World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Impact of heavy metals in plant tissues (roots, stems and leaves) of *Acrostichum aureum* (L.) in the coastal regions of Akwa Ibom State, Nigeria

Ekaete David Udo *, EnoAbasi Deborah Anwana and Felix Okpako Ogbemudia

Department of Botany and Ecological Studies, University of Uyo, Akwa Ibom State, Nigeria.

World Journal of Advanced Research and Reviews, 2025, 26(01), 2599-2605

Publication history: Received on 05 March 2025; revised on 14 April 2025; accepted on 16 April 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.1.1210

Abstract

This study investigated the impact of heavy metals in the plant tissues in the coastal regions of Akwa Ibom State. This study was carried out at three mangrove locations within Iko Town, Okoroutip and Uta Ewa in Eastern Obolo, Ibeno and Ikot Abasi Local Government Areas respectively. Vegetation sampling and analysis of heavy metals in plant tissues was done using acid digestion for inductively coupled plasma optical emission spectrophotometry. The study analyzed the seasonal characterization of heavy metals in *A. aureum* tissues (leaf, stem, root) across mangrove communities during dry and wet seasons. In the dry season, Okoroutip recorded the highest concentrations of Zn (leaf), Cu (stem), and V (root), with Ag, As, Cd, and Hg below detectable limits. Iko Town showed Zn as the dominant metal across tissues, while Hg, Ni, and Pb had minimal presence. Uta Ewa had Zn and V as the most prevalent metals in leaves and roots, respectively. In the wet season, heavy metals like Pb, V, and Cr showed higher concentrations, particularly in Uta Ewa, while Ag and Cd were minimally present or below detectable limits. Across all communities, Zn and V remained dominant in specific tissues, while Ni, Pb, and Hg consistently exhibited low levels. The findings highlight significant spatial and seasonal variations in metal concentrations and emphasize the need for monitoring and management of mangrove ecosystems. *Acrostichum aureum* adapts to polluted environments by accumulating heavy metals, demonstrating its phytoremediation potential. It is a recommended plant species for remediation, monitoring pollution, and enforcing measures to limit industrial effluents in mangroves.

Keywords: *Acrostichum aureum*; Heavy Metals; Pollution; Seasonality; Costal Regions; Akwa Ibom State

1. Introduction

The mangrove ecosystem is a complex assemblage with various plant species. The composition, structure, and plant distribution within mangroves are influenced by soil characteristics, including organic matter content, salinity levels, nutrient availability and soil contents (Otero *et al.,* 2009). The degradation of mangrove ecosystems on a global scale, both in terms of quality and quantity, can be attributed to the escalation of anthropogenic activities (Husodo *et al.,* 2017). These activities have resulted in alterations in precipitation patterns, climate change, elevated sea levels, heightened salinity levels, and a significant risk to the growth and survival of these ecosystems (Akpabio *et al.,* 2024). These mangroves serve for diverse purposes which include shelter and habitat, food, commercial and medicinal uses for both animals and humans. *A. aureum* is a typical example of medical important plant species of the mangrove ecosystem (Essien *et al.,* 2007). It is a member of the Pteridaceae family which is commonly known to the locals as the Swamp Fern or Mangrove Fern. It is an evergreen shrub, found in a hostile environment. It thrives in a hostile environment replete with bacteria, fungi or virus synthesize defensive natural products against these pathogens, which may also exhibit bactericidal, fungicidal or virucidal activity in the human system (Chikezie *et al.,* 2015). However, anthropogenic activities such as mining, road construction, industrial waste release has posed threats to the mangrove species in abundance and usage (Akpabio *et al.,*2024). The adverse effects of pollution, degradation, and depletion on mangrove

* Corresponding author: Ekaete David Udo Email: ekaetedudo@uniuyo.edu.ng

ecosystems can result in a reduction of the ecosystem services they offer (Moonsammy, 2021) and by extension, due to bioaccumulation, it will affect the fauna species in the ecosystem (Essien *et al.,* 2025). Crude oil exploitation is one of the major causes of pollution to the ecosystem (Akpabio *et al.,* 2024) which contains high concentrations of toxic heavy metals (Ogbemudia *et al.,* 2018).

Heavy metals could be hazardous pollutants with density above $5gcm^{-3}$, and have the potential to alter the composition of the plant species (Alsafran *et al.,* 2021). Anwana *et al.,* (2024) reported low abundance of *Acrostichum aureum* and likely attributed it to accumulation of heavy metals in the soil. They have the propensity to accumulate in living organisms, including fish, plankton, and bottom sediments within aquatic environments and even in tissues of plants (Yan *et al.,* 2020). Heavy metals and metalloids (HMs) such as cadmium (Cd), arsenic (As), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) are dispersed in the environmental media (Arshad *et al.,* 2020) and are persistent pollutants which may be transported from one environmental medium to another, or may be absorbed by the apoplast of plant roots from the pedosphere (Lwin *et al.,* 2018). They wend their way there from to the edible/non-edible parts of the plants, enter the trophic chain, and imperil human health (Ahamad *et al.,* 2020). Human beings are commonly exposed to Pb, Cd, Cu, As and Cr through the ingestion of contaminated food items (Usman *et al.,* 2020). The consistent release of wastes to the environment as a result of uncontrolled mining activities has resulted to unsafe concentration of these heavy metals in the environment. This has aroused concerns by ecologist to investigate the implication of heavy metals in plant tissues (leaves, stem and root) of *Acrostichum aureum* in the coastal regions of Akwa Ibom State, Nigeria.

2. Methodology

2.1. Study Area

This study was carried out at three mangrove locations in Akwa Ibom State. These were Iko Town in Eastern Obolo Local Government Area, Okoroutip community in Ibeno Local Government Area and Uta Ewa community in Ikot Abasi Local Government Area. The coordinates of the Mangrove locations were Latitudes and Longitudes 4° 33' N to 23 °02' N and 7° 44' E to 50 °60' E and 4° 33' N to 06° 74' N and 7° 32' E to 48 °64' E and 4° 32' N to 48 °50' N and 7°32' E to 4 °83' E Iko Town, Okoroutip and Uta Ewa respectively (Field data, 2021).

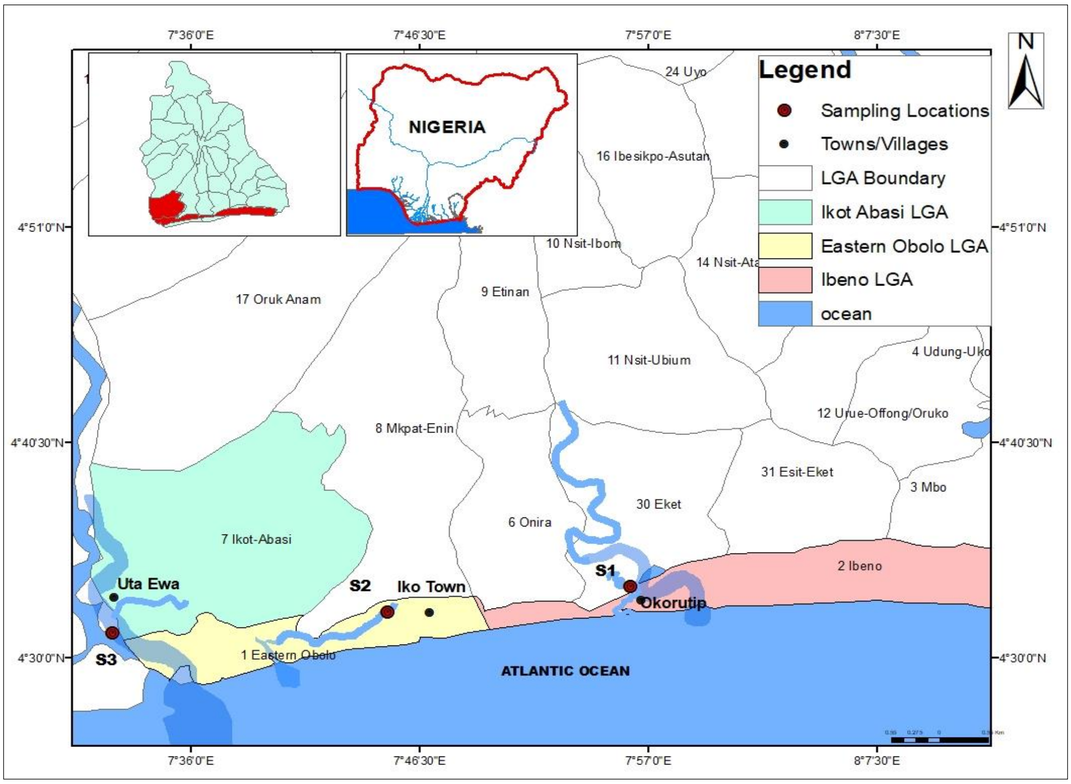

Figure 1 Map of the study areas showing sampling location (Field data, 2021)

2.2. Vegetation Sampling

Four vegetation plots were randomly chosen, and within each plot, three belt transects were established. Systematic sampling was employed in each plot to gather data on vegetation and soil. Sampling was conducted using a 10 m x 10 m quadrat placed at regular 20 m intervals along the transects. Within each quadrat, two soil samples were collected using a soil corer at depths of 0–15 cm and 15–30 cm, corresponding to rooting zones. These individual samples were combined into a composite sample, which was then stored in appropriately labeled ziploc bags. Vegetative components, including roots, stems, and leaves of *A. aureum*, were also collected from each quadrat and preserved in similarly labeled ziploc bags. The soil samples and vegetative components of *A. aureum* were then transported to the laboratory for physicochemical property analysis and heavy metal concentration assessment.

2.3. Analysis of Heavy Metals in Plant Tissues

2.3.1. Acid Digestion for Inductively Coupled Plasma Optical Emission Spectrophotometry (ICP-OES)

The plant tissues were dried and homogenized and 0.5 g of each sample was weighed. Samples were transferred into beakers in addition to 20 ml of Aqua Regia. The digestion was carried out on a heating block in a fume hood with the temperature not exceeding 90^{o}C for about an hour. The beakers were allowed to cool and 2 ml of Hydrogen peroxide was added to each beaker and heated for 10 minutes. After the digestion was completed, the digested volume of each sample was measured. The Digested volume was then filtered and diluted to 50 ml using ultra-pure deionized water for ICP-OES analysis.

The exhaust line was properly fastened, the gas lines were successfully linked, and the gas supplies were activated. The tubing for the spray chamber, nebulizer, and peristaltic tubes were appropriately interconnected. The power supply, high voltage switch, and auto-sampler were activated. The Inductively Coupled Plasma Optical Emission Spectrophotometry (ICP-OES 720) instrument, along with the computer and ICP-OES software interface, were activated and left to operate for duration of 10 minutes in order to complete the initialization process. The Plasma Enable Switch was verified to be in the enable state, indicated by being pushed in. The instrument was permitted to undergo a warm-up and initialization process for approximately ten minutes. The instrument underwent a rinsing process using a rinse-solution consisting of 2-5 % HNO_3.

Working standards with appropriate concentrations were prepared using the serial dilution method, starting from a single or multi-elements stock standard. A novel approach was devised whereby a new worksheet or a template from the ICP-OES expert software was utilized to create a method. The conditions and parameters for fitting the calibration curve on the created worksheet were appropriately established. A selection was made of the elements of interest (arsenic, silver, chromium, copper, nickel, lead, mercury, cadmium, titanium, vanadium, and zinc) along with the appropriate wavelengths for their measurement. The method, input sample matrix, blank, standards, and sample codes were developed and stored. The placement of the blank and standards in their respective rack positions on the autosampler was performed. The blank and subsequent implementation guidelines were reviewed. The calibration coefficient was examined to verify that the regression equation met the criterion of R2≥ 0.995. The input of the sample codes for the samples to be analysed on the sequence page was completed before the commencement of the analysis. At the end of the analysis, the blank and rinse solution were subjected to a brief period of running and rinsing, after which the resulting data were recorded and stored. The instrument was deactivated following a rinse period of approximately five minutes.

3. Results

3.1. Dry Season Characterization of Heavy Metals in *A. aureum* tissues (Leaf, Stem and Root) across the Mangrove Communities

The dry season characterization of heavy metals in tissues of *A. aureum* across the mangrove communities is presented in Table 1a. In Okoroutip mangrove community, heavy metals such as Ag, As, Cd and Hg were below detectable limits in the leaf, stem and root of *A. aureum*. Zn (2.25±0.03 mg/kg), Cu (3.45±0.02 mg/kg) and V (1.10±0.03 mg/kg) recorded the highest concentrations in the leaf, stem and root, respectively, while V (0.05±0.02 mg/kg), Pb (0.10±0.03 mg/kg) and Cr (0.20±0.04 mg/kg) had the lowest concentrations in the leaf, stem and root respectively.

In Iko Town community mangrove, Ag, As and Cd were below detectable limits in all plant tissues except Ag (0.02±0.01) in the Stem. Zn recorded 4.25±0.01 mg/kg, 1.85±0.01 mg/kg and 1.50±0.58 mg/kg as the highest concentration in the leaves, stems and roots respectively. Hg (0.02±0.01 mg/kg) had the lowest concentrations in the leaves and was below detectable limits in the stems and roots. Ni (0.10±0.03 mg/kg) and Pb (0.10±0.01 mg/kg) had the lowest concentrations in the roots.

In Uta Ewa community mangrove, exception of Ag in leaves (0.002±0.001 mg/kg), Ag, As, Cd and Hg were below detectable limits in the leaves, stem and roots. Zn recorded the highest in both leaves (3.45±0.03 mg/kg) and stems (1.60±0.12 mg/kg). In the stem, Zn (1.60±0.12 mg/kg) and Ti (0.05±0.01 mg/kg) had the largest and least concentrations respectively. V (1.45±0.03 mg/kg) had the largest concentration in the root while and Cr (0.15±0.02 mg/kg) and Ni (0.15±0.01 mg/kg) had the least concentrations in the root.

Table 1a Mean values of Dry Season Characterization of Heavy Metals in *A. aureum* tissues (Leaf, Stem and Root) across the Mangrove Communities

Heavy metals (mg/kg)	**Okoroutip**			**Iko Town**			**Uta Ewa**		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Ag	BDL	BDL	BDL	BDL	0.02±0.01	BDL	0.002±0.001	BDL	BDL
As	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cd	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr	0.55±0.03	0.65±0.03	0.20±0.04	0.55±0.03	0.35±0.01	0.20±0.06	0.50±0.29	0.45±0.06	0.15±0.02
Cu	1.25±0.03	3.45±0.02	0.40±0.01	1.25±0.58	1.85±0.58	0.50±0.03	0.85±0.03	0.70±0.01	0.35±0.03
Hg	BDL	BDL	BDL	0.02±0.01	BDL	BDL	BDL	BDL	BDL
Ni	0.25±0.01	0.30±0.03	BDL	0.25±0.06	0.15±0.01	0.10±0.03	0.25±0.03	0.20±0.03	0.15±0.01
Pb	0.70±0.01	0.10±0.03	BDL	0.50±0.03	0.05±0.01	0.10±0.01	0.75±0.01	0.40±0.06	BDL
Ti	0.20±0.03	0.15±0.03	0.50±0.01	0.55±0.01	0.30±0.12	0.80±0.12	0.25±0.02	0.05±0.01	0.45±0.06
V	0.05±0.02	0.20±0.01	1.10±0.03	0.25±0.03	0.20±0.02	1.10±0.03	0.20±0.06	0.10±0.01	1.45±0.03
Zn	2.25±0.03	1.35±0.06	0.65±0.03	4.25±0.01	1.85±0.01	1.50±0.58	3.45±0.03	1.60±0.12	1.05±0.01

± Standard error; BDL – Below Detectable Limits; Source: Field data (2021).

Table 1b Permissible limits of metals in plants

Metals	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Ti	V	Zn
Units (mg/kg)	0.30	0.01	0.02	1.30	1.30	0.001	0.02	0.30	0.60	1.00	0.60

Source: WHO Standard (1996).

3.2. Wet Season Characterization of Heavy Metals in *A. aureum* tissues (Leaf, Stem and Root) across the Mangrove Communities

The wet season characterization of heavy metals in *A.aureum* across the mangrove communities is presented in Table 2a. In Okoroutip mangrove, Pb (0.32±0.01 mg/kg) and Cd (0.03±0.01 mg/kg) had the highest and least concentrations in the leaf respectively. In the stem, V (1.53±0.58 mg/kg) had the highest concentration while Ag (0.01±0.001 mg/kg) and Cd (0.01±0.001 mg/kg) had the least concentrations in the stem. In the root, V (1.24±0.01 mg/kg) also had the highest concentration while Cu (0.06±0.01 mg/kg) and Ni (0.06±0.04 mg/kg) had the least concentrations.

In Iko Town mangrove, Pb (0.33±0.02 mg/kg) and Cd (0.04±0.01 mg/kg) had the highest and least concentrations in the leaf respectively while Cr (0.25±0.02 mg/kg) and Ni (0.02±0.01 mg/kg) had the highest and least concentrations in the stem, respectively. In the root, V (1.22±0.01 mg/kg) had the highest concentration while Cu (0.04±0.02 mg/kg) and Ni (0.04±0.01 mg/kg) had the least concentrations in the root.

In Uta Ewa mangrove, V (1.73±0.01 mg/kg) and Cu (0.11±0.01 mg/kg) had the highest and least concentrations in the leaf respectively, Cr (1.23±0.02 mg/kg) and Ni (0.03±0.01 mg/kg) had the highest and least concentrations in the stem respectively while in the root, V (1.25±0.03mg/kg) and Ag (0.01±0.01 mg/kg) had the highest and least concentrations, respectively.

Table 2 Mean values of Wet Season Characterization of Heavy Metals in *A. aureum* tissues (Leaf, Stem and Root) across the Mangrove Communities

Heavy metals (mg/kg)	**Okoroutip**			**Iko Town**			**Uta Ewa**		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Ag	0.04±0.04	0.01±0.001	BDL	0.05±0.01	0.03±0.01	BDL	BDL	BDL	0.01±0.01
As	0.07±0.01	0.30±0.09	0.20±0.03	0.08±0.05	0.06±0.01	0.18±0.01	0.21±0.01	0.16±0.01	0.21±0.01
Cd	0.03±0.01	0.01±0.001	BDL	0.04±0.01	0.03±0.02	BDL	BDL	BDL	BDL
Cr	0.31±0.01	0.46±0.04	1.06±0.01	0.32±0.01	0.25±0.02	1.04±0.01	1.30±0.12	1.23±0.02	1.07±0.01
Cu	0.14±0.02	0.20±0.03	0.06±0.01	0.15±0.01	0.13±0.02	0.04±0.02	0.11±0.01	0.05±0.01	0.07±0.01
Hg	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni	0.05±0.01	0.03±0.01	0.06±0.04	0.06±0.01	0.02±0.01	0.04±0.01	BDL	0.03±0.01	0.07±0.06
Pb	0.32±0.01	0.21±0.01	BDL	0.33±0.02	0.21±0.01	BDL	BDL	BDL	BDL
Ti	0.17±0.01	0.63±0.02	0.51±0.01	0.18±0.01	0.14±0.01	0.49±0.01	0.77±0.01	0.41±0.01	0.52±0.01
V	0.30±0.06	1.53±0.58	1.24±0.01	0.31±0.01	0.10±0.03	1.22±0.01	1.73±0.01	1.04±0.01	1.25±0.03
Zn	0.09±0.01	0.05±0.02	BDL	0.10±0.06	0.08±0.01	BDL	BDL	BDL	BDL

± Standard error; BDL – Below Detectable Limits; Source: Field data (2021).

4. Discussion

Plants have the capacity to uptake heavy metals via their roots, branches, and leaves, subsequently accumulating these metals inside different plant tissues. In addition, the dispersion and aggregation of heavy metals are impacted by the categorization of plants, origins of metals, and levels of metal concentration in sediments (Seleiman *et al*., 2017). The study observed variations in the distributions of heavy metals across different sections of *A. aureum* throughout several mangrove locations. The observed phenomenon can be ascribed to the disparities in heavy metal concentrations found in soils, which are influenced by their geographical distribution and subsequently impact their exposure to river or marine influences.

López-González *et al.,* (2006) investigated the positioning of sites concerning industrial effluents and sediment background. The plant's capacity for phytoextraction and subsequent remobilization of metals from soil to various plant parts was evident from the differing concentrations of metals observed in the leaf, stem, and root (Ali *et al*., 2013). Additionally, this fern demonstrates its ability to adapt and tolerate heavy metal pollution. The order of heavy metal accumulation in *A. aureum* varied throughout the three mangrove locations, namely Okoroutip, Iko Town, and Uta Ewa. In Okoroutip, the highest accumulation was observed in the stem, followed by the leaf and root. In Iko Town, the leaf exhibited the highest accumulation, followed by the stem and root. Lastly, in Uta Ewa, the leaf had the highest accumulation, followed by the root and stem. The present outcome diverges from the observations made by Kannan *et al*. (2016) and Salim *et al*. (2019), since they documented elevated metal levels in the roots of mangrove plants. The observed phenomenon of low concentrations of heavy metals in the roots and high concentrations in the stems and leaves of the Okoroutip and Iko Town mangroves suggests a significant mobilization of these metals from the roots to the other vegetative parts. In general, the heavy metal content in plant parts was found to be higher during the dry season compared to the wet season. This observation can be attributed to the dilution effect of rainwater on heavy metals in the soil, resulting in reduced absorption concentrations of these metals by plants. The mangrove in Iko town had a lower pH level in comparison to Okoroutip. A drop in soil pH can enhance the bioavailability of heavy metals, leading to an increased uptake of these metals by plants.

Furthermore, it was observed that the soil in the mangrove area of Iko town exhibits a higher level of acidity in comparison to the soil found in Okoroutip. Plants grown in acidic soil have greater access to micronutrients compared to those cultivated in neutral or alkaline environments. Zinc (Zn), copper (Cu), and nickel (Ni) are crucial elements that are necessary in trace amounts for the growth and development of plants (Alloway, 2013). The observed high concentrations of zinc (Zn) and copper (Cu) in the leaves and stem of *Acrostichum aureum* in this study can be attributed to the crucial role these metals play in the growth and metabolism of the plant. Consequently, *Acrostichum aureum* actively absorbs and utilizes these metals. These metals play a crucial role in the creation of proteins, nucleic acids, and photosynthetic pigments. The reported concentrations of zinc (Zn) and copper (Cu) in the plant tissues exceed the acceptable limits as defined by the World Health Organization (WHO) (1996) (Table 1a). This suggests that *Acrostichum aureum* exhibits a high tolerance for accumulating elevated levels of zinc (Zn) and copper (Cu), both of which can be hazardous to plants at high concentrations. The elevated concentration of heavy metals in plant tissues can be attributed to their occurrence in sediments. Chromium (Cr), Nickel (Ni), and Lead (Pb) are heavy metals that are considered non-essential for plants, as they do not possess any biological functions inside the plant system. The findings indicate that *Acrostichum aureum* possesses the ability to uptake and retain non-essential heavy metals inside its root system, as evidenced by the observed buildup of these elements. The concentrations of nickel (Ni), lead (Pb), and chromium (Cr) in plant roots exceed the acceptable thresholds outlined by the World Health Organization (WHO, 1996) which calls for concern. Udo *et al.,* (2024) reported presence of heavy metals such as Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Ti, V and Zn in the Soil of Coastal Areas of Akwa Ibom State, Nigeria and thus facilitating the capacity of *Acrostichum aureum* in the community to amass these metals within its biological tissues. These were likely attributed to the abundance and density of *Acrostichum aureum* (Anwana *et al.,* 2024).

5. Conclusion

Acrostichum aureum demonstrates remarkable adaptability by accumulating both essential and non-essential heavy metals, tolerating high concentrations in polluted environments. Its metal uptake varies across locations and seasons, influenced by soil pH, sediment composition, and environmental factors, highlighting its phytoremediation potential and ecological significance.

Recommendations

Based on the findings, it is recommended to utilize *Acrostichum aureum* for phytoremediation in polluted mangrove ecosystems to mitigate heavy metal contamination, regularly monitor and enforcement of pollution control measures to reduce industrial effluent discharge into mangrove environments.

Compliance with ethical standards

Disclosure of conflict of interest

There was no conflict of interest among authors.

References

[1] Ahamad, M. I., Song, J., Sun, H., Wang, X., Mehmood, M. S., Sajid, M., Su, P. and Khan, A. J. (2020). Contamination level, ecological risk, and source identification of heavy metals in the hyporheic zone of the Weihe River, China. *Int. J. Environ. Res. Public Health*, 17, 1070. [CrossRef]

[2] Akpabio, J. U., Okon, A. O., Ebong, G. A., Udoinyang, E. P., Essien, E. A., Josiah, I. U. and Akpan, A. W. (2024). Perturbation of Road Construction and Inorganic Sedimentation on the Macroinvertebrate Fauna in the Midstream Segment of Qua Iboe River, Nigeria. *Asian J Adv Res Rep.* 18(4):24–33.

[3] Alsafran, M., Usman, K., Al Jabri, H. and Rizwan, M. (2021). Ecological and Health Risks Assessment of Potentially Toxic Metals and Metalloids Contaminants: A Case Study of Agricultural Soils in Qatar. *Toxics*, 9:35-46.

[4] Anwana, E. D., Udo, E. D., Ogbemudia, F. O., and Ita, R. E. (2024). "Abundance and Density of *Acrostichum aureum* L. In Coastal Ecosystems of Southern Nigeria". *Asian Journal of Research in Botany 7 (2):258-62. https://journalajrib.com/index.php/AJRIB/article/view/225.*

[5] Arshad, M., Silvestre, J., Pinelli, E., Kallerhoff, J., Kaemmerer, M., Tarigo, A., Shahid, M., Guiresse, M., Pradere, P. and Dumat, C. (2020). Afield study of lead phytoextraction by various scented Pelargonium cultivars. Chemosphere, 71, 2187–2192.

[6] Chikezie, P. C., Ibegbulem, C. O., and Mbagwu, F. N. (2015). Bioactive Principles from Medicinal Plants. *Res. J. Phytochem*. 9: 88 -115.

[7] Essien, J., Benson, N. and Antai, S. (2007). Seasonal dynamics of physicochemical properties and Heavy Metal burdens in Mangrove Sediments and surface water of the Brackish Qua Iboe Estuary, Nigeria. *Toxicological and Environmental Chemistry*, 90(2): 259-273.

[8] Essien, Ubong Bernard, Emmanuel Anietie Essien, Benjamin Nnamdi Okechukwu, Ifeanyi Francis Merenini, Kumar Yogesh, Mahnaz Ensafy, Uduak Friday Udotong, and Okoroafor Uzoma. (2025). “Heavy Metals Composition in Fish Species from Oron River Metropolis, Akwa Ibom State, Nigeria”. Journal of Materials Science Research and Reviews 8 (1):223-33. https://doi.org/10.9734/jmsrr/2025/v8i1391.

[9] Husodo, T., Palabbi, S., Abdoellah, O., Nursaman, M., Fitriani, N. and Partasasmita, R. (2017). Short Communication: Seagrass Diversity and Carbon Sequestration: Case Study on Pari Island, Jakarta Bay, Indonesia. Biodiversitas, 18(4): 1596-1601.

[10] Lwin, C. S., Seo, B. H., Kim, H. U., Owens, G. and Kim, K. R. (2018). Application of soil amendments to contaminated soils for heavy metal immobilization and improved soil quality—A critical review. Soil Sci. Plant Nutr., 64, 156–167.

[11] Moonsammy, S. (2021). Ecosystem Services and Rehabilitation of Mangroves- An Economic Perspective. Journal of Academic Research in Economics (JARE) University of Guyana, 12(3):99-107.

[12] Ogbemudia, F., Ita, R. and Udo, E. (2018). Pedological and Risk Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in Farmlands of a Tropical Oil Producing Region in Akwa Ibom State, Nigeria. International Journal of Biological and Environmental Engineering, 1 (1): 17 – 23.

[13] Otero, X., Ferreirra, T., Huerta- Diaz, M., Partiti, C., Vidal- Torrado, S. and Macias, F. (2009). Geochemistry of Iron and Manganese in Soils and Sediments of a Mangrove System, Island of Pai Matos (Canancia- SP, Brazil), Geoderma, 148: 318-335.

[14] Udo, E. D., Anwana, E. D., and Ogbemudia, F. O. (2024). “Pertubations of Physicochemical Properties and Heavy Metal in the Soil of Coastal Areas of Akwa Ibom State, Nigeria”. Asian Journal of Environment & Ecology 23 (11):131-42. https://doi.org/10.9734/ajee/2024/v23i11628.

[15] Usman, K., Abu-Dieyeh, M. H., Zouari, N. and Al-Ghouti, M.A. (2020). Lead (Pb) bioaccumulation and antioxidative responses in Tetraenaqataranse. Sci. Rep. 2020, 10, 17070.

[16] Yan, A., Wang, Y., Tan, N. S., Yusof, M. L. M., Ghosh, S. and Chen, Z. (2020). Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. Front. Plant Sci., 11, 359-369.

[17] Seleiman, M., Selim, S. Jaakkola, S. and Mäkelä, P. (2017). Chemical Composition and In Vitro Digestibility of whole-crop Maize fertilized with Synthetic Fertilizer or Digestate and harvested at two maturity stages in Boreal growing Conditions. *Agricultural Food Science*, 26: 47–55.

[18] López-González, N., Borrego, J. Ruiz, F. Carro, B. Lozano-Soria, O. and Abad, M. (2006). Geochemical Variations in Estuarine Sediments: Provenance and Environmental Changes (Southern Spain). *Estuarine*, *Coastal and Shelf Science,* 67: 313–320.

[19] Ali, H., Khan, E. and Sajad, M. (2013). Phytoremediation of Heavy Metals-Concepts and Applications. *Chemosphere*, 91: 869 – 881.

[20] Kannan, N., Thirunavukkarasu, N. Suresh, A. and Rajagopal, K. (2016). Analysis of Heavy Metals Accumulation in Mangroves and Associated mangroves species of Ennore Mangrove Ecosystem, East Coast India. *Indian Journal of Science and Technology*, 9(46): 1 – 13.

[21] Salim, I., Sajjad, R. Paule-Mercado, M. Memon, S. Lee, B. Sukhbaatar, C. and Lee, C. (2019). Comparison of Two Receptor Models PCA-MLR and PMF for Source Identifiation and apportionment of pollution carried by Runoff from Catchment and Sub-Watershed areas with mixed land cover in South Korea. *Science of the Total Environment*, 663: 764–775.

[22] Alloway, P. (2013). Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Bioavailability, *Environmental Pollution* 3-9p.

[23] WHO (World Health Organization) (1996). Permissible Limits of Heavy Metals in Soil and Plants. WHO, Geneva, Switzerland.