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A PRELIMINARY ENVIRONMENTAL AND ECOTOXICOLOGICAL STUDY ON THE MANGROVE STRAND OF THE SOUTHWESTERN BUNDAL ISLAND

Fatima Zaim, Hafiz Hamdan Ur Rehman, Syeda Ayesha Iman, Jibran Anwer, Lubaba Javed Iqbal and Muhammad Shoaib Kiani

Institute of Marine Science, University of Karachi-75270, Karachi, Pakistan
Corresponding author: mshoaibkiani.ims@uok.edu.pk

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ABSTRACT

This study investigates heavy metal contamination in the mangrove strand of the southwestern Bundal Island near Karachi, in the vicinity of major industrial zones. Concentrations of nine heavy metals (Cd, Cu, Fe, Ni, Mn, Co, Cr, Zn, Pb) were analyzed in surface sediments, the mangrove *Avicennia marina* (Forssk.) Vierh (A. marina) and the gastropod mollusk *Telescopium telescopium* (Linnaeus, 1758). The collected samples were analyzed using Atomic Absorption Spectrophotometry. Contamination was assessed via Geo-accumulation Index (Igeo), Enrichment Factor (EF), Bioconcentration Factor (BCF), and Translocation Factor (TF). Sediments showed high pollution by Fe, Mn, Zn, and Cr (the highest Igeo = 23.20 for Iron), while Cd remained below harmful levels. *T. telescopium* had the highest BCF for Cd (5.77) and Zn (2.22). *A. marina* accumulated the most Fe (307.78 ppm) in pneumatophores, with Pb showing the highest translocation (TF = 1.03). The findings reveal ecological stress and highlight the need for ongoing monitoring and sustainable management. Given its ecological significance and vulnerability, the Bundal Island should be considered for designation as a suitable category of Marine Protected Area (MPA) to ensure the long-term conservation of its mangrove habitats and associated biodiversity.

Keywords: Bundal Island, sediments, heavy metals, mangroves, *Avicennia marina*, *Telescopium telescopium*, Karachi

INTRODUCTION

The Bundal Island, located on the southeastern coastal belt of Karachi, is part of the Indus deltaic system and hosts ecologically important habitats, including mangrove swamps, sandy beaches, backwater channels, tidal inlets, sand dunes sand and mudflats (Abbas *et al*., 2021). Positioned at the eastern side of Karachi harbor and at the confluence of Gizri creek, Korangi creek, and Phitti creek, the Island takes on a triangular shape with a broad northern side (ca. 4 km wide) and a narrow southern side (ca. 1 km wide) (Waqas *et al*., 2019). Total area of the Bundal Island is about 22 km² (Abbas *et al*., 2021) *A. marina* mangroves covering 10.47% area of the island represents a key productive habitat supporting variety of life and acting as buffer against natural climatic disasters e.g. cyclones, storm surges and protecting Karachi coast. A conservative estimate of economic worth of mangroves of the Bundal Island is 32.08 Million PKR per years (Abbas *et al*., 2021). The Bundal Island holds significant socio-economic importance by safeguarding Phitti Creek, a crucial navigational channel for Port Bin Qasim, and nearby human settlements from high-energy waves (Waqas *et al*. 2019).

Bundal, as a biodiversity-rich spot, is supported by IUCN's paper titled "The future of Bundal Island" depicting it as a crucial area for the breeding, roosting, and feeding activities of both migratory and resident bird species. Migratory birds, including pelicans, flamingos, cormorants, and cranes, join resident species such as herons, waders, terns, egrets, and kites. The adjacent waters act as feeding grounds for Indian Ocean humpback and Indo-Pacific bottlenose dolphins. Bundal Island is rich in fauna, hosting a significant Jackal population within the mangroves. Various snake species, including Boas, Vipers and sea snakes contribute to the Island's status as a biodiversity Besides, this report also touches upon role of this island as important breeding ground for green turtles (*Chelonia mydas*) (IUCN, 2005; Danish, 2019). However, no supporting evidence is provided for these assertions specifically about jackals, snakes and green turtles on the Bundal Island.

The fragile ecosystem of the Bundal island is under increasing threat due to encroaching urbanization, industrial effluent discharge, and recently proposed mega real estate development projects (Abbas *et al*., 2023). The environment of the creeks is under serious stress because they receive a really great deal of pollutants from three major zones: steel mills, shipping routes and power plants. The proximity of Bundal Island to densely industrialized zones—Korangi Industrial Area (KIA), Korangi Creek Industrial Park, Landhi Industrial Estate (LITE), Sindh

Industrial Trading Estate (SITE), Port Qasim, Pakistan Steel Mills—renders it highly susceptible to metal contamination. These metals can originate from diverse industrial processes, including metal plating, tanning, pharmaceuticals, textiles, and petrochemical operations, and are often discharged untreated or partially treated into marine and estuarine waters (Yuan *et al*., 2019; Bhardwaj *et al*., 2020; Abbas *et al*., 2021; Aziz *et al*., 2023).

Heavy metals (HMs), once introduced into the environment, persist due to their non-biodegradable nature (Ferrey *et al*., 2017). Owing to their chronic toxicity, non-biodegradability, and propensity for environmental bioaccumulation, heavy metals stand out as highly detrimental environmental pollutants (Valdés *et al*., 2014). They can accumulate in sediments and biomagnify through food chains, ultimately affecting higher trophic levels, including fish, birds, and humans (Yalcin *et al*., 2008; Yi *et al*., 2011; Weber *et al*., 2013; Aziz *et al*., 2023). Essential metals such as Cu, Fe, Mn, and Zn are vital at trace levels but become toxic at elevated concentrations, while non-essential metals like Cd, Pb, and Cr are inherently toxic even at low concentrations (Aziz *et al*., 2023).

To understand the ecological consequences of heavy metal exposure on Bundal Island, we selected two key bioindicator organisms: the mangrove species *Avicennia marina* (Forsk.) Vierh (Family: Acanthaceae) and the intertidal gastropod mollusk *Telescopium telescopium* (Linnaeus, 1758) (Family: Potamididae). *A. marina* absorb higher quantities of heavy metals from their surroundings, which demonstrate the importance of these plants in cleaning the coastal environments from pollutants, showcasing phytoremediation capabilities and metal tolerance (Defew *et al*. 2005; Fernandes *et al*. 2012; Bodin *et al*. 2013; Subiandono, 2013; Usman *et al.* 2013; Fernández-Cadena *et al*. 2014, Li *et al*. 2016; Besley and Birch, 2021) while *T. telescopium*, due to its sedentary nature and feeding behavior, is a reliable indicator of localized contamination levels in sediments (Bertine and Goldberg, 1972; Ferrel *et al*., 1973; Ismail and Safahieh, 2005; Yap, 2014; Koliyar, 2018; Singh, 2021). The sediments surrounding *A. marina* roots, characterized by high clay and organic carbon content, create anoxic and sulphidic conditions, making them a sink for many elements (Parida and Kumari, 2021).

Our research has an ecotoxicology focus, specifically on the identification of heavy metals in mangrove swamps, accompanied by soil analysis. The study is conducted on the Bundal Island mangrove ecosystem on the southwest flank having significance in terms of ecology, economy, aesthetics, and protective services that it renders to the local coastal communities. The island has been in the news for its potential development into a mega real estate project being right next to Karachi. There have been multiple previous attempts led by the Pakistani government, investors, and foreign partners to reclaim this island for development (The Daily Dawn, 2023). This context adds a layer of significance to our research, prompting a closer examination of the potential environmental implications and ecological risks associated with such proposed developments on the Bundal Island.

This study aims to quantify the concentrations of heavy metals in sediments and in *A. marina*, and *T. telescopium* tissues. It also attempts to evaluate metal contamination using geochemical indices Igeo (Geo-Accumulative Index) and EF (Enrichment Factor), assessment of metal bioavailability and accumulation through BCF (Bioconcentration Factor) and TF (Translocation Factor) calculations. In the end, it analyses inter-metal correlations to infer possible contamination sources and pathways. In doing so, this study seeks to provide an ecotoxicological risk assessment that informs conservation strategies and regulatory frameworks for the protection of Bundal Island's unique mangrove ecosystem.

MATERIALS AND METHODS

Study Area

The study was conducted on the Bundal Island, located approximately 1.5 km south of DHA Phase VIII, Karachi, within the Indus Deltaic region (24°.42'.529" N / 067°.08'.267" E).

Sampling Strategy

Fieldwork was carried out in December 2023 during low tide. Composite samples of surface sediments (0–15 cm depth), gastropod mollusks (*Telescopium telescopium*), and *Avicennia marina* mangrove tissues (leaves, twigs, and pneumatophores) were collected.

Sample Preparation and Digestion

- **Sediments:** Samples were oven-dried at 80°C for 24 hours, sieved (<0.2 mm), and digested in aqua regia (12 mL HCl + 4 mL HNO_3). The digested solution was filtered and diluted to 50 mL using deionized water.
- **Gastropods:** Soft tissues were dissected, dried (80°C, 24 hours), ground, and digested in 20 mL HNO_3. Shells were crushed, sieved, and digested in a 4:1 mixture of concentrated HNO_3 and $HClO_4$.

- **Mangroves:** Leaves, twigs, and pneumatophores were rinsed, cut, dried (105°C, 12 hours), and subjected to ignition in a muffle furnace at 600–650°C for 3–4 hours. Ash residues were digested with HNO_3 and $HClO_4$ (2:1), then diluted and filtered.

Metal Analysis

Concentrations of Cd, Cu, Fe, Ni, Mn, Co, Cr, Zn, and Pb were determined using Flame Atomic Absorption Spectrophotometry (FAAS). Calibration standards were prepared for each element, and quality control was ensured through blank and replicate analyses.

Fig. 1. Bundal Island on a map with mangrove strand study station marked with a yellow icon and the coordinates.

Fig. 2(A-F). Sediment, *Telescopium telescopium* body and shell samples used for analysis in present study.

Fig. 3(A-D). *A. marina* wire roots, pnumatophores, twigs & leaves samples used of anlaysis in present study.

Contamination and Risk Assessment Indices

- **Geo-accumulation Index (Igeo):** The Equation devised by Muller (1969) quantifies metal contamination using background values.Calculated using: Igeo = $\log_2$(Cn/1.5Bn).

According to Muller (1963), I_{geo} values are classified into seven classes: practically unpolluted ($I_{geo} < 0$), unpolluted to moderately polluted ($0 < I_{geo} < 1$), moderately polluted ($1 \leq I_{geo} < 2$), moderately to strongly polluted ($2 \leq I_{geo} < 3$), strongly polluted ($3 \leq I_{geo} < 4$), strongly to extremely polluted ($4 \leq I_{geo} < 5$), extremely polluted ($I_{geo} \geq 5$).

- **Enrichment Factor (EF):** Determines anthropogenic input using Fe as a reference element. EF = (C_{metal}/Fe) sample / (C_{metal}/Fe) background (Mokhtarzadeh *et al.,* 2020). Samples with an EF value exceeding 1.5 are indicative of potential human-induced activities (Birch, 2008). The categorization of sediment enrichment factor is as follows according to Mazurek *et al*. (2017): EF < 1 signifies no enrichment, 1 ≤ EF < 3 indicates partial enrichment, 3 ≤ EF < 5 represents medium enrichment, 5 ≤ EF < 10 denotes severe enrichment, 10 ≤ EF < 25 signifies very severe enrichment, 25 ≤ EF < 50 indicates very intense enrichment, and EF = 50 signifies extremely intense enrichment.
- **Bioconcentration Factor (BCF):** Formulated by Ghosh and Singh (2005), measures metal accumulation in organisms relative to sediment. BCF = $C_{organism}$ / $C_{sediment}$ Bini *et al*., (1999) has provided categories for classification: species falling in range of 1-10 are high accumulators, 0.1-1 are moderate accumulators, 0.01-0.1 are low accumulators and <0.01 are non-accumulators.
- **Translocation Factor (TF):** Stated by Marchiol *et al*. (2004), it evaluates the internal mobility of metals within *A. marina*. TF = C_{leaf} /C_{root}

Plants demonstrating bio-concentration and translocation factors exceeding 1 are identified as potential bio accumulators, as emphasized by Usman *et al.* (2013). High bio-concentration values > 2 are considered significant according to Mellem *et al.* (2012). Sopyan *et al*. (2014) suggests that plants exhibiting bioconcentration factors > 1 and translocation factors < 1 can be utilized as Phyto-stabilizers. Moreover, Usman *et al*. (2013) assert that plants with translocation factor values >1 generally possess a high affinity for metal accumulation in polluted environments.

Statistical Analysis

Pearson correlation matrices were computed to identify relationships among metal concentrations. Statistical analysis was performed using Microsoft Excel and verified manually to ensure consistency across data points.

RESULTS

Sediment

- **Heavy Metal Concentrations:** The surface sediment samples revealed a distinct pattern of heavy metal distribution. Iron (Fe) recorded the highest mean concentration at 306.34 ppm, followed by Chromium (Cr) at 8.44 ppm, Manganese (Mn) at 4.85 ppm, and Zinc (Zn) at 3.29 ppm. Cadmium (Cd), the least concentrated, measured only 0.013 ppm. The decreasing order of mean metal concentrations in sediment was: Fe > Cr > Mn > Zn > Pb > Ni > Co > Cu > Cd.

- **Geo-accumulation Index (Igeo):** Sediments showed extreme pollution levels for Fe (Igeo = 23.20), Mn (11.42), Zn (7.70) and Cr (8.98). Ni and Pb were strongly prevalent, with Igeo values of 4.77 and 3.18 respectively. In contrast, Cd had an Igeo of -8.58, categorizing it as uncontaminated.
- **Enrichment Factor (EF):** Cr exhibited the highest EF (14.45), indicating very severe enrichment, followed by Zn (5.33), Cd (6.67), and Pb (5.25), all categorized as highly enriched. Cu and Mn showed no enrichment, while Fe, Ni, and Co showed partial enrichment.

Table 1. Heavy metal concentration in sediment samples.

Heavy Metals Concentration (ppm)									
Sample Type	**Cu**	**Ni**	**Mn**	**Zn**	**Cd**	**Co**	**Fe**	**Cr**	**Pb**
Sediment	0.119	0.605	4.846	3.289	0.013	0.182	306.34	8.441	0.681

Telescopium telescopium

- **Heavy Metals**
  Heavy metal concentrations in the soft tissues and shells of *T. telescopium* showed notable variation. Zinc (Zn) was the most abundant in tissue (13.67 ppm), while Iron (Fe) dominated in the shell (8.08 ppm).
- **Bioconcentration Factor in *Telescopium telescopium***
  The highest BCF was observed for Cd (5.77), indicating strong bioaccumulative potential despite its low environmental concentration. BCFs above 1 were also recorded for Zn (2.22), Cu (1.24), and Pb (0.91).

Table 2. Heavy metal conc. in *Telescopium telescopium* tissues.

Heavy Metals Concentration (ppm)									
-	Essential elements				Non-Essential elements				
Telescopium telescopium	**Cu**	**Ni**	**Mn**	**Zn**	**Cd**	**Co**	**Fe**	**Cr**	**Pb**
Tissue	0.246	0.063	0.886	13.67	0.025	0.043	6.861	0.169	0.399
Shell	0.049	0.338	0.108	0.949	0.125	0.286	8.076	0.329	0.837
Total concentration	16.309				17.15				
Mean concentration	0.1475	0.2005	0.497	7.3095	0.075	0.1645	7.485	0.2249	0.618

Avicennia marina

- **Heavy Metals:** Among mangrove tissues, pneumatophores exhibited the highest metal concentrations, particularly for Fe (307.78 ppm), Zn (4.62 ppm), and Cr (2.89 ppm). Leaves and twigs showed lower levels across all metals.
- **Bioconcentration Factor in *Avicennia Marina*:** The BCF values in *A. marina* followed the trend: Cd (14.69) > Pb (3.34) > Zn (3.04) > Co (2.80) > Cu (1.61). Notably, all these metals exhibited BCF > 1, confirming effective metal uptake.
- **Translocation Factor in *Avicennia marina*:** The translocation factor (TF) analysis revealed that Pb had the highest TF value (1.03), indicating efficient translocation from roots to aerial parts. Other metals with TF > 0.8 included Co (0.95), Zn (0.94), and Cd (0.88), suggesting potential for internal transport.

Table 3. Heavy metal conc. in mangrove *Avicennia marina* sample.

Heavy Metals Concentration (ppm)									
Sample name	**Essential elements**				**Non-Essential elements**				
	Cu	Fe	Mn	Zn	Cd	Co	Ni	Cr	Pb
Leaves	0.068	239.25	1.859	4.342	0.078	0.23	0.389	0.874	0.928
Twigs	0.077	52.55	1.228	4.122	0.084	0.198	0.426	0.985	1.051
Pneumatophores	0.141	307.78	2.833	4.617	0.088	0.241	0.476	2.889	0.894
Total concentration	618.867				9.831				
Mean concentration	0.192	394.39	4.031	10.003	0.191	0.508	0.973	2.822	2.277

Table 4. Bioconcentration (BCF) values for the different heavy metals in *Avicennia marina.*

Bio-Concentration (BCF) values for the different heavy metals									
Sample name	**Essential elements**				**Non-Essential elements**				
	Cu	Fe	Mn	Zn	Cd	Co	Ni	Cr	Pb
Mangroves mean conc.	1.61	1.287	0.381	3.041	14.69	2.796	1.608	0.334	3.343
Leaves	0.571	0.78	0.38	1.32	6	1.26	0.64	0.1	1.36
Twigs	0.64	0.171	0.25	1.25	6.46	1.08	0.7	0.11	1.54
Pneumatophore	1.18	1	0.58	1.4	6.76	1.32	0.78	0.34	1.31

Table 5. Translocation Factor (TF) values for the different heavy metals in mangrove.

Translocation Factor (TF) values for the different heavy metals									
Sample	**Essential elements**				**Non-Essential elements**				
	Cu	Fe	Mn	Zn	Cd	Co	Ni	Cr	Pb
Leaves	0.48	0.78	0.65	0.94	0.88	0.95	0.82	0.29	**1.03**

Correlation Analysis

Pearson correlation coefficients demonstrated significant positive correlations between Fe, Mn, Cr, and Ni ($r > 0.7$), suggesting a common geogenic or industrial source. Cd correlated positively with Co and Pb, while Zn and Cu were closely linked ($r = 0.92$), indicating possible co-mobilization. Negative correlations were observed between Zn and Fe ($r = -0.30$), and between Cu and Pb ($r = -0.83$).

Table 6 . Correlation matrix of all the metals in a consolidated form.

	Cd (mg/L)	**Cu (mg/L)**	**Fe (mg/L)**	**Ni (mg/L)**	**Mn (mg/L)**	**Co (mg/L)**	**Cr (mg/L)**	**Zn (mg/L)**	**Pb (mg/L)**
Cd(mg/L)	1								
Cu(mg/L)	-0.67225	1							
Fe(mg/L)	-0.26118	-0.0984	1						
Ni(mg/L)	0.041746	-0.57646	0.73742	1					
Mn(mg/L)	-0.60063	0.079742	0.86423	0.730772	1				
Co(mg/L)	0.781295	-0.88417	0.275559	0.611356	-0.01189	1			
Cr(mg/L)	-0.57189	0.007006	0.70571	0.73922	0.94584	0.028811	1		
Zn(mg/L)	-0.58458	0.921354	-0.30282	-0.7691	-0.17274	-0.93542	-0.27563	1	
Pb(mg/L)	0.682749	-0.82895	0.209902	0.578283	-0.04944	0.785279	-0.11152	-0.74769	1

Overall, the data underscore the notable heavy metal burden within the sediments and biota of the Bundal Island southwestern mangrove strand ecosystem, pointing to ongoing industrial pollution and highlighting the ecological vulnerability of this coastal system.

DISCUSSION

The findings of this study provide a reasonably strong evidence of heavy metal contamination in the mangrove ecosystem of the Bundal Island. The observed concentrations and spatial distribution patterns suggested persistent

and multifactorial pollution inputs, primarily of anthropogenic origin. One of the major contributors to this pollution is the dense network of industrial zones surrounding the Karachi coastline.

For instance, the Sindh Industrial and Trading Estate (S.I.T.E) alone hosts nearly 2,000 industries, with approximately 60% being textile mills. The remainder include pharmaceutical, chemical, detergent, iron and steel, vegetable oil, beverage, and food product industries (Hashmi, 2010). Port Qasim, another major industrial hub, accommodates 80% of Pakistan's automotive industry, as well as large-scale operations like Pakistan Steel Mills (PSM) and the K-Electric Power Plant (Alamgir *et al*., 2023). In addition, the Korangi Industrial Area (KIA) is home to nearly 4,500 businesses, ranging from textile and pharmaceutical units to chemical, steel, and automobile manufacturers (Rahman *et al.,* 2021). The sheer scale and diversity of these industries produce a vast and continuous output of industrial effluents and solid waste, much of which enters the marine environment untreated or inadequately managed.

The Bundal Island, being directly exposed to the open sea and positioned downstream of these industrial zones, is particularly susceptible to this anthropogenic burden. The study mangrove pacth (strand) is marginally located at the southwestern flank of the island and is also highly vulnerable to sea level rise (SLR), increasing salinity, and changes in sediment characteristics. These cumulative pressures significantly increase the risk of ecological degradation and potential extirpation of this mangrove habitat. Therefore, this specific ecosystem requires urgent attention in any conservation planning and policy implementation, with a focus on controlling land-based industrial pollution and mitigating climate-induced stressors.

The high concentrations of Fe, Cr, Mn, and Zn in sediments, supported by their Igeo and EF values, indicate both natural geological sources and extensive anthropogenic inputs. Very high Igeo values for Fe (23.20) and Mn (11.42) reflect severe environmental stress. Notably, Cr and Zn showed very high enrichment (EF > 5), likely due to industrial discharge from tanneries, electroplating units, and textile processing facilities. The elevated Igeo for Pb (3.18) and Ni (4.77) further emphasizes industrial sources, particularly fuel combustion, metal smelting, and waste disposal.

Cadmium, although present in very low sediment concentrations (0.013 ppm), displayed a high EF (6.67), confirming that even minimal input can result in significant bioaccumulation and ecological risk due to its high toxicity and mobility.

T. telescopium, a gastropod mollusk inhabiting intertidal mudflats, demonstrated remarkable bioaccumulative capacity for Cd (BCF = 5.77), Zn (2.22), and Cu (1.24). This is consistent with its feeding behavior and its exposure to sediment-bound contaminants. These values align with the mollusk's ability to concentrate trace metals several folds higher than environmental levels, especially for elements with known affinity for soft tissues.

Iron and Pb, though present in moderate concentrations in tissue, were found in significant levels in the shells, indicating historical exposure and long-term environmental integration. As the shell provides a chronological archive of metal exposure, this distinction further supports the utility of *T. telescopium* as a bioindicator species in ecotoxicological assessments. Gastropods usually become a major indicator of ecological changes in biological communities, such as in mangroves, one of their habitats (Arifianti *et al*. 2021; Putri *et al.*, 2021).

Among all plant tissues, pneumatophores of *A. marina* accumulated the highest concentrations of Fe (307.78 ppm), Zn (4.62 ppm), and Cr (2.89 ppm). This is attributable to their direct interaction with sediments and their well-developed capacity for metal sorption and immobilization. Pneumatophores and bark, being perennial organs with elevated tannin content, exhibit a strong affinity for metal binding (Jayasekera, 1988; Lacerda *et al.,* 1988; Silva *et al*., 1990; Tam & Wong, 1997; Zheng *et al*., 1997; Ismail *et al*., 2014). These tissues have been reported to accumulate higher concentrations of heavy metals than other mangrove parts, which is consistent with the results of the present study.

Elevated BCF values for Cd (14.69), Pb (3.34), Zn (3.04), and Co (2.80) confirm the metal-scavenging efficiency of mangrove roots.

Translocation Factor (TF) analysis revealed that Pb (TF = 1.03), Co (0.95), and Zn (0.94) were actively translocated to aerial parts. This suggests that *A. marina* exhibits both phytostabilization and phytoextraction traits depending on the metal species involved. The relatively low TF for Cr (0.29) indicates sequestration at the root level, supporting the protective strategy of limiting translocation of highly toxic elements.

The strong correlations observed between Fe, Mn, Cr, and Ni suggest that these elements share a common source, possibly geogenic with anthropogenic enhancement. The strong positive association between Cd, Co, and Pb hints at co-contamination from industrial effluents, possibly involving pigments, batteries, and alloy manufacturing waste.

The high bioaccumulation of toxic metals in both flora and fauna raises serious concerns for the ecological integrity of the Bundal Island. Faunal species higher in the food web, including commercially important fish and wading birds, may be at risk due to biomagnification. Moreover, given the ongoing interest in developing the

Bundal Island into a commercial real estate hub, these findings underscore the urgent need to prioritize environmental safeguards and a proper Environmental Impact Assessment (EIA) before any developmental interventions.

CONCLUSION

This research underscores the critical ecotoxicological burden faced by the mangrove ecosystems of the Bundal Island due to persistent heavy metal contamination. The elevated concentrations of Fe, Cr, Mn, Zn, and Pb in sediments, coupled with high enrichment factors and geo-accumulation indices, reveal a high degree of anthropogenic influence, likely from industrial discharge, urban runoff, and marine traffic. Bioindicator species—*Telescopium telescopium* and *Avicennia marina*—confirmed the bioavailability and bioaccumulative potential of toxic metals, particularly Cd, Pb, and Zn. The strong translocation and bioconcentration capacities observed in *A. marina* further highlight its dual role as a metal accumulator and potential phytoremediator.

Given the island's ecological significance and its proposed transformation into a commercial development zone, the findings of this study present a strong case for urgent environmental management and policy intervention. Comprehensive Environmental Impact Assessments (EIA) must be mandated before initiating any developmental projects. This study not only provides baseline data for future monitoring and remediation efforts but also contributes to a growing body of evidence advocating for the preservation and sustainable management of Pakistan's coastal ecosystems. In this connection, this study furthers reiterates that rather than developing the island into a real estate mega-project, it should be designated as an ecotourism focused marine protected area as per IUCN MPA Categories (Category # 6: Protected Area with Sustainable Use of Natural Resources).

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