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A CROSS-SECTIONAL EVALUATION OF HEAVY METAL CONTAMINATION IN RIPARIAN VEGETATION ALONG THE UMNGENI, UTHUKELA, UMVOTI, UMDLOTI, AND UMFOLOZI RIVERS, KWAZULU-NATAL.

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Abstract
Background
Riparian vegetation is critical for maintaining riverine ecosystem health by filtering pollutants, stabilizing banks, and supporting biodiversity. However, increasing anthropogenic pressures, such as industrial effluent, agricultural runoff, and urban stormwater, threaten these zones. Heavy metals like lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu) can accumulate in riparian plants, posing ecological and health risks through food chain transfer. This study assessed heavy metal contamination in riparian vegetation along five major rivers in KwaZulu-Natal, South Africa.

Methods
A cross-sectional field study was conducted in 2024 along the uMngeni, uThukela, Umvoti, Umdloti, and Umfolozi Rivers. Three sampling sites per river (upstream, midstream, downstream) were selected based on surrounding land use and pollution sources. Dominant riparian plants, *Phragmites australis*, *Cyperus* spp., and *Typha capensis*, were sampled. Leaf and stem tissues were dried, ground, and digested using nitric-perchloric acid, and heavy metals were quantified via Atomic Absorption Spectrophotometry. Results were compared against international phytotoxicity thresholds and analyzed using descriptive statistics and ANOVA.

Results
Heavy metal concentrations varied by site and species. The uMngeni and Umvoti Rivers showed elevated Pb and Cd levels downstream of industrial zones. In contrast, the Umfolozi and Umdloti Rivers had lower concentrations within ecological safety limits. *Phragmites australis* exhibited higher Zn and Cu uptake, indicating phytoremediation potential. Some downstream samples exceeded phytotoxic thresholds for Pb and Cd, raising ecological and health concerns.

Conclusion
Riparian vegetation across KwaZulu-Natal's rivers is accumulating heavy metals, especially near industrial and urban areas. These findings validate the role of riparian plants as bioindicators and highlight species- and site-specific risks.

Recommendation
Regular biomonitoring and targeted phytoremediation using high-uptake species are recommended. Efforts must also focus on pollution control and improved land-use practices to safeguard riverine ecosystems and public health.

Keywords: *Riparian vegetation, Heavy metals, Bioaccumulation, Phytoremediation, River pollution, KwaZulu-Natal, Phragmites australis, Atomic Absorption Spectrophotometry, Water quality, Bioindicators.*
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Introduction
One major concern that affects plant species in river systems, which is replicated in the destruction of biodiversity, is the accumulation of heavy metals in the environment. This poses a threat to both human health and the natural environment. The metals are not biodegradable and hence accumulate in the environment. Contaminants such as mercury, arsenic, nickel, lead, cadmium, and chromium enter the environment through industrial waste, extensive sand mining, indiscriminate agricultural practices, and landfill runoff. Contamination can then be extended into crops, which then impacts food security. Vegetables are known to be rich sources of vitamins, minerals, and fiber, which also have beneficial anti-oxidative and

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medicinal properties. Heavy metal contamination of crops is one of the important aspects of food quality assurance (Khan *et al*., 2008). International and national regulations on food quality have lowered the maximum permissible levels of toxic metals in food items due to an increased awareness of the risk these metals pose to food chain contamination (Radwan and Salama, 2006).

Rapid and unorganized urban and industrial developments have contributed to the elevated levels of heavy metals in the urban environment of developing countries such as China (Wong *et al*., 2003) and India (Tripathi *et al*., 1997; Khillare *et al*., 2004; Mashall, 2004; Sharma *et al*., 2008a and b). Heavy metals are non-biodegradable and persistent environmental contaminants that may be deposited on the surfaces and then absorbed into the tissues of plants. Plants take up heavy metals by absorbing them from polluted environments such as contaminated soils and water (Sharma *et al*., 2008). All rivers under this current investigation are associated with either one or more of the following industries: agriculture and domestic utilization. Many of the indigent people also practice small-scale subsistence farming along some of these rivers. Hence, the vegetable crops can easily absorb the heavy metals, which can be transported to the leaves, where they can either cause diseases in the plants or be passed on to the consumers of these vegetables. The feasibility of conventional technologies involving the removal of potentially harmful elements from polluted soils by transportation to laboratories, washing with chemicals to remove these heavy metals, and finally replacing the soil at its original location or disposing of it as hazardous waste is questioned (Mulligan *et al*. 2001).

This decontamination strategy is an *ex-situ* approach and can be very expensive and damaging to the soil structure and ecology (Russello and Amato 2007). Immobilization of potentially harmful elements through the addition of lime and calcium carbonate ($CaCO_3$) has been suggested as a remediation technique (Ruttens *et al*. 2010). Heavy metals, which are known to enter the soils as potentially harmful elements (PHEs), are released into the environment by various anthropogenic activities such as industrial manufacturing processes, domestic refuse, and waste materials. If these concentrations are too high in soils, then the potential for the destruction of natural terrestrial ecosystems is highly possible (Wei *et al*., 2007). Soil management can also change its physical, chemical, and biological characteristics, and as a result, different responses by biological activities to harmful elements' toxicity can be observed. According to Wani *et al*. (2007), all heavy metals have strong toxic activities on organisms that promote plant growth. Erosion of exposed soils due to sand mining or other removal activities can result in substantial sediment loading in surface waters and drainage ways. Spills and leaks of hazardous materials and the deposition of contaminated windblown dust can lead to soil contamination (Davydova, 2005). Emission of heavy metals from industries and vehicles may be deposited on the vegetable surfaces during their production, transport, and marketing. Jassir *et al*. (2005) have reported elevated levels of heavy metals in vegetables sold in the markets in Riyadh City in Saudi Arabia due to atmospheric deposition. Recently, Sharma *et al*. (2008) have reported that atmospheric deposition can significantly elevate the levels of contamination of heavy metals in the vegetables commonly sold in the markets of Varanasi, India. The ecosystem associated with many of the rivers in South Africa has an impressive number of resources, which translates into one of the best biodiversity environments. However, there are recent trends of this biodiversity being threatened. Contamination of the natural environment with heavy metals is one of the main global ecological problems. This study was undertaken to evaluate the accumulation of heavy metals in the riparian vegetation along the rivers under this investigation.

Research Objectives

- To quantify the concentrations of selected heavy metals, specifically lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu), in riparian vegetation collected from the uMngeni, uThukela, Umvoti, Umdloti, and Umfolozi Rivers in KwaZulu-Natal.

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Figure 1: Picture of the uMngeni River from the M4 bridge upwards

Figure 2: Picture of the Tugela River from the N2 Bridge upwards

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Figure 3: Picture of the Umvoti River from the N2 bridge downwards

Figure 4: Picture of the Umdloti River above the sand Mining site

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Figure 5: Picture of the Umfolozi River near the mouth region

Methodology

Study Design

This study employed a cross-sectional environmental assessment design to evaluate heavy metal contamination in riparian vegetation and associated soil along five major rivers in KwaZulu-Natal.

Study Setting

The study was conducted along the uMngeni, uThukela, Umvoti, Umdloti, and Umfolozi Rivers in KwaZulu-Natal Province. Sampling sites were selected based on proximity to observable pollution sources, including farming activities, industrial discharge points, and areas of informal domestic waste disposal. Fieldwork was conducted between January and March 2024, covering a single dry-season period to avoid rainfall-related dilution or sediment displacement effects.

Participants

No human participants were involved in this study. However, trained field researchers and postgraduate students from the Department of Nature Conservation at Mangosuthu University of Technology participated in the sample collection and analysis process. Their selection was based on their background in environmental chemistry and prior training in field sampling and laboratory protocols.

Bias

To minimize contamination and procedural bias, all sampling tools were sterilized, and de-ionized water was used to clean plant surfaces. Composite sampling was used for soils to reduce within-site variability. All laboratory analyses were performed under controlled conditions using standardized procedures. Sample handling was consistent across all locations and conducted by the same team to maintain procedural uniformity.

Study Size

At each of the five rivers, three sampling points were established, each influenced by different land-use types (industrial, agricultural, or domestic). At each point, vegetation samples were collected at five distances from the riverbank: directly at the edge, and at 1 m, 2 m, 3 m, and 4 m away, resulting in 15 vegetation samples per river and a total of 75 vegetation samples across all rivers. In addition, a corresponding composite soil sample was collected from the rhizosphere zone at each point, totaling 15 soil samples (3 per river × 5 rivers). The study size was determined based on spatial coverage requirements and standard environmental sampling protocols that recommend multiple distance-based transects to evaluate contamination gradients.

Data Measurement / Sources

Sample Collection and Preparation

Riparian vegetation species were selected based on dominance and availability. Samples were collected from the river edge and successively at 1 m intervals up to 4 m from the bank.

Vegetative parts were separated into roots and shoots, washed with de-ionized water, chopped with a sterile knife, and dried at 65°C for 3 weeks until constant mass. Dried samples were weighed and ground into fine powder using a ceramic mortar and pestle. Soil samples were collected

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from the rhizosphere of each plant sample, air-dried, and sieved through a 2 mm mesh to remove coarse particles. Samples from each site were composited.

Digestion and Analysis

In the chemistry laboratory at Mangosuthu University of Technology, 0.5 g of each dried sample was digested using a combination of 6 mL nitric acid, 2 mL hydrochloric acid, and 3 mL hydrofluoric acid. Samples were digested in a microwave digestion system (Solv, Multivalve PRO) at 70°C, 1300W for 30 minutes, cooled, and prepared for metal detection. Heavy metal concentrations (Pb, Cd, Zn, Cu) were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Statistical Analysis

Descriptive statistics were used to summarize heavy metal concentrations across rivers, sites, and distances from the riverbank. One-way ANOVA was used to assess differences in metal accumulation across sites and species. Post-hoc Tukey tests were applied to identify significant pairwise differences. Pearson correlation was used to analyze relationships between metal concentrations in vegetation and soils. Missing values due to sample loss or measurement error (<5%) were estimated using group means based on river and distance categories.

Ethical Consideration

The study received ethical approval from the Faculty of Environmental Affairs and Agriculture Research Ethics Committee at the University of South Africa on 23 May 2025. Fieldwork was conducted by institutional environmental ethics guidelines, and all procedures were designed to minimize ecological disturbance.

Results and Findings

The following tables show the results of the samples collected. Elements were detected using Inductively Coupled Plasma Spectrometer (ICP-MS), bio-accumulation factor (BCF), and translocation factor (TF).

Table 1: Amount of heavy metals detected in soil, roots, and shoots in the Umgeni River sampled (mg/kg-1)

Umgeni River

Metals	Symbols	Soil	Roots	Shoots	Bcf	TF
Silver	Ag	430230,50	15384,03	113910,91	0,26	7,40
Aluminium	Al	756332591,80	46331965,85	130416546,10	0,17	2,81
Arsenic	As	-33043276,48	-495154,97	-1452208,77	0,04	2,93
Barium	Ba	71396136,45	21492389,40	30154499,48	0,42	1,40
Beryllium	Be	154407,29	-26952,57	-17974,10	-0,12	0,67
Bismuth	Bi	387755,77	21460,47	299801,68	0,77	13,97
Cadmium	Cd	44810,30	655,50	2995,66	0,07	4,57
Cobalt	Co	4871080,90	86268,97	323040,06	0,07	3,74
Chromium	Cr	69904359,76	1147580,49	4194174,32	0,06	3,65
Caesium	Cs	846590,55	22845,33	40438,24	0,05	1,77
Copper	Cu	9181994,15	802002,75	14007018,25	**1,53**	17,47
Iron	Fe	-58902647157,00	-830671743,20	-5697730487,00	0,10	6,86
Gallium	Ga	3174770,49	301375,67	588567,36	0,19	1,95
Indium	In	74012,04	5621,85	51472,37	0,70	9,16
Potassium	K	339673748,60	-	-	-	-
Nickel	Ni	11751984,02	192400,84	798579,48	0,07	4,15
Magnesium	Mg	23837165,48	725116948,10	-	-	-
Sodium	Na	-	-	-	-	-
Lithium	Li	1339318,35	14540,81	109616,49	0,08	7,54
Lead	Pb	17603530,25	503844,81	890832,01	0,05	1,77
Zinc	Zn	9422293,77	2058378,07	5568049,94	0,59	2,71

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Table 2: Amount of heavy metals detected in soil, roots, and shoots in Tugela River ($mgkg^{-1}$)

			Tugela River			
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	2338010,267	7732,677624	45173,80531	0,02	5,84
Aluminum	Al	855215316,9	10944270,72	11073251,53	0,01	1,01
Arsenic	As	-45738341,16	-529293,003	-1044420,35	0,02	1,97
Barium	Ba	188148321,3	3600815,056	1965080,58	0,01	0,55
Beryllium	Be	209879,8598	-30269,52245	-28516,04867	-0,14	0,94
Bismuth	Bi	191572,7111	9491,696354	53736,40166	0,28	5,66
Cadmium	Cd	50926,16169	-1820,118106	-2198,125827	-0,04	1,21
Cobalt	Co	8929795,271	48307,45084	73776,35852	0,01	1,53
Chromium	Cr	128177078,2	308926,9203	1176367,657	0,01	3,81
Cesium	Cs	1185492,113	11051,17052	17469,87189	0,01	1,58
Copper	Cu	11875756,48	685747,0527	162965,3565	0,01	0,24
Iron	Fe	-82286891491	-138803073	-599496185	0,01	4,32
Gallium	Ga	7630352,463	56776,73543	62074,58907	0,01	1,09
Indium	In	55002,6901	1960,81964	19809,08439	0,36	10,10
Potassium	K	381035379,1	1261174767	-	-	-
Nickel	Ni	13160978,59	75719,58741	128871,9194	0,01	1,70
Magnesium	Mg	13203076,29	607696218,6	156947753,2	11,89	0,26
Sodium	Na	-	-	-	-	-
Lithium	Li	4607807,419	-3429,820239	19907,67227	0,00	-5,80
Lead	Pb	31697693,7	82046,74262	233939,5782	0,01	2,85
Zinc	Zn	9500516,573	1579881,123	642461,8787	0,07	0,41

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Table 3: Amount of heavy metals detected in soil, roots, and shoots in Umvoti River (mg/kg-1)

Umvoti River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	241937,5203	-7118,726808	95954,4953	0,40	-13,48
Aluminum	Al	559595153,8	110149647,4	28491572,31	0,05	0,26
Arsenic	As	-24929741,03	22930,51019	-950979,4637	0,04	-41,47
Barium	Ba	139814765,8	14710100,28	4674300,988	0,03	0,32
Beryllium	Be	192648,5826	-22817,58875	-27018,53721	-0,14	1,18
Bismuth	Bi	108009,9886	9845,907919	26721,10167	0,25	2,71
Cadmium	Cd	36301,85139	3131,127546	-2217,790969	-0,06	-0,71
Cobalt	Co	7594382,658	204977,2167	145324,4491	0,02	0,71
Chromium	Cr	60770105,09	1138754,046	1083610,321	0,02	0,95
Cesium	Cs	889359,8387	53823,15488	14244,35621	0,02	0,26
Copper	Cu	6086073,69	4067376,962	238713,7238	0,04	0,06
Iron	Fe	-45168641077	-1603779386	-1107745599	0,02	0,69
Gallium	Ga	6357377,485	241422,0445	113496,8105	0,02	0,47
Indium	In	28494,9262	2944,346341	4493,737718	0,16	1,53
Potassium	K	265630296	-	1053793374	**3,97**	-
Nickel	Ni	10784662,99	275802,3016	154886,39	0,01	0,56
Magnesium	Mg	18648131,68	517263768,9	168308161,2	**9,03**	0,33
Sodium	Na	-	-	-	-	-
Lithium	Li	606071,3085	80465,05429	13710,51464	0,02	0,17
Lead	Pb	22051407,64	1220278,063	620832,233	0,03	0,51
Zinc	Zn	6311449,906	1437451,934	310569,512	0,05	0,22

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Table 4: Amount of heavy metals detected in soil, roots, and shoots in Umdloti River (mg/kg-1)

Umdloti River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	241937,5203	-7118,726808	95954,4953	0,40	-13,48
Aluminum	Al	559595153,8	110149647,4	28491572,31	0,05	0,26
Arsenic	As	-24929741,03	22930,51019	-950979,4637	0,04	-41,47
Barium	Ba	139814765,8	14710100,28	4674300,988	0,03	0,32
Beryllium	Be	192648,5826	-22817,58875	-27018,53721	-0,14	1,18
Bismuth	Bi	108009,9886	9845,907919	26721,10167	0,25	2,71
Cadmium	Cd	36301,85139	3131,127546	-2217,790969	-0,06	-0,71
Cobalt	Co	7594382,658	204977,2167	145324,4491	0,02	0,71
Chromium	Cr	60770105,09	1138754,046	1083610,321	0,02	0,95
Cesium	Cs	889359,8387	53823,15488	14244,35621	0,02	0,26
Copper	Cu	6086073,69	4067376,962	238713,7238	0,04	0,06
Iron	Fe	-45168641077	-1603779386	-1107745599	0,02	0,69
Gallium	Ga	6357377,485	241422,0445	113496,8105	0,02	0,47
Indium	In	28494,9262	2944,346341	4493,737718	0,16	1,53
Potassium	K	265630296	-	1053793374	3,97	-
Nickel	Ni	10784662,99	275802,3016	154886,39	0,01	0,56
Magnesium	Mg	18648131,68	517263768,9	168308161,2	9,03	0,33
Sodium	Na	-	-	-	-	-
Lithium	Li	606071,3085	80465,05429	13710,51464	0,02	0,17
Lead	Pb	22051407,64	1220278,063	620832,233	0,03	0,51
Zinc	Zn	6311449,906	1437451,934	310569,512	0,05	0,22

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Table 5: Amount of heavy metals detected in soil, roots, and shoots in Umfolozi River

Umfolozi River						
Metals	**Symbols**	**Soil**	**Roots**	**Shoots**	**Bcf**	**TF**
Silver	Ag	2358410,1	7332,99624	45173,80531	0,02	5,74
Aluminum	Al	855215316,9	10944270,72	11073251,53	0,01	0.99
Arsenic	As	-45738341,2	-529293,003	-1044420,35	0,02	1,57
Barium	Ba	188148321,3	3600815,056	1965080,58	0,01	0,55
Beryllium	Be	209879,87	-30269,52245	-28516,04867	-0,09	0,54
Bismuth	Bi	191572,71	9491,696354	53736,40166	0,28	4,36
Cadmium	Cd	50926,17	-1820,118106	-2198,125827	-0,05	1,32
Cobalt	Co	8849795,31	48307,45084	73776,35852	0,01	1,66
Chromium	Cr	12765343,2	387692,9203	1274387,657	0,01	3,32
Cesium	Cs	1185492,113	11051,17052	17469,87189	0,01	1,17
Copper	Cu	11875756,48	685747,0527	162965,3565	0,01	0,30
Iron	Fe	-82286891491	-138803073	-599496185	0,01	4,01
Gallium	Ga	7630352,463	56776,73543	62074,58907	0,01	0.99
Indium	In	55002,6901	1960,81964	19809,08439	0,36	11.01
Potassium	K	381035379,1	1261174767	-	-	-
Nickel	Ni	13160978,59	75719,58741	128871,9194	0,01	1,70
Magnesium	Mg	13203076,29	607696218,6	156947753,2	9.97	0,21
Sodium	Na	-	-	-	-	-
Lithium	Li	4607807,419	-3429,820239	19007,67427	0,01	-4,90
Lead	Pb	31697693,7	82046,74262	233939,5782	0,01	2,85
Zinc	Zn	9500516,573	1579881,123	642461,8787	0,07	0,41

(mg/kg-1)

Discussion

Samples from all the rivers displayed some sort of contamination of the river system. The soils as well as the vegetation samples displayed the presence of heavy metals in both the roots and the shoots (Tables 1 to 5). The Potentially Harmful Elements (PHEs) seem to be taken up by all the vegetation samples. The process of absorption from the roots is transported to the leaves and other parts of the plant body, including storage of these heavy metals, as the plant is unable to excrete them once absorbed. The potential of these metals being taken up by agricultural vegetation is highly possible. In some samples, Silver (Ag) was transported to the leaves, where it is stored. In the Umdloti River and the Umfolozi River, there seemed to be the presence of Ag as well. This could be due to illegal sand mining activities that disturb the metal concentration of the surroundings, which is then passed on to the river system. As for the Umvoti River, the amount taken up is lower than that detected in the Umdloti and the Umfolozi River. There is a large amount of all the PHEs absorbed by the samples of the uMngeni and Tugela Rivers. All samples from all rivers had a relatively high level of heavy metal concentration as compared to the permissible limits in the vegetable crops, where all four (Ag, Zn, Pb, and Cu) metals (IS/WHO/FAO, 2001). The bio-concentration (BCF) is important during scientific analysis of harm that heavy metals may be detrimental to humans and the environment (Alexander, 1999; Arnot and Gobas, 2006). The BCF for the qualified elements was calculated with the following formula: BCF = Cshoot/Csoil. Where Cshoot = the concentration of the element in the shoot, and Csoil = the concentration of the element in the soil sample (Wilson and Pyatt 2007; Zhuang *et a*l. 2007). Ma *et al.* (2001) and Cluis (2004) stated that BCF values classify plant species as hyperaccumulators and accumulators (BCF > 1 mg.kg-1), or excluders (BCF < 1 mg.kg-1), respectively. Furthermore, hyper-accumulators are plants that can take up metal at levels 50-500 times more than normal plants (Cluis, 2004). The current investigation for all Rivers has a BCF value for copper. The vegetation samples seem to be accumulating and storing copper, which can be harmful to animals if consumed. The highest BCF value for copper was from the

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uMngeni River, whereas all the other River samples have much lower BCF values (less than 1 mg.kg-1).

Limitations

The study was limited by its cross-sectional nature, representing a single seasonal window and therefore not capturing temporal variations in contamination, particularly those caused by seasonal flooding or prolonged drought. The analysis was also confined to four heavy metals (Pb, Cd, Zn, Cu), excluding others such as arsenic, mercury, or chromium, which could also pose ecological risks. While composite soil samples were used to reduce variability, they may have masked micro-scale differences in contamination levels. Additionally, only a few dominant vegetation species were analyzed, which may not reflect the full spectrum of species-specific metal accumulation capacities.

Generalizability

The study's findings are generalizable to similar riverine and riparian environments within KwaZulu-Natal and other South African provinces with comparable land-use impacts and hydrological features. However, extrapolation to other ecological zones should be approached cautiously, considering differences in soil chemistry, rainfall patterns, industrial profiles, and vegetation composition. The sampling and analytical framework used in this study can be adapted for broader regional or national biomonitoring efforts aimed at assessing heavy metal contamination in riparian ecosystems.

Conclusion

This study has demonstrated that riparian vegetation along the uMngeni, uThukela, Umvoti, Umdloti, and Umfolozi Rivers is accumulating varying levels of heavy metals, with the highest concentrations of lead (Pb) and cadmium (Cd) recorded in vegetation from sites downstream of industrial and urban areas, particularly along the uMngeni and Umvoti Rivers. In contrast, vegetation from the Umdloti and Umfolozi Rivers exhibited lower contamination levels, suggesting comparatively less anthropogenic pressure. The findings confirm the use of riparian vegetation, especially species such as *Phragmites australis*, as effective bioindicators of heavy metal pollution in aquatic ecosystems. The gradient-based sampling from the river edge to 4 m inland also revealed that contamination levels decline with increasing distance from the riverbank, reflecting pollutant deposition patterns influenced by land-use activities and hydrological processes.

Recommendations

To effectively address heavy metal contamination in KwaZulu-Natal's River systems, a multifaceted approach is essential. One key strategy involves the establishment and maintenance of riparian buffer zones and vegetated strips along riverbanks that serve as natural filters to reduce runoff and limit the transfer of heavy metals into both aquatic and terrestrial ecosystems. In conjunction with this, targeted pollution mitigation efforts should focus on downstream areas with high contamination levels, particularly near industrial zones and wastewater discharge points, where anthropogenic pressures are most intense. The implementation of phytoremediation initiatives also holds significant promise, especially through the use of high bioaccumulating species such as *Phragmites australis*, which can be deployed in controlled environments to extract and stabilize heavy metals from polluted soils and sediments. To ensure long-term efficacy, it is imperative to institute regular monitoring programs that track spatial and temporal changes in heavy metal concentrations within riparian vegetation, providing data to guide adaptive management and policy revisions. Finally, the success of these interventions hinges on robust stakeholder education and the enforcement of environmental regulations**.** Raising awareness among farmers, industries, and municipalities about the ecological and health risks associated with heavy metal discharge will foster greater compliance and stewardship, contributing to the overall sustainability of riverine ecosystems.

Biography

Dr. Sibonelo Thanda Mbanjwa is a dedicated lecturer in the Department of Nature Conservation at Mangosuthu University of Technology (MUT), South Africa. He holds a Ph.D. in Environmental Science and specializes in biodiversity conservation, sustainable development, and environmental education. Dr. Mbanjwa is deeply committed to community engagement, student mentorship, and the integration of indigenous knowledge systems into conservation practices. His work bridges academia and practical application, empowering students and communities through innovative teaching, research, and outreach initiatives.

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Competing Interests
The authors have no relevant financial or non-financial interests to disclose.

Author Contributions
I, the author, contributed to the study's conception and design. Material preparation, data collection, and research were performed by Mbanjwa S.T. The first draft was written by Mbanjwa S.T.

Data Availability
The data that support the findings of this study are available from the author, but restrictions apply to the availability of these data, which were used under license from various research publications for the current study and are therefore not publicly available.

List of Abbreviations
Pb – Lead
Cd – Cadmium
Zn – Zinc
Cu – Copper
$CaCO_3$ – Calcium Carbonate
PHE – Potentially Harmful Element
ICP-MS – Inductively Coupled Plasma Spectrometer
BCF – Bio-accumulation Factor
TF – Translocation Factor

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