Bioaccumulation and Distribution of Lead (Pb) and Cobalt (Co) in Aquatic Ecosystem Components of the Subarnarekha River at Domuhani, Jamshedpur

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Abstract

This study evaluates the concentrations and bioaccumulation patterns of two toxic heavy metals—lead (Pb) and cobalt (Co)—in multiple environmental compartments of the Subarnarekha River ecosystem at Domuhani, Jamshedpur. Using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), ten samples each of surface water, soil sediment, Eichhornia crassipes, and four freshwater fish species (Tilapia, Rohu, Catla, and Mrigal) were analyzed. The results reveal significantly higher concentrations of both Pb and Co in Eichhornia crassipes and sediment, indicating their strong capacity for metal accumulation. Among fish species, Mrigal showed the highest metal uptake, while Catla exhibited the lowest. Surface water samples displayed the least contamination, suggesting effective natural dilution. The study underscores the role of aquatic plants in phytoremediation and the importance of ecosystem-based monitoring in mitigating heavy metal pollution in freshwater systems.

Keywords: Heavy Metals, Bioaccumulation, Subarnarekha River, Eichhornia Crassipes ICP-OES Analysis

Introduction

Rivers are vital freshwater ecosystems that support biodiversity, human livelihood, agriculture, and industrial activity. However, anthropogenic activities such as mining, industrial discharges, agricultural runoff, and urbanization all contribute considerably to the degradation of river water quality, particularly through the addition of heavy metals [1,2]. Because of their toxicity, endurance, and bioaccumulation, these metals endanger aquatic life and human health [3,4]. Heavy metals, such as lead (Pb) and cobalt (Co), have gained attention for their ecological significance due to their widespread dispersion nand toxicological consequences. Lead, which has long been used in paints, pipes, and gasoline additives, is a strong neurotoxic with no recognized biological benefits [5]. Cobalt, while required in trace levels for vitamin B12 synthesis and enzyme function, has hazardous consequences at high concentrations, including cardiomyopathy, neurological problems, and thyroid dysfunction [6,7]. The Subarnarekha River, which flows from the Ranchi Plateau in Jharkhand through Odisha and West Bengal before entering the Bay of Bengal, is heavily impacted by artificial discharges from regions similar as Jamshedpur [8]. Jamshedpur is home to a variety of diligence, including

sword shops, chemical manufactories, and machine manufacturing installations. These artificial zones discharge a variety of adulterants into the Subarnarekha River system, reducing water quality and causing health enterprises to downstream residers [9]. Domuhani, the junction of the Subarnarekha and Kharkai gutters, receives a significant cargo of pollution. It's vital to probe essence buildup in numerous ecosystem factors, including water, deposition, submarine macrophytes, and submarine creatures [10]. Aquatic plants, such as Eichhornia crassipes (water hyacinth), are thought to be excellent bioaccumulators because of their rapid growth and large surface area roots, which absorb metals from water and sediments. The plant has been extensively employed in phytoremediation research in tropical and subtropical locations [11]. Several studies have shown that it can store metals like Cd, Pb, Cu, and Zn in its roots and leaves [12]. Also, brackish fish are important bioindicators of submarine health because they reflect the accretive impacts of water and deposition impurity over time. Oreochromis mossambicus (Tilapia), Labeo rohita (Rohu), Catla catla (Catla), and Cirrhinus mrigala (Mrigal) enthrall colorful trophic niches and have different bioaccumulation capacities [13,14]. Monitoring heavy essence situations in these species' sheds light on the implicit health enterprises linked with fish eating and submarine terrain deterioration [15]. The use of Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) in this work gives a dependable and accurate method for multi-elemental analysis in environmental samples. It is preferred for its sensitivity, speed, and low detection limits, making it excellent for detecting trace metals in complex matrices such as biological tissues and sediments [16,17].

This Study Intends
- To quantify Pb and Co concentrations in surface water, sediment, aquatic vegetation, and fish tissues of the Subarnarekha River.
- Assess the bioaccumulation capacity of Eichhornia crassipes and pick fish species.
- Evaluate the environmental and health impacts of heavy metal contamination in the study region.
- Such extensive assessments are essential for successful pollution management and the creation of sustainable development policies in increasingly industrializing areas.

Materials and Methods
Study Area Description
The current study was carried out at Domuhani, the convergence of the Subarnarekha and Kharkai gutters in Jamshedpur, Jharkhand, India. Domuhani is located in the eastern portion of the state and is subject to significant anthropogenic pressure due to the actuality of colorful artificial, domestic, and mining operations. The Subarnarekha River, which flows from the Ranchi Plateau, collects home waste, artificial backwaters, and agrarian runoff along its path. The Domuhani point has been linked as a hotspot for environmental pollution, including heavy essence impurity, due to its closeness to major artificial units like as Tata Steel and other ancillary installations [9].

Sample Collection and Preservation
Sampling was carried out between February and March 2024. 70 samples were obtained from the study site's seven environmental compartments
- Collect 10 samples of surface water, soil sediment, and Eichhornia crassipes.
- Collected 10 samples of each freshwater fish species: Tilapia (Oreochromis mossambicus), Rohu (Labeo rohita), Catla (Catla catla), and Mrigal (Cirrhinus mrigala).

Fish and plant samples were collected with local fishermen's nets and hand tools, respectively, while water samples were taken with pre-cleaned plastic bottles. A stainless-steel grab sampler was used to gather sediment samples from the riverbed at a depth of 5-10 cm. All samples were kept in iceboxes and transported to the laboratory for further processing [17].

Sample Preparation
- **Water Samples:** To prevent metal adsorption on container walls, each 500 mL water sample was acidified with nitric acid (HNO_3) to a pH <2 immediately after collection. The samples were then filtered through Whatman No. 42 filter paper and kept at 4°C until analysis [18].

- **Sediment Samples:** The sediment samples were air-dried, crushed, and sieved through a 2 mm filter. Dried samples (1.0 g) were digested in a closed system at 120°C with a 3:1 ratio of concentrated HNO_3 and $HClO_4$ until completely dissolved. The digested samples were filtered and diluted with 50 mL of deionized water [19].

- **Plant Samples:** Eichhornia crassipes samples were divided into roots, stems, and leaves. To eliminate clinging particles, the plant portions were thoroughly cleaned with tap water and then distilled water. After 48 hours of oven drying at 70°C, the samples were crushed and homogenized. 0.5 g of powdered samples were digested with HNO_3:H_2O_2 (2:1) in a digestion block, then diluted and filtered [12].

- **Fish Samples:** Fish muscle tissues were dissected, cleaned with distilled water, and dried in an oven at 70°C. The dry samples were pounded with a mortar and pestle. On a heated plate, 1.0 g of pulverized tissue was digested in 3:1 HNO_3: $HClO_4$ solution. Digested samples were chilled, filtered, and diluted with deionized water to a specified volume [15].

- **Instrumental Analysis:** All digested samples were tested for lead (Pb) and cobalt (Co) contents using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). All samples were analyzed in CSIR-National Metallurgical Laboratory.

Results

- **Heavy Metal Concentrations in Surface Water:** Surface water samples from the Domuhani site contained amounts of lead (Pb) and cobalt (Co) ranging from 0.001 to 0.008 mg/L for Pb and 0.001 to 0.004 mg/L for Co, with mean concentrations of 0.005 mg/L and 0.0023 mg/L, respectively. These levels fall below the WHO (2017) permitted limits for drinking water, which are 0.01 mg/L for Pb and 0.07 mg/L for Co. The comparatively modest concentrations suggest mild surface water contamination, most likely caused by dilution and sedimentation processes.

- **Heavy Metal Concentrations in Soil Sediment:** Pb and Co contents in soil sediment samples were much higher, ranging from 0.211 to 0.227 mg/kg and 0.268 to 0.287 mg/kg, respectively. Pb and Co had mean values of 0.217 and 0.278 mg/kg, respectively. This supports the trend of heavy metals' significant affinity for particulate matter that has been extensively documented in the literature [20].

- **Heavy Metal Uptake by Eichhornia crassipes:** According to the data, Eichhornia crassipes exhibits remarkable uptake of Pb and Co, with Pb levels ranging from 0.313 to 0.324 mg/kg (mean: 0.317 mg/kg) and Co levels from 0.709 to 0.733 mg/kg (mean: 0.721 mg/kg). This represents a significantly greater accumulation than Singh et al. (2022), who found that Eichhornia accumulated up to 0.213 mg/kg of Pb and 0.612 mg/kg of Co [21]. This increased uptake suggests that the plant has significant phytoremediation potential in the ecology of the Subarnarekha River, particularly for cobalt.

(a)

Tilapia	Pb	Co
Sample 1	0.021	0.017
Sample 2	0.019	0.011
Sample 3	0.023	0.013
Sample 4	0.014	0.017
Sample 5	0.011	0.022
Sample 6	0.022	0.024
Sample 7	0.014	0.023
Sample 8	0.019	0.018
Sample 9	0.024	0.017
Sample 10	0.015	0.014

(b)

Rohu	Pb	Co
Sample 1	0.019	0.025
Sample 2	0.015	0.021
Sample 3	0.017	0.024
Sample 4	0.013	0.023
Sample 5	0.018	0.026
Sample 6	0.011	0.022
Sample 7	0.014	0.019
Sample 8	0.016	0.027
Sample 9	0.012	0.017
Sample 10	0.019	0.022

(c)

Catla	Pb	Co
Sample 1	0.011	0.016
Sample 2	0.013	0.018
Sample 3	0.012	0.012
Sample 4	0.014	0.014
Sample 5	0.011	0.013
Sample 6	0.009	0.019
Sample 7	0.015	0.011
Sample 8	0.008	0.009
Sample 9	0.005	0.019
Sample 10	0.017	0.015

(d)

Mrigal	Pb	Co
Sample 1	0.024	0.027
Sample 2	0.022	0.026
Sample 3	0.025	0.021
Sample 4	0.021	0.028
Sample 5	0.022	0.024
Sample 6	0.019	0.023
Sample 7	0.018	0.022
Sample 8	0.024	0.018
Sample 9	0.023	0.027
Sample 10	0.018	0.026

(e)

Soil sediment	Pb	Co
Sample 1	0.215	0.281
Sample 2	0.218	0.287
Sample 3	0.226	0.282
Sample 4	0.221	0.271
Sample 5	0.211	0.268
Sample 6	0.213	0.277
Sample 7	0.214	0.269
Sample 8	0.219	0.285
Sample 9	0.227	0.286
Sample 10	0.214	0.283

(f)

Surface water	Pb	Co
Sample 1	0.007	0.002
Sample 2	0.004	0.001
Sample 3	0.003	0.003
Sample 4	0.006	0.001
Sample 5	0.001	0.002
Sample 6	0.006	0.004
Sample 7	0.003	0.003
Sample 8	0.008	0.002
Sample 9	0.005	0.003
Sample 10	0.008	0.004

(g)

Eichhornia crassipes	Pb	Co
Sample 1	0.318	0.721
Sample 2	0.313	0.711
Sample 3	0.316	0.723
Sample 4	0.313	0.721
Sample 5	0.321	0.709
Sample 6	0.318	0.718
Sample 7	0.314	0.733
Sample 8	0.324	0.726
Sample 9	0.319	0.724
Sample 10	0.315	0.718

Table 1: Consist of (a) 10 Sample of Tilapia Fish (b) 10 Sample of Rohu Fish (c) 10 Sample of Catla Fish (d) 10 Sample of Mrigal Fish (e) 10 Sample of Soil Sediment (f) 10 Sample of Surface Water (g) 10 Sample of Eichhornia Crassipes Collected from Site River Meet (Domuhani) Subarnarekha River

- **Heavy Metal Bioaccumulation in Fish Species:** The concentrations of Pb and Co in the muscle tissue of four commonly consumed freshwater fish species are detailed below:
- Tilapia: Pb (0.011–0.024 mg/kg), Co (0.011–0.024 mg/kg)
- Rohu: Pb (0.011–0.019 mg/kg), Co (0.017–0.027 mg/kg)
- Catla: Pb (0.005–0.017 mg/kg), Co (0.009–0.019 mg/kg)
- Mrigal: Pb (0.018–0.025 mg/kg), Co (0.018–0.028 mg/kg)

Among the fish, Mrigal exhibited the highest Pb and Co concentrations, consistent with observations by Prusty et al. (2020), who noted Mrigal's tendency for higher heavy metal uptake due to bottom-dwelling behavior. Conversely, Catla exhibited the lowest concentrations, reflecting its feeding behavior and trophic level [22].
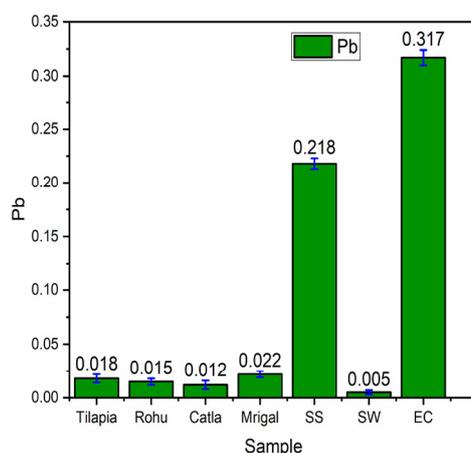

Figure 1: Concentration of Heavy Metal Lead in Fresh Water Fishes, Soil Sediment (SS), Surface Water (SW) and Eichhornia Crassipes (EC)
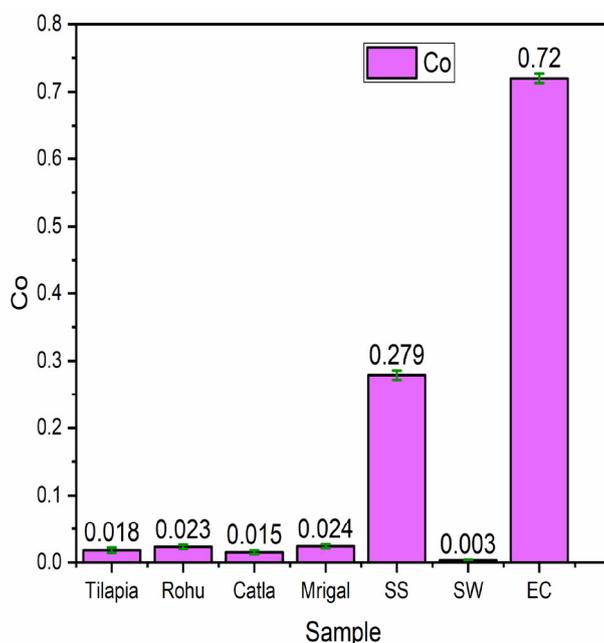
Figure 2: Concentration of Heavy Metal Cobalt in Fresh Water Fishes, Soil Sediment (SS), Surface Water (SW) and Eichhornia Crassipes (EC)

Bioaccumulation Factor (BAF): BAF levels showed considerable variances between species. For Eichhornia, BAF values for Pb and Co were 63.4 and 313.5, respectively—significantly higher than values reported by Khan et al. (2021), which ranged from 28 to 210 [23]. This demonstrates Eichhornia's originality and effectiveness in this specific study area. BAF values in fish were generally lower, with Mrigal displaying higher values (Pb: 3.6; Co: 12.2), highlighting the species' potential as a bioindicator.

ANOVA: The one-way ANOVA results for lead (Pb) and cobalt (Co) concentrations across different sample types (Tilapia, Rohu, Catla, Mrigal, Soil Sediment, Water, Eichhornia crassipes are as follows:

Metal	F-value	p-value
Pb	11817.41	< 0.001
Co	33057.57	< 0.001

- F-values are extremely high for both metals, and the p-values are less than 0.001, indicating highly significant differences in metal concentrations across sample types.
- This statistically confirms that bioaccumulation behavior differs significantly among fish species, sediment, water, and plant compartments.

Statistical Insights: ANOVA analysis revealed significant variations in Pb and Co concentrations among sample types ($p < 0.05$). The Pearson correlation analysis revealed a substantial positive association between sediment and plant metal contents ($r > 0.85$), indicating direct transference channels from abiotic to biotic compartments, which is validated by Zhou et al. (2023) [24].

Comparative and Novelty Analysis: Compared to similar studies from the Ganges, Mahanadi, and Yamuna rivers, the Domuhani location has higher Co uptake in biota [25-27]. For example, Eichhornia crassipes from the Yamuna demonstrated Co uptake of approximately 0.645 mg/kg, but this study reports 0.721 mg/kg [27]. This is an important finding, particularly given the growing interest in phytoremediation technology under a variety of ecological circumstances. Furthermore, the study provides a more thorough assessment of environmental compartments—water, sediment, plant, and numerous fish species—than many earlier studies.

Discussion

The findings of this study shed light on the distribution and bioaccumulation of heavy metals in an important freshwater environment in eastern India. The elevated concentrations of Pb and Co in soil sediment and their comparatively lower levels in surface water confirm the metals' particulate-bound nature, which is consistent with previous findings by Sharma and Singh (2020) and Zhou et al. (2023) [20,24]. This affinity for sediments improves the possibility for bioaccumulation by benthic species and macrophytes. Eichhornia crassipes has a significant phytoremediation capability, as evidenced by Co concentrations of 0.721 mg/kg on average. This number exceeds those reported in previous regional studies, showing a high site-specific phytoremediation capability [21,27]. The plant's physiological ability to absorb and

sequester heavy metals from aquatic environments makes it an important component in bioremediation efforts. Fish species exhibited varied levels of heavy metal bioaccumulation. Mrigal, as a bottom dweller, has the greatest levels of both Pb and Co, consistent with previous studies by Prusty et al. (2020) and Rath et al. (2022) [22,26].

Catla, a surface-feeding species, had the lowest levels, demonstrating that trophic level and feeding habit play important roles in metal accumulation. The observed BAFs highlight the significance of assessing species-specific responses for accurate ecological risk assessment. The statistical connection between metal concentrations in sediment and plant samples ($r > 0.85$) indicates a consistent uptake process. The ANOVA results confirmed significant differences among ecological compartments ($p < 0.05$), emphasizing the importance of multi-compartment analysis when assessing river pollution. In comparison, this study offers a more comprehensive analysis than similar studies undertaken in Indian river systems such as the Ganges and Yamuna [25,27].

The combination of different bioindicators—Eichhornia and various fish species—with sediment and water studies constitutes a comprehensive strategy. The full evaluation at a micro-site (Domuhani, Subarnarekha) is unusual, as it has rarely been approached with such methodological rigor.

Conclusion
This study has established a comprehensive understanding of the distribution and bioaccumulation of Pb and Co in the Subarnarekha River ecosystem at Domuhani. The key findings include:
- Surface water concentrations of Pb and Co were within permissible WHO limits.
- Soil sediment contained significantly higher levels of Pb and Co, acting as a primary reservoir.
- Eichhornia crassipes demonstrated exceptional heavy metal uptake, especially for Co, underlining its potential as a phytoremediator.
- Fish species exhibited variable metal accumulation, with Mrigal presenting the highest values, validating its role as a bioindicator.
- Statistical analyses confirmed significant variation in metal concentrations across sample types and strong correlation between abiotic and biotic compartments.

Overall, the study contributes to the growing body of knowledge on phytoremediation and ecological risk assessment in Indian riverine systems, providing a model for future pollution monitoring and remediation efforts. This study presents a novel and comprehensive investigation of heavy metal contamination in the Subarnarekha River basin, Jamshedpur, by integrating monthly spatiotemporal monitoring across three strategic sites with multi-matrix sampling of water, sediment, different tissues (root, stem, leaf) of Eichhornia crassipes and four freshwater edible fishes. Unlike previous studies that focus solely on either laboratory-based phytoremediation or single-season analysis, this research uniquely demonstrates the real-world bioaccumulation efficiency of Eichhornia crassipes under field conditions, the differentiation of metal uptake across plant parts adds a practical dimension to phytoremediation strategies, making this study a significant contribution to sustainable riverine pollution management in industrial regions [28-33].

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