Meanwhile, trace elements/micro-nutrients like Cu, Mn, Fe, Ni, Co, Zn, and Mo also play a role in the growth and development of mangroves within concentrations that do not exceed the threshold. However,

there is also a group of trace elements that are non-essential and often toxic to plant growth, such as Pb, Cd, Al, and Cr (Bhardwaj et al. 2017; Sreenivasulu et al. 2017).

Several studies have reported the important role of roots in the risk assessment of mangrove ecosystems. The metals detected with the highest concentrations in mangrove roots found in different locations were Cu at Asaluyeh: 198 $\mu\text{g/g}$, Bord khun: 1,756 $\mu\text{g/g}$, and Mahshahr : 1,617 $\mu\text{g/g}$ (Rezaei et al. 2021). Nazli and Hashim (2010) found Cu and Pb accumulation in the roots and leaves of *Sonneratia caseolaris* (L.) Engl. They concluded that the roots of this species have a high capacity to absorb heavy metals and could be a potential phytoremediation species for heavy metal treatment in Malaysian mangroves. Mangroves *Rhizophora apiculata* Blume, *Ceriops tagal* (Perr.) C.B.Rob., *Bruguiera gymnorhiza* (L.) Lam., *Lumnitzera racemosa* Willd., *Xylocarpus granatum* J.Koenig, *Sonneratia alba* Sm., and *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff. have heavy metal translocation and bioaccumulation factors that show varying trends (Analuddin et al. 2017). Monitoring the ecological risk level from heavy metal pollution is effective for monitoring heavy metal concentrations in the marine environment. Ecological risk is a condition in which the ecological function of an ecosystem is subject to external pressures, thus adversely affecting the health and productivity of coastal ecosystems, especially mangroves (Awuku-sowah et al. 2022; Rodrigues-Filho et al. 2023).

This study aims to assess the environmental risk due to heavy metals Pb, Cu, Zn, and Cd accumulation in mangrove roots and surrounding sediments. This assessment utilizes geochemical approaches such as Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI), which serve to interpret the quality and evaluate the effect of heavy metal

pollutants on mangrove and their habitats. The author emphasizes that environmental quality research on mangrove species originating from areas with anthropogenic activities is based on zone and root differences is a form of novelty in this research.

MATERIALS AND METHODS

Study area and sampling

This study was conducted in September 2023. Mangrove roots and sediments were taken at three observation stations with the purposive sampling method in the Payung Island mangrove ecosystem, Banyuasin District, South Sumatra, Indonesia, namely: St.1 (2°21'42.55"S, 104°54'59.31"E), St.2 (2°21'48.74"S, 104°54'57.19"E), and St.3 (2°22'53.25"S, 104°55'3.39"E) (Figure 1). Coastal ecosystems are associated with anthropogenic activities such as ports, ship transportation, fisheries, agriculture, and other industrial activities that potentially produce waste and pollutants (Fitria et al. 2023; Rozirwan et al. 2023b). Pollutants that accumulate in coastal areas will have an impact on biota that causes damage and even death to an ecosystem if they exceed the tolerance threshold (Rozirwan et al. 2023c).

Sample handling: Samples were stored in ice boxes and wrapped in zip-lock plastic bags to prevent contamination of mangrove root and sediment. Samples were transported to the Marine Bioecology Laboratory at the Faculty of Mathematics and Natural Sciences, Sriwijaya University. Quantitative analysis of heavy metal concentrations was carried out at the Environmental Agency Laboratory, South Sumatra Province, Indonesia.

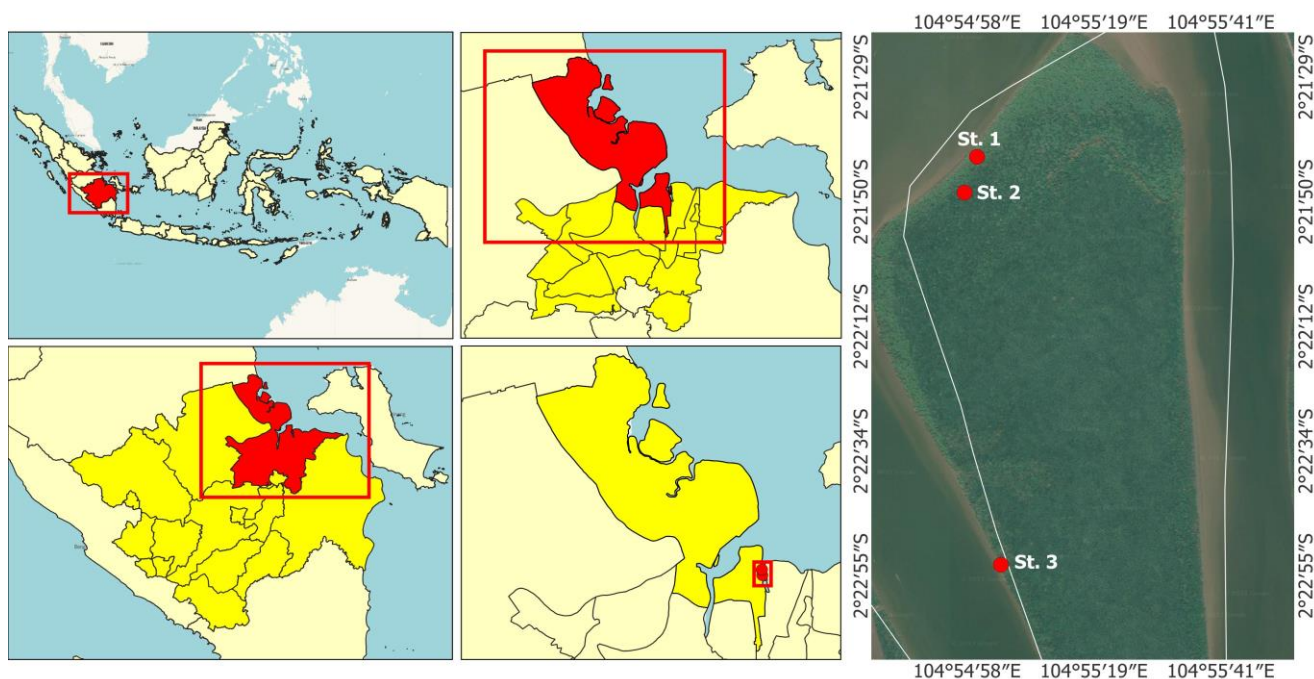


Figure 1. Map of sampling locations in Payung Island mangrove ecosystem, Banyuasin District, South Sumatra, Indonesia

Procedures

The destruction of mangrove roots was carried out by wet destruction to determine heavy metal elements (Nguyen et al. 2020a). The sample that has been weighed is put into an Erlenmeyer, and HNO₃ (5-10 mL) and H₂O₂ (2 mL) are added. Digestion is carried out by setting up a hotplate at 120°C. The digests were transferred to 50-mL vials with ultra-distilled water and stored in polyethylene containers at room temperature until further measurement. The sediment sample was prepared by cleaning it from foreign objects, drying it in an electric oven at 60°C for 30 minutes, grinding it into powder until it had fine particles, and storing it in a polyethylene bottle (Smeds et al. 2022). Next, the root samples were cleaned and crushed using a pestle mortar (Rapi et al. 2020). Destruction carried out using wet destruction refers to (Gao et al. 2021; Rizk et al. 2022). Put 50 mL of the water sample into the Erlenmeyer and add 5 mL of HNO₃, then heat it with a C-MAG HS 7 hotplate stirrer until the water sample reaches 15-20 mL. Furthermore, the sediment is destroyed by acid by putting ±3 g of sample into the Erlenmeyer and adding 25 mL of distilled water to be heated on a hotplate at a temperature of 105°C-120°C. Mix 5 mL of HNO₃ and wait until the volume reaches 10 mL. Once removed and cooled, add 5 mL HNO₃ and 1 mL-3 mL HClO₄. The sample was heated again until white smoke appeared and was clear, followed by heating for 30 minutes. After cooling, it was filtered using quantitative filter paper with a pore size of 8.0 µm. Finally, measure Pb, Cu, Zn, and Cd concentrations using an atomic absorption spectrophotometer (Zhong et al. 2016; Susilowati et al. 2022).

Ecological risk assessment

There are calculations of the Bioconcentration Factor (BCF), Geoaccumulation Index (I_{geo}), Contamination Factor (Cf), and Pollution Load Index (PLI) (Hakanson 1980). Heavy metal concentrations in sediments guided by Sediment Quality Guidelines (SQGs), which include Threshold Effect Level (TEL), Probable Effect Level (PEL), Low Effect Range (ERL), Severe Effect Level (SEL), Moderate Effect Range (ERM), and Lowest Effect Level (LEL), were applied to evaluate the possible biotic influence of metals estimated in sediment samples (Long and MacDonald 1998; Rahman et al. 2022).

Bioconcentration Factor (BCF)

Metal absorption by roots from sediments occurs through a process known as bioaccumulation. The BCF value determines metal bioaccumulation in mangrove roots from sediments (Almahasheer 2019). The formula is as follow: $BCF = \frac{\text{Concentration of root}}{\text{Concentration of sediment}}$. BCF <1 implies that roots are an excluder; BCF = 1 implies that roots are an indicator; and BCF >1 implies that roots are a hyperaccumulator.

Geoaccumulation index (I_{geo})

I_{geo} quantitatively evaluates the extent of heavy metal contamination and assigns pollution levels according to the classification criteria (Zhang et al. 2021; Xie et al. 2022). The formula of $I_{geo} = \log_2\left(\frac{\text{Concentration heavy metals in sediment}}{1.5 \cdot \text{Background}}\right)$. I_{geo} value criteria: I_{geo} <0 =

not polluted; 0 < I_{geo} <1 = slightly polluted; 1 < I_{geo} <2 = moderately polluted; 2 < I_{geo} <3 = severely polluted; 3 < I_{geo} <4 = severely polluted; 4 < I_{geo} <5 = extremely polluted; I_{geo} >5 = extremely severely polluted (Muller 1979; Xie et al. 2022).

Contamination factor (Cf)

A contamination factor is a condition in which something is polluted by another element with a certain effect (Antoniadis et al. 2019). The formula of Cf = (Concentration of heavy metals in sediment)/Background. Contamination Factor criteria according to (Shaheen et al. 2017): Cf < 1 = low level of contamination; 1 < Cf < 3 = medium level of contamination; 3 < Cf < 6 = enough level of contamination; Cf > 6 = contamination level is very high.

Pollution Load Index (PLI)

The pollution load index is used to determine the quality of pollution. The pollution load index value uses the formula (Shaheen et al. 2019; Singh et al. 2020). The formula of Pollution Load Index (PLI) = $[Cf_1 \times Cf_2 \times Cf_3 \dots \times Cf_n]^{1/n}$. Criteria for Pollution Load Index (PLI): PLI <0 = not polluted; PLI 0-2 = not polluted to slightly polluted; PLI 2-4 = moderately polluted; PLI 4-6 = severely polluted; PLI 6-8 = severely polluted; PLI 8-10 = extremely pollute.

Quality standards and recovery values

Quality standards for the heavy metals Pb, Cu, Zn, and Cd in sediment and plants are presented in Table 1. The recovery values for the heavy metals in the standard reference material are presented in Table 2.

Data analysis

The data were tested for homogeneity of variance with the Levene test and for normality of distribution with the Shapiro-Wilk test. Significant differences within each root by pollution source were assessed by one-way Analysis of Variance (ANOVA), followed by a post-hoc Tukey test if the conditions were met (Carricavur et al. 2018; Rozirwan et al. 2023c). The level of significance was p < 0.05. All statistical analyses were performed using the IBM SPSS V.26 application.

Table 1. Quality standards (mg/kg)

Sample	Pb	Cu	Zn	Cd	References
Sediment	50	65	50	0.8	(ANZECC/ARMCANZ 2000)
Plant	2	10	0.60	0.02	WHO (1996) in (Ogundele et al. 2015)

Table 2. Recovery values (Ağca and Özdel 2014)

Metals	Recovery (%)
Pb	75.8
Cu	92.4
Zn	78.6
Cd	68.9

RESULTS AND DISCUSSION

Description of mangrove roots

The mangrove species found in the field were *Sonneratia caseolaris* (L.) Engl., *Rhizophora apiculata* Blume, and *Xylocarpus granatum* J.Koenig (Figure 2). In general, these three species have different root morphologies.

Based on the results, mangrove species have different root systems that adjust to their habitat. The roots found in *S. caseolaris* were breathing roots (vertical cone-shaped), *R. apiculata* were aerial roots, and *X. granatum* were plank roots.

Determination of heavy metals in sediment and mangrove root

The results of the concentrations of heavy metal elements Pb, Cu, Zn, and Cd in sediment and mangrove roots collected from all stations are summarized in Table 3. Station three (sediment) had the highest concentrations for Pb of 12.786 ± 0.26 mg/kg, Cu was 10.405 ± 0.011 mg/kg, Zn was 42.752 ± 0.05 mg/kg, and Cd (not detected). While in mangrove roots, the highest heavy metal concentration was in *S. caseolaris* for Pb was 2.596 ± 0.002 and Zn was 11.881 ± 0.015 , while for Cu and Cd it was highest in *X. granatum* at 8.850 ± 0.011 and 0.160 ± 0.020 . A comparative reference of heavy metal concentrations in roots with different species and locations is summarized in Table 4.

Based on the heavy metal concentration results (Table 1), the differences in each species statistically analyzed using ANOVA and post hoc Tukey ($P < 0.05$) showed that each species was significantly different. Sediment heavy metal concentrations in this study were still below the quality standards set by Sediment Quality Guidelines (SQGs) (Batley and Simpson 2013). Mangrove root heavy metal

concentrations varied with habitat conditions, zonation, and root species.

Ecological risk assessments of heavy metals concentration

The results of the ecological risk assessment of heavy metal pollution in mangrove roots and surrounding sediments are summarized in Figure 3. Overall, the Bioconcentration Factor (BCF) results of roots in bioaccumulating soil metals were exclusionary for all heavy metals: Pb (0.3535, 0.1504, 0.0402), Cu (0.8091, 0.2011, 0.8506), and Zn (0.2931, 0.1419, 0.0920). The geoaccumulation index showed uncontaminated properties for Pb (-1.3523, -1.0731, -0.5523), Cu (-3.6120, -3.4205, -2.9871), and Zn (-1.3732, -1.4566, -0.5523). 1,2963). The Contamination Factor (Cf) showed that the contamination was low and medium in Pb (0.5876, 0.7130, 1.0229), Cu (0.1227, 0.1401, 0.1892), and Zn (0.5790, 0.5465, 0.6107). The PLI ranges from 0.3856 - 0.5269, indicating that the pollution quality at the three stations and species points is not polluted.

Bioconcentration Factor (BCF), Geoaccumulation Index (Igeo), Contamination Factor (Cf), and Pollution Load Index (PLI) were calculated for heavy metals Pb, Cu, and Zn which showed no decrease in $BCF < 1$, $I_{geo} < 0$, $CF < 1$, and $PLI < 1$). Meanwhile, the ecological risk assessment was not carried out for the heavy metal Cd because it was not detected in the sediment at each station; it was only detected in the roots of *X. granatum*. An evaluation of the ecological risk assessment of sediment pollution needs to be carried out to understand the extent to which the sediment can affect plant health.

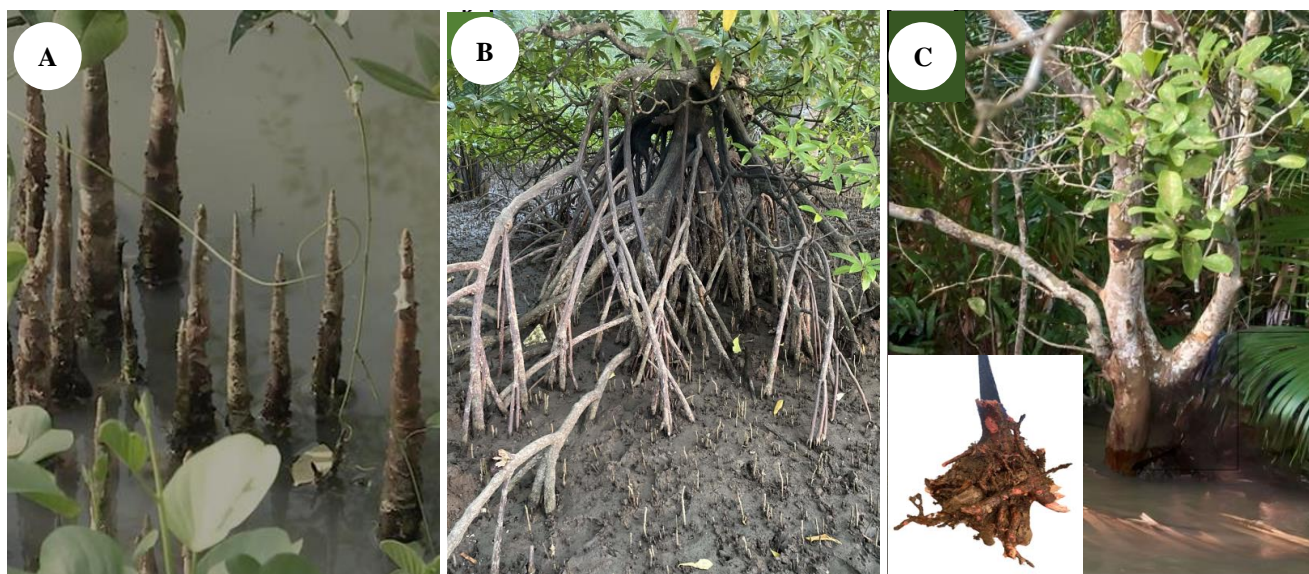


Figure 2. Morphology of mangrove roots. A. *Sonneratia caseolaris*, B. *Rhizophora apiculata*, C. *Xylocarpus granatum*

Table 3. Variation of average heavy metal concentrations (mg/kg) in mangrove sediments and roots

	Pb	Cu	Zn	Cd
Sediments				
St.1	7.344±0.20*	6.747±0.012*	40.533±0.13*	nd
St.2	8.912±0.08*	7.705±0.008*	38.256±0.03*	nd
St.3	12.786±0.26*	10.405±0.011*	42.752±0.05*	nd
ERL	46.7	34	150	1.2
ERM	218	270	410	9.6
TEL	30.2	18.7	124	0.68
PEL	112	108.2	271	4.2
Mangrove roots				
<i>S. caseolaris</i> (St.1)	2.596±0.002*	5.459±0.030*	11.881±0.015*	nd
<i>R. apiculata</i> (St.2)	1.340±0.075*	1.532±0.016*	5.428±0.004*	nd
<i>X. granatum</i> (St.3)	0.514±0.129*	8.850±0.011*	3.933±0.010*	0.160±0.020
F Table	19,33	19.33	19.33	
F Value	444.114	94856.92	496580.302	

Note: nd: Not detected, *The mean difference is significant at the 0.05 level

Table 4. Comparison of heavy metal concentrations associated with various mangrove roots

Species	Heavy metals	Reference
<i>R. apiculata</i>	Cr (0.26 - 11.69 mg/kg), Cu (0.21-8.17 mg/kg), Ni (0.11 - 854 mg/kg)	(Nguyen et al. 2020b)
<i>Sonneratia apetala</i> & <i>Avicennia officinalis</i>	Cu (25.89 mg/kg), Fe (1376.7 mg/kg), Cr (2.85 mg/kg)	(Chowdhury et al. 2017)
<i>Lumnitzera racemosa</i>	Cu (83.85µgg ⁻¹) and Hg (0.52µgg ⁻¹)	(Analuddin et al. 2017)
<i>Bruguiera gymnorrhiza</i>	Cd (10.81µgg ⁻¹)	
<i>Bruguiera parviflora</i>	Zn (70.41µgg ⁻¹)	
<i>Ceriops tagal</i>	Pb (1.36µgg ⁻¹)	
<i>E. agallocha</i> > <i>A. officinalis</i> > <i>S. apetala</i>	Fe (737.37±153.06) > Mn (151.13±34.26) > Sr (20.98±6.97) > Cu (16.12±4.34) > Zn (11.3±2.39) mg/kg	(Hossain et al. 2022)
<i>Phoenix paludosa</i>	Cu, Mn, Zn, Ni, Fe, Cr, Cd and Pb (162.2, 563.3, 289.1, 228.8, 31,524.3, 475.5, 8.5 and 256.8 mg/kg)	(Kumar et al. 2021)
<i>Avicennia marina</i>	Cd, Ca, Zn, Cr, Al (0.24, 18234, 14.4, 7.24 and 1982 µg/g)	(Salimi et al. 2019)
<i>Avicennia marina</i>	Cu (200 µg/g)	(MacFarlane et al. 2003)
<i>A. marina</i> , <i>R. mucronata</i> , <i>S. caseolaris</i>	Zn (18.08-54.64 mg/kg, 9.75-54.75 mg/kg, and 19.58-33.33 mg/kg)	(Takarina 2020)
<i>Rhizophora racemosa</i>	Cu (0.33-0.89 mg/kg, 0.2-54.75 mg/kg and 0.4-0.99 mg/kg)	
<i>Avicennia marina</i>	Pb (1.34 mg/g), Cu (0.08 mg/g), and Cd (0.04 mg/g)	(Eribo et al. 2021)
	Cu (153 mg/kg), Pb (189 mg/kg), Zn (378 mg/kg), Ar (16 mg/kg), Cr (21 mg/kg), Ni (11 mg/kg)	(Chaudhuri et al. 2014)

Discussion

The habitat of the three mangrove species *S. caseolaris*, *R. apiculata*, and *X. granatum*, are found on characteristic muddy substrates that are influenced by environmental factors. For example, physicochemical factors: temperature, salinity, DO, pH, currents, tides, and waves (Rozirwan et al. 2023d). According to Saputra et al. (2021), the substrate tends to be muddy in the leading zone of the mangrove ecosystem. Mangrove roots closely associated with sediment to bind and retain heavy metals from their surrounding environment. Differences in the morphology of roots can influence the plant's ability to absorb and accumulate heavy metals in its tissues (Hu et al. 2023). Roots that are broader or deeper may have a greater capacity to absorb heavy metals (DalCorso et al. 2019). Longer or more branched roots can reach a wider soil area and penetrate deeper layers where heavy metals may be concentrated (Audah et al. 2022). *Sonneratia caseolaris* is a pioneer species in

mangrove ecosystem found in the leading zone. The roots are cone-like vertical breath (up to 1 m high) that are numerous and very strong. *Sonneratia caseolaris* has four types of roots: cable, pneumatophores, feeding, and anchor. In addition, the roots of *S. caseolaris* also have root periderms that play an important role in salt exclusion, and the appearance of tanniferous cells is related to salt elimination (Tatongjai et al. 2021).

Rhizophora apiculata has characteristic rooting that reaches up to 5 meters in height and sometimes has aerial roots from the branches. Prop roots and stilt roots (lateral roots from the base of the stem often curving downward to meet the substrate) are mainly seen in *R. apiculata* (Shamin-Shazwan et al. 2021). One of the characteristics of *R. apiculata* is that it has structures that protrude in various directions around its trunk to the ground, which are specialized branches with positive geotropism that form a large number of roots when in contact with the soil (De

Oliveira et al. 2021). *Xylocarpus granatum* has plank roots that extend laterally, twisting and forming cleavages. The stem has buttresses and above-ground roots extending far on either side. Buttress or buttress roots (laterally or vertically compressed and flattened board-like roots near the trunk) (Dey et al. 2021).

Concentrations of heavy metals Pb, Cu, Zn, and Cd (detected in *X. granatum* roots) in sediment were higher than in mangrove roots. This shows that mangrove roots are effective in preventing the entry of heavy metals into the upper parts of the plant (Guo et al. 2023), even though the metal concentration in the roots exceeds the threshold specified in *S. caseolaris* for Pb >2 mg/kg, Zn in each species >0.60 mg/kg, Cd in *X. granatum* >0.02 mg/kg, and for Cu each species does not exceed the specified threshold. Mangrove sediments have great potential to absorb heavy metals in the long term, with the characteristics of being anaerobic, reduced, rich in organic matter, and a fine substrate. The finer the sediment, the higher its strength in binding heavy metals, so roots do not absorb more heavy metal concentrations (Briffa et al. 2020). In addition, mangrove roots are able to release oxygen to avoid the toxic effects of anaerobic conditions on sediments (Castro et al. 2022). In line with the opinion of Lin et al. (2021), submerged roots in the sediment will differ from some types of roots that grow outside the sediment surface.

Differences in root types will also affect the concentration of heavy metals in mangrove tissue (Rezaei et al. 2021; Hossain et al. 2022). The plank root of *X. granatum* has the lowest heavy metal concentration compared to the breath root of *S. caseolaris* and the aerial root of *R. apiculata*. Plank roots under the surface sediment are able to store a lot of water to dilute the concentration of heavy metals in their body tissues, thereby reducing the toxicity of these metals (Dhalaria et al. 2020; Huang et al. 2020). In this study, *X. granatum* was found in the upper zone, periodically submerged by coastal tides. Mangrove efficiently retain heavy metals within the root system and may significantly reduce their translocation to other parts (Yan et al. 2017). According to Mathivanan et al. (2021), possible coping mechanisms include localization, excretion, and dilution to weaken the toxic effects of these heavy metals. These mangrove root's ability to defend themselves against environmental pressure can reduce negative impacts on the ecosystem (Sunkur et al. 2023). Variations in the accumulation of specific metals depend on their respective physiological rhythms and the ecological conditions of the environment they inhabit (Kumar et al. 2021). Since roots are the first tissue to be exposed to excess heavy metal content excess in the soil, toxic symptoms due to excessive heavy metal exposure are more common in roots than in other tissues (Zhang et al. 2019).

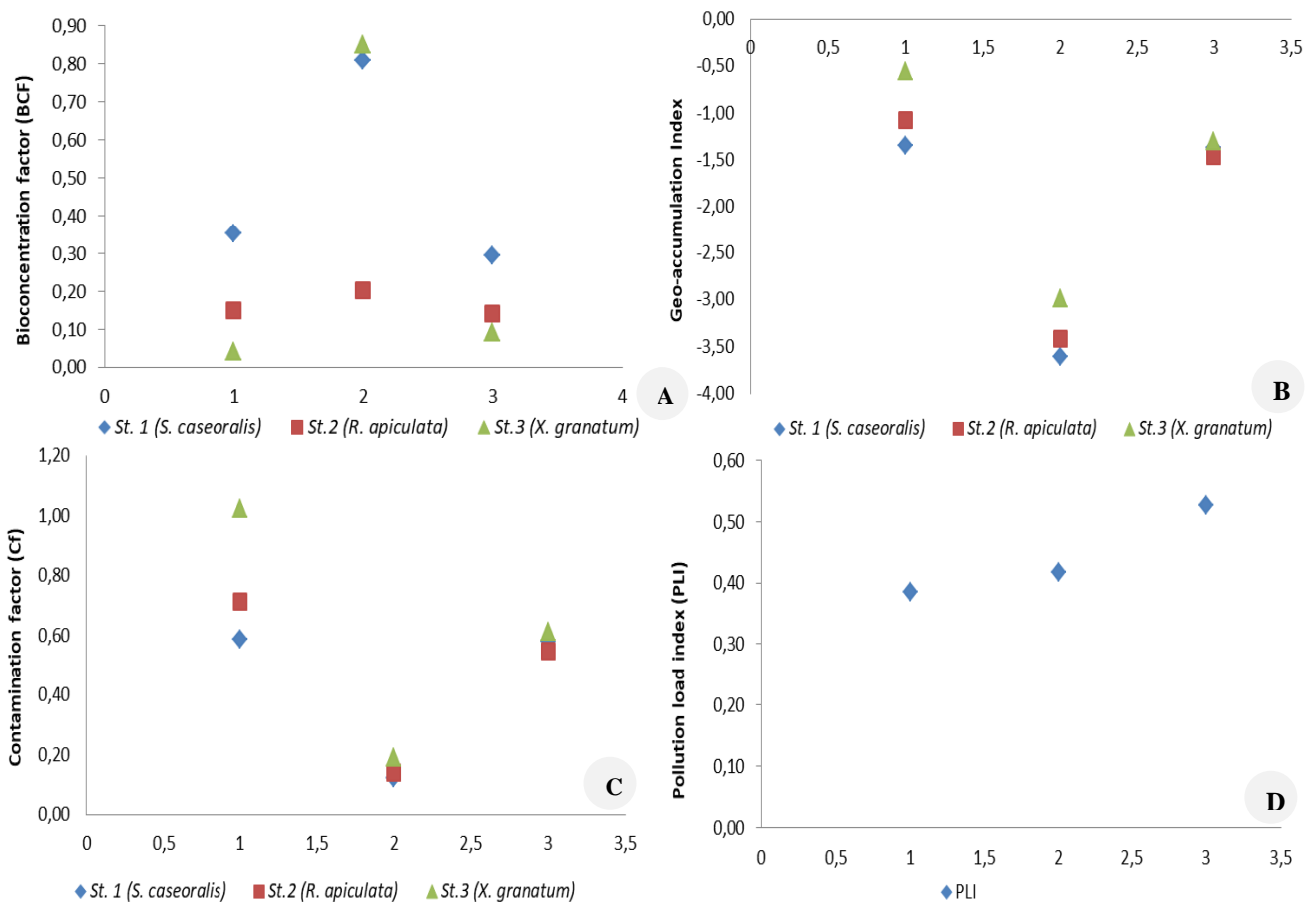


Figure 3. (A-D) Pollution indices. A. Bioconcentration Factor (BCF), B. Geo-accumulation Index (Igeo), C. Contamination Factor (Cf), and D. Pollution Load Index (PLI)

Mangrove ecosystems located in coastal areas have the potential to be exposed to pollutants, especially heavy metals, because of their function both ecologically and socio-economically for the community. Based on Figure 3 for bioconcentration factor (Bcf) <1 for all heavy metals caused by the ability of mangrove roots to detoxify metals by exclusion mechanism (Aljahdali and Alhassan 2020). In line with the opinion of Bakshi et al. (2017), the ability of plants to bioaccumulate metals and other pollutants from sediments can be evaluated using the bioconcentration factor between the total concentration of metals in plants and the concentration in sediments. The Igeo values observed in this study indicate that the Payung Island mangrove ecosystem sediments are not contaminated (Igeo <0). Geo-accumulation Index values can be efficiently applied to determine sediment quality (Singh et al. 2020). Different metals in sediments may be due to the increased particulate matter with relatively unpolluted sediments combinations (Li et al. 2022; Shou et al. 2022). The study's Contamination factor (Cf) shows that each metal causes low contamination, except for the heavy metal Pb, which is included in moderate contamination. In line with the findings of Rezaei et al. (2021) contamination showed of heavy metal accumulation in sediments in the north of the Persian Gulf, but this is associated with gas and petrochemical activities, which can be considered a potential source of heavy metal release into the aquatic environment. PLI can be used to characterize or establish conclusions about the pollution status of the ecosystem (Jiang et al. 2020; Hummel et al. 2021). PLI values of sediments collected from mangrove ecosystems are classified as unpolluted to slightly polluted (PLI = 0-2). The highest Pollution Load Index (PLI) value is at station 3 (*X. granatum*), which is higher because this station is directly opposite Sungsang Village, which is an area filled with fishing activities and household waste such as detergent, soap, and organic/inorganic waste (Rozirwan et al. 2022). Apart from that, station 3 is located in the estuary area of a consequent river (the flow is in the same direction as the slope). In contrast, stations 1 and 2 are located in the open river estuary, which is directly connected to the Bangka Strait, which has an inconsistent nature (irregular flow) caused by high currents and waves, so the heavy metals concentrations in both the water and sediment is dynamic (Rozirwan et al. 2021). This factor have a significant impact on the water content of various environments (Rozirwan et al. 2019; Ramses et al. 2020). This could be a result of the dense activities around the area, ranging from fisheries, boat transportation, and household waste (Rozirwan et al. 2024). These findings are align by Pejman et al. (2015) study conducted in Northwest sediments from the Persian Gulf. The results showed sediment contamination (PLI<1) associated with wastewater discharge activities from the area's petrochemical industry and tanker leachate.

In conclusion, the total concentrations of Pb, Cu, Zn, and Cd (only detected in *X. granatum* roots) evaluated statistically had significant differences ($p < 0$) at each sediment station and mangrove root species. Furthermore, Pb, Cu, Zn, and Cd (not detected) concentrations in soil were still below the quality standards. While for *S. caseolaris* Pb >2 mg/kg, Zn for each species >0.60 mg/kg,

Cd for *X. granatum* >0.02 mg/kg, and Cu for each species do not exceed the specified threshold. The environmental risk assessment of Pb, Cu, and Zn metals in mangrove sediments and roots was also assessed based on bioconcentration factors, geoaccumulation index, pollution factors, and ecological risk assessment. Except for Cd, because it was only detected in the roots of *X. granatum*, whereas the ecological risk assessment found a link between sediment as a growth medium and the plant. The heavy metals Pb, Cu, and Zn were observed not to accumulate in mangrove roots due to their low concentrations in the sediment, so they do not pose a significant ecological risk.

ACKNOWLEDGEMENTS

The research for this article was funded by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia (Grant Number: 164/E5/PG.02.00. PL/2023). The authors would like to thank all Marine Bioecology Laboratory's assistants for supporting this work's accomplishment.

REFERENCES

- Ağca N, Özdel E. 2014. Assessment of spatial distribution and possible sources of heavy metals in the soils of Sariseki-Dörtöyl District in Hatay Province (Turkey). *Environ Earth Sci* 71 (3): 1033-1047. DOI: 10.1007/s12665-013-2507-8.
- Aljahdali MO, Alhassan AB. 2020. Ecological risk assessment of heavy metal contamination in mangrove habitats, using biochemical markers and pollution indices: A case study of *Avicennia marina* L. in the Rabigh lagoon, Red Sea. *Saudi J Biol Sci* 27 (4): 1174-1184. DOI: 10.1016/j.sjbs.2020.02.004.
- Almahasheer H, Serrano O, Duarte CM, Irigoien X. 2018. Remobilization of heavy metals by mangrove leaves. *Front Mar Sci* 5: 484. DOI: 10.3389/fmars.2018.00484.
- Almahasheer H. 2019. High levels of heavy metals in Western Arabian Gulf mangrove soils. *Mol Biol Rep* 46 (2): 1585-1592. DOI: 10.1007/s11033-019-04603-2.
- Almaniar S, Rozirwan, Herpandi. 2021. Abundance and diversity of macrobenthos at Tanjung Api-Api Waters, South Sumatra, Indonesia. *AACL Bioflux* 14 (3): 1486-1497.
- Amos D, Akib S. 2023. A review of coastal protection using artificial and natural countermeasures-Mangrove vegetation and polymers. *Eng* 4 (1): 941-953. DOI: 10.3390/eng4010055.
- Analuddin K, Sharma S, Jamili, Septiana A, Sahidin I, Rianse U, Nadaoka K. 2017. Heavy metal bioaccumulation in mangrove ecosystem at the coral triangle ecoregion, Southeast Sulawesi, Indonesia. *Mar Pollut Bull* 125 (1-2): 472-480. DOI: 10.1016/j.marpolbul.2017.07.065.
- Antoniadis V, Golia EE, Liu Y-T, Wang S-L, Shaheen SM, Rinklebe J. 2019. Soil and maize contamination by trace elements and associated health risk assessment in the industrial area of Volos, Greece. *Environ Intl* 124: 79-88. DOI: 10.1016/j.envint.2018.12.053.
- ANZECC/ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand, Canberra.
- Audah KA, Ettin J, Darmadi J, Azizah NN, Anisa AS, Hermawan TDF, Tjampakasari CR, Heryanto R, Ismail IS, Batubara I. 2022. Indonesian mangrove *Sonneratia caseolaris* leaves ethanol extract is a potential super antioxidant and anti methicillin-resistant *Staphylococcus aureus* drug. *Molecules* 27 (23): 8369. DOI: 10.3390/molecules27238369.
- Awuku-Sowah EM, Graham NAJ, Watson NM. 2022. Investigating mangrove-human health relationships: A review of recently reported

- physiological benefits. *Dialogues Heal* 1: 100059. DOI: 10.1016/j.dialog.2022.100059.
- Bakshi M, Ram SS, Ghosh S, Chakraborty A, Sudarshan M, Chaudhuri P. 2017. Micro-spatial variation of elemental distribution in estuarine sediment and their accumulation in mangroves of Indian Sundarban. *Environ Monit Assess* 189 (5): 221. DOI: 10.1007/S10661-017-5891-9.
- Batley GE, Simpson S. 2013. Sediment Quality Guidelines. In: Féraud JF, Blaise C (eds). *Encyclopedia of Aquatic Ecotoxicology*. Springer, Dordrecht. DOI: 10.1007/978-94-007-5704-2_92.
- Bhardwaj R, Gupta A, Garg JK. 2017. Evaluation of heavy metal contamination using environmetrics and indexing approach for River Yamuna, Delhi stretch, India. *Water Sci* 31 (1): 52-66. DOI: 10.1016/j.wsj.2017.02.002.
- Briffa J, Sinagra E, Blundell R. 2020. Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon* 6 (9): e04691. DOI: 10.1016/j.heliyon.2020.e04691.
- Cahyaningsih AP, Deanova AK, Pristiawati CM, Ulumuddin YI, Kusumawati L, Setyawan AD. 2022. Review: Causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia. *Intl J Bonorowo Wetl* 12 (1): 12-22. DOI: 10.13057/bonorowo/w120102.
- Carricavur AD, Boudet LC, Romero MB, Polizzi P, Marcovecchio JE, Gerpe M. 2018. Toxicological responses of *Laonereis acuta* (Polychaeta, Nereididae) after acute, subchronic and chronic exposure to cadmium. *Ecotoxicol Environ Saf* 149: 217-224. DOI: 10.1016/j.ecoenv.2017.11.048.
- Castro E, Pinedo J, Marrugo J, León I. 2022. Retention and vertical distribution of heavy metals in mangrove sediments of the protected area swamp of Mallorquin, Colombian Caribbean. *Reg Stud Mar Sci* 49: 102072. DOI: 10.1016/j.rsma.2021.102072.
- Chaudhuri P, Nath B, Birch G. 2014. Accumulation of trace metals in grey mangrove *Avicennia marina* fine nutritive roots: The role of rhizosphere processes. *Mar Pollut Bull* 79 (1-2): 284-292. DOI: 10.1016/j.marpolbul.2013.11.024.
- Chowdhury R, Favas PJC, Jonathan MP, Venkatachalam P, Raja P, Sarkar SK. 2017. Bioremoval of trace metals from rhizosediment by mangrove plants in Indian Sundarban Wetland. *Mar Pollut Bull* 124 (2): 1078-1088. DOI: 10.1016/j.marpolbul.2017.01.047.
- DalCorso G, Fasani E, Manara A, Visioli G, Furini A. 2019. Heavy metal pollutions: State of the art and innovation in phytoremediation. *Intl J Mol Sci* 20 (14): 3412. DOI: 10.3390/ijms20143412.
- de Oliveira Barbirato J, C. Ferreira N, B. Dobbss L. 2021. Effect of trace elements accumulation on mangrove ecosystem and their interaction with humic substances: The case of nickel and iron. In: Mikan A (eds). *Humic Substances*. IntechOpen, Croatia. DOI: 10.5772/intechopen.96778.
- Dey D, Quispe C, Hossain R, Jain D, Khan RA, Janmeda P, Islam MT, Suleria HAR, Martorell M, Daştan SD, Kumar M, Taheri Y, Petkoska AT, Sharifi-Rad J. 2021. Ethnomedicinal use, phytochemistry, and pharmacology of *Xylocarpus granatum* J. Koenig. *Evid Based Complement Alternat Med* 2021: 8922196. DOI: 10.1155/2021/8922196.
- Dhalaria R, Kumar D, Kumar H, Nepovimova E, Kuča K, Islam MT, Verma R. 2020. Arbuscular mycorrhizal fungi as potential agents in ameliorating heavy metal stress in plants. *Agronomy* 10 (6): 815. DOI: 10.3390/agronomy10060815.
- Eribo O, Oterai SO, Inegbenijesu OB. 2021. Bioconcentration and translocation factors of heavy metals in *Rhizophora racemosa* and sediments from Egbokodo Mangrove Swamp, Delta State, Nigeria. *Afr Sci* 22 (4): 135-140.
- Fitria Y, Rozirwan, Fitriani M, Nugroho RY, Fauziah, Putri WAE. 2023. Gastropods as bioindicators of heavy metal pollution in the Banyuasir estuary shrimp pond area, South Sumatra, Indonesia. *Acta Ecol Sin* 43 (6): 1129-1137. DOI: 10.1016/j.chnaes.2023.05.009.
- Gao Y, Qiao Y, Xu Y, Zhu L, Feng J. 2021. Assessment of the transfer of heavy metals in seawater, sediment, biota samples and determination the baseline tissue concentrations of metals in marine organisms. *Environ Sci Pollut Res Intl* 28 (22): 28764-28776. DOI: 10.1007/S11356-021-12650-1.
- Guo Z, Gao Y, Yuan X, Yuan M, Huang L, Wang S, Liu C, Duan C. 2023. Effects of heavy metals on stomata in plants: A review. *Intl J Mol Sci* 24 (11): 9302. DOI: 10.3390/ijms24119302.
- Hakanson L. 1980. An ecological risk index for aquatic pollution control: a sedimentological approach. *Water Res* 14 (8): 975-1001. DOI: 10.1016/0043-1354(80)90143-8.
- Hanarisanty L, Titah HS. 2019. Range finding phytotoxicity test of lead to mangrove plants of *Rhizophora mucronata*. *Jurnal Teknik ITS* 8 (2): B26-B31. DOI: 10.12962/j23373539.v8i2.49706.
- Henriques M, Granadeiro JP, Piersma T, Leão S, Pontes S, Catty T. 2021. Assessing the contribution of mangrove carbon and of other basal sources to intertidal flats adjacent to one of the largest West African mangrove forests. *Mar Environ Res* 169: 105331. DOI: 10.1016/j.marenvres.2021.105331.
- Hossain MB, Masum Z, Rahman MS, Yu J, Noman MA, Jolly YN, Begum BA, Paray BA, Arai T. 2022. Heavy metal accumulation and phytoremediation potentiality of some selected mangrove species from the world's largest mangrove forest. *Biology* 11 (8): 1144. DOI: 10.3390/biology11081144.
- Hu Z, Zhao C, Li Q, Feng Y, Zhang X, Lu Y, Ying R, Yin A, Ji W. 2023. Heavy metals can affect plant morphology and limit plant growth and photosynthesis processes. *Agronomy* 13 (10): 2601. DOI: 10.3390/agronomy13102601.
- Huang R, Zeng J, Zhao D, Cook KV, Hambright KD, Yu Z. 2020. Sediment microbiomes associated with the rhizosphere of emergent macrophytes in a shallow, subtropical lake. *Limnol Oceanogr* 65 (S1): S38-S48. DOI: 10.1002/lno.11325.
- Hummel CA, Mellink YAM, Bienfait LJ, Adamescu MC, Cazacu C, Heurich M, Medina FM, Morkūnė R, Švajda J, Hummel H. 2021. A practical novel assessment tool for the socio-ecological condition of protected areas: The Protection Level Index (PLI). *J Nat Conserv* 64: 126065. DOI: 10.1016/j.jnc.2021.126065.
- Jiang H-H, Cai L-M, Wen H-H, Luo J. 2020. Characterizing pollution and source identification of heavy metals in soils using geochemical baseline and PMF approach. *Sci Rep* 10 (1): 6460. DOI: 10.1038/s41598-020-63604-5.
- Khan WR, Aljahdali MO. 2022. Elemental composition of above and belowground mangrove tissue and sediment in managed and unmanaged compartments of the Matang Mangrove Forest Reserve. *Plants* 11 (21): 2916. DOI: 10.3390/plants11212916.
- Kumar M, Mohapatra S, Karim AA, Dhal NK. 2021. Heavy metal fractions in rhizosphere sediment vis-à-vis accumulation in *Phoenix paludosa* (Roxb.) mangrove plants at Dhamra Estuary of India: Assessing phytoremediation potential. *Chem Ecol* 37 (1): 1-14. DOI: 10.1080/02757540.2020.1836165.
- Li J, Zuo Q, Feng F, Jia H. 2022. Occurrence and ecological risk assessment of heavy metals from Wuliangshuai Lake, Yellow River Basin, China. *Water* 14 (8): 1264. DOI: 10.3390/w14081264.
- Lin Z, Zhong C, Yu G, Fu Y, Guan B, Liu Z, Yu J. 2021. Effects of sediments phosphorus inactivation on the life strategies of *Myriophyllum spicatum*: Implications for lake restoration. *Water* 13 (15): 2112. DOI: 10.3390/w13152112.
- Long ER, MacDonald DD. 1998. Recommended uses of empirically derived, sediment quality guidelines for marine and estuarine ecosystems. *Hum Ecol Risk Assess Intl J* 4 (5): 1019-1039. DOI: 10.1080/10807039891284956.
- MacFarlane GR, Pulkownik A, Burchett MD. 2003. Accumulation and distribution of heavy metals in the grey mangrove, *Avicennia marina* (Forsk.) Vierh.: Biological indication potential. *Environ Pollut* 123 (1): 139-151. DOI: 10.1016/S0269-7491(02)00342-1.
- Mariam H, Alamgir ANM. 2020. Micronutrient contents of *Heritiera fomes* species at three saline zones of the Sundarban Mangrove Forest, Bangladesh. *Open Access Libr J* 7 (6): 1-9. DOI: 10.4236/oalib.1106425.
- Mathivanan K, Chandirika JU, Vinothkanna A, Yin H, Liu X, Meng D. 2021. Bacterial adaptive strategies to cope with metal toxicity in the contaminated environment - A review. *Ecotoxicol Environ Saf* 226: 112863. DOI: 10.1016/j.ecoenv.2021.112863.
- Montgomery JM, Bryan KR, Horstman EM, Mullarney JC. 2018. Attenuation of tides and surges by mangroves: Contrasting case studies from New Zealand. *Water* 10 (9): 1119. DOI: 10.3390/w10091119.
- Muller G. 1979. Schwermetalle in den sedimenten des Rheins. *Veränderungen Seit 1971 - ScienceOpen*. <https://www.scienceopen.com/document?vid=879b4fc9-0fe1-44a4-8e33-b23cb9b12c98>.
- Nazli MF, Hashim NR. 2010. Heavy metal concentrations in an important mangrove species, *Sonneratia caseolaris*, in Peninsular Malaysia. *EnvironmentAsia* 3: 50-55. DOI: 10.14456/ea.2010.39.
- Nguyen A, Le BVQ, Richter O. 2020a. The role of mangroves in the retention of heavy metal (Chromium): A simulation study in the Thi Vai River Catchment, Vietnam. *Intl J Environ Res Public Health* 17 (16): 5823. DOI: 10.3390/ijerph17165823.

- Nguyen A, Richter O, Le BVQ, Phuong NTK, Dinh KC. 2020b. Long-term heavy metal retention by mangroves and effect on its growth: A field inventory and scenario simulation. *Intl J Environ Res Public Health* 17 (23): 9131. DOI: 10.3390/ijerph17239131.
- Nizam A, Meera SP, Kumar A. 2022. Genetic and molecular mechanisms underlying mangrove adaptations to intertidal environments. *iScience* 25 (1): 103547. DOI: 10.1016/j.isci.2021.103547.
- Ogundele DT, Adio AA, Oludele OE. 2015. Heavy metal concentrations in plants and soil along heavy traffic roads in North Central Nigeria. *J Environ Anal Toxicol* 5: 1000334. DOI: 10.4172/2161-0525.1000334.
- Pejman A, Bidhendi GN, Ardestani M, Saeedi M, Baghvand A. 2015. A new index for assessing heavy metals contamination in sediments: A case study. *Ecol Indic* 58: 365-373. DOI: 10.1016/j.ecolind.2015.06.012.
- Purwaningdyah AR, Takarina ND. 2020. Translocation factor of Zinc (Zn) in water and sediment by root and stem of *Rhizophora* sp. at Blanakan Riparian, West Java. *IOP Conf Ser: Earth Environ Sci* 550 (1): 012006. DOI: 10.1088/1755-1315/550/1/012006.
- Rahman MS, Ahmed Z, Seefat SM, Alam R, Islam ARMT, Choudhury TR, Begum BA, Idris AM. 2022. Assessment of heavy metal contamination in sediment at the newly established tannery industrial Estate in Bangladesh: A case study. *Environ Chem Ecotoxicol* 4: 1-12. DOI: 10.1016/j.enceco.2021.10.001.
- Ramses, Ismarti, Amelia F, Rozirwan, Suheryanto. 2020. Diversity and abundance of polychaetes in the west coast waters of Batam island, Kepulauan Riau province-Indonesia. *AACL Bioflux* 13 (1): 381-391.
- Rapi HS, Soh N'AC, Azam NSM, Maulidiani M, Assaw S, Haron MN, Ali AM, Idris I, Ismail WIW. 2020. Effectiveness of aqueous extract of marine baitworm *Marphysa moribidii* Idris, Hutchings and Arshad, 2014 (Annelida, Polychaeta), on acute wound healing using Sprague Dawley Rats. *Evid Based Complement Alternat Med* 2020: 1408926. DOI: 10.1155/2020/1408926.
- Ray R, Mandal SK, González AG, Pokrovsky OS, Jana TK. 2021. Storage and recycling of major and trace element in mangroves. *Sci Total Environ* 780: 146379. DOI: 10.1016/j.scitotenv.2021.146379.
- Razif M, Farhan I. 2017. A removal of Zn metal concentrate using *Rhizophora apiculata* mangrove plants. *Asian J Agric Biol* 5 (4): 328-336.
- Rezaei M, Kafaei R, Mahmoodi M, Sanati AM, Vakilabadi DR, Arfaenia H, Dobaradaran S, Sorial GA, Ramavandi B, Boffito DC. 2021. Heavy metals concentration in mangrove tissues and associated sediments and seawater from the north coast of Persian Gulf, Iran: Ecological and health risk assessment. *Environ Nanotechnol Monit Manag* 15: 100456. DOI: 10.1016/j.enmm.2021.100456.
- Rizk R, Juzsakova T, Ali MB, Rawash MA, Domokos E, Hedfi A, Almalki M, Boufahja F, Shafik HM, Rédey Á. 2022. Comprehensive environmental assessment of heavy metal contamination of surface water, sediments and Nile Tilapia in Lake Nasser, Egypt. *J King Saud Univ Sci* 34 (1): 101748. DOI: 10.1016/j.jksus.2021.101748.
- Rodrigues-Filho JL, Macêdo RL, Sarmento H et al. 2023. From ecological functions to ecosystem services: Linking coastal lagoons biodiversity with human well-being. *Hydrobiologia* 850 (12-13): 2611-2653. DOI: 10.1007/S10750-023-05171-0.
- Rozirwan R, Az-Zahra SAF, Khotimah NN, Nugroho RY, Putri WAE, Fauziyah F, Melki M, Agustriani F, Siregar YI. 2024. Ecological risk assessment of heavy metal (Pb, Cu) contamination in water, sediment, and Polychaeta (*Neoleanira tetragona*) from coastal areas affected by aquaculture, urban rivers, and ports in South Sumatra. *J Ecol Eng* 25 (1): 303-319. DOI: 10.12911/22998993/175365.
- Rozirwan R, Iskandar I, Hendri M, Apri R, Supardi, Azhar N, Mardiansyah W. 2019. Distribution of phytoplankton diversity and abundance in Maspari island waters, South Sumatera, Indonesia. *J Phys Conf Ser* 1282 (1). DOI: 10.1088/1742-6596/1282/1/012105.
- Rozirwan R, Hananda H, Nugroho RY, Apri R, Khotimah NN, Fauziyah F, Putri WAE, Aryawati R. 2023a. Antioxidant activity, total phenolic, phytochemical content, and HPLC profile of selected mangrove species from Tanjung Api-Api Port Area, South Sumatra, Indonesia. *Trop J Nat Prod Res* 7 (7): 3482-3489. DOI: 10.26538/tjnpr/v7i7.29.
- Rozirwan R, Muhtadi M, Ulqodry TZ, Nugroho RY, Khotimah NN, Fauziyah F, Putri WAE, Aryawati R, Mohamed CAR. 2023b. Insecticidal activity and phytochemical profiles of *Avicennia marina* and *Excoecaria agallocha* leaves extracts. *Ilmu Kelautan: Indones J Mar Sci* 28 (2): 148-160. DOI: 10.14710/ik.Ijms.28.2.148-160.
- Rozirwan R, Nugroho RY, Hendri M, Fauziyah F, Putri WAE, Agussalim A. 2022. Phytochemical profile and toxicity of extracts from the leaf of *Avicennia marina* (Forssk.) Vierh. collected in mangrove areas affected by port activities. *S Afr J Bot* 150: 903-919. DOI: 10.1016/J.SAJB.2022.08.037.
- Rozirwan R, Ramadani S, Putri WAE, Fauziyah F, Khotimah NN, Nugroho RY. 2023c. Evaluation of calcium and phosphorus content in Scallop shells (*Placuna placenta*) and Blood cockle shells (*Anadara granosa*) from Banyuasin Waters, South Sumatra. *Egypt J Aquat Biol Fish* 27 (3): 1053-1068. DOI: 10.21608/ejabf.2023.309326.
- Rozirwan R, Saputri AP, Nugroho RY, Khotimah NN, Putri WAE, Fauziyah F, Purwiyanto AIS. 2023d. An assessment of Pb and Cu in waters, sediments, and Mud crabs (*Scylla serrata*) from mangrove ecosystem near Tanjung Api-Api Port Area, South Sumatra, Indonesia. *Sci Technol Indones* 8 (4): 675-683. DOI: 10.26554/sti.2023.8.4.675-683.
- Rozirwan, Melki, Apri R, Nugroho RY, Fauziyah, Agussalim A, Iskandar I. 2021. Assessment of phytoplankton community structure in Musi Estuary, South Sumatra, Indonesia. *AACL Bioflux* 14 (3): 1451-1463.
- Salimi L, Sezavar S, Agah H. 2019. Assessment of Cd, Ca, Zn, Cr, Al concentrations in water, sediment and tissues of mangrove forest, *Avicennia marina* from Qeshm Island, Persian gulf. *Indian J Geo Mar Sci* 48 (6): 899-906.
- Saputra A, Nugroho RY, Isnaini R, Rozirwan R. 2021. A review: The potential of microalgae as a marine food alternative in Banyuasin Estuary, South Sumatra, Indonesia. *Egypt J Aquat Biol Fish* 25 (2): 1053-1065. DOI: 10.21608/ejabf.2021.170654.
- Savarino G, Corsello A, Corsello G. 2021. Macronutrient balance and micronutrient amounts through growth and development. *Ital J Pediatr* 47 (1): 109. DOI: 10.1186/S13052-021-01061-0.
- Shaheen SM, Abdelrazek MAS, Elthoth M, Moghanm FS, Mohamed R, Hamza A, El-Habashi N, Wang J, Rinklebe J. 2019. Potentially toxic elements in saltmarsh sediments and common reed (*Phragmites australis*) of Burullus coastal lagoon at North Nile Delta, Egypt: A survey and risk assessment. *Sci Total Environ* 649: 1237-1249. DOI: 10.1016/j.scitotenv.2018.08.359.
- Shaheen SM, Shams MS, Khalifa MR, El-Dali MA, Rinklebe J. 2017. Various soil amendments and environmental wastes affect the (im)mobilization and phytoavailability of potentially toxic elements in a sewage effluent irrigated sandy soil. *Ecotoxicol Environ Saf* 142: 375-387. DOI: 10.1016/j.ecoenv.2017.04.026.
- Shamin-Shazwan K, Shahari R, Che Amri CNA, Kassim Z, Ahmad Z. 2021. Morphological structures of *Rhizophora apiculata* Blume. and *Rhizophora mucronata* Lam. *Sci Herit J* 5 (1): 01-04. DOI: 10.26480/gws.01.2021.01.04.
- Shou Y, Zhao J, Zhu Y, Qiao J, Shen Z, Zhang W, Han N, Núñez-Delgado A. 2022. Heavy metals pollution characteristics and risk assessment in sediments and waters: The case of Tianjin, China. *Environ Res* 212: 113162. DOI: 10.1016/j.envres.2022.113162.
- Singh JK, Kumar P, Kumar R. 2020. Ecological risk assessment of heavy metal contamination in mangrove forest sediment of Gulf of Khambhat region, West Coast of India. *SN Appl Sci* 2 (12): 2027. DOI: 10.1007/s42452-020-03890-w.
- Smeds J, Öquist M, Nilsson MB, Bishop K. 2022. A simplified drying procedure for analysing Hg concentrations. *Water Air Soil Pollut* 233: 216. DOI: 10.1007/s11270-022-05678-7.
- Sreenivasulu G, Jayaraju N, Sundara Raja Reddy BC, Lakshmi Prasad T, Lakshmana B, Nagalakshmi K. 2017. Coastal morphodynamics of Tupilipalem Coast, Andhra Pradesh, Southeast Coast of India. *Curr Sci* 112 (4): 823-829. DOI: 10.18520/cs/v112/i04/823-829.
- Sunkur R, Kantamaneni K, Bokhoree C, Ravan S. 2023. Mangroves' role in supporting ecosystem-based techniques to reduce disaster risk and adapt to climate change: A review. *J Sea Res* 196: 102449. DOI: 10.1016/j.seares.2023.102449.
- Susilowati DI, Affandi R, Sulistiono. 2022. Analysis of heavy metals content Hg, Cd, Pb, and Cu of green mussel *Perna viridis* (Linnaeus, 1758) in Bojonegara Coastal Waters of Banten Bay, Indonesia. *IOP Conf Ser Earth Environ Sci* 1083 (1): 012046. DOI: 10.1088/1755-1315/1083/1/012046.
- Takarina ND. 2020. Mangrove root diversity and structure (cone, pencil, prop) effectiveness in accumulating Cu and Zn in sediments and water in River Blanakan. *IOP Conf Ser: Earth Environ Sci* 550 (1): 012009. DOI: 10.1088/1755-1315/550/1/012009.
- Tatongjai S, Kraichak E, Kermaee P. 2021. Comparative anatomy and salt management of *Sonneratia caseolaris* (L.) Engl. (Lythraceae) grown in saltwater and freshwater. *PeerJ* 9: e10962. DOI: 10.7717/peerj.10962
- Thanh-Nho N, Marchand C, Strady E, Huu-Phat N, Nhu-Trang T-T. 2019. Bioaccumulation of some trace elements in tropical mangrove plants

- and snails (Can Gio, Vietnam). *Environ Pollut* 248: 635-645. DOI: 10.1016/j.envpol.2019.02.041.
- WHO [World Health Organization]. 1996. *World Health Organization on Heavy metals-Permissible limits of heavy metals in soil and plants*. (Geneva: World Health Organization), Switzerland.
- Xie Z, Zhu G, Xu M, Zhang H, Yi W, Jiang Y, Liang M, Wang Z. 2022. Risk assessment of heavy metals in a typical mangrove ecosystem - A case study of Shankou Mangrove National Natural Reserve, southern China. *Mar Pollut Bull* 178: 113642. DOI: 10.1016/j.marpolbul.2022.113642.
- Yan Z, Sun X, Xu Y, Zhang Q, Li X. 2017. Accumulation and tolerance of mangroves to heavy metals: A review. *Curr Pollut Rep* 3 (4): 302-317. DOI: 10.1007/S40726-017-0066-4.
- Yap CK, Al-Mutairi KA. 2023. Potentially toxic metals in the tropical mangrove non-salt secreting *Rhizophora apiculata*: A field-based biomonitoring study and phytoremediation potentials. *Forests* 14 (2): 237. DOI: 10.3390/f14020237.
- Zhang H, Yang J, Li W, Chen Y, Lu H, Zhao S, Li D, Wei M, Li C. 2019. PuHSA4a enhances tolerance to excess Zinc by regulating reactive oxygen species production and root development in *Populus*. *Plant Physiol* 180 (4): 2254-2271. DOI: 10.1104/pp.18.01495.
- Zhang Q, Ren F, Xiong X, Gao H, Wang Y, Sun W, Leng P, Li Z, Bai Y. 2021. Spatial distribution and contamination assessment of heavy metal pollution of sediments in coastal reclamation areas: A case study in Shenzhen Bay, China. *Environ Sci Eur* 33 (1): 90. DOI: 10.1186/s12302-021-00532-9.
- Zhong W-S, Ren T, Zhao L-J. 2016. Determination of Pb (Lead), Cd (Cadmium), Cr (Chromium), Cu (Copper), and Ni (Nickel) in Chinese tea with high-resolution continuum source graphite furnace atomic absorption spectrometry. *J Food Drug Anal* 24 (1): 46-55. DOI: 10.1016/j.jfda.2015.04.010.