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Spatial Distribution and Pollution Assessment of Heavy Metals in the Sediments of River Gwagwalada

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Abstract: *Sediments serve as long-term sinks for heavy metals in river systems, reflecting the cumulative effects of natural and anthropogenic inputs. This study assessed the concentrations, spatial distribution, seasonal variation, and contamination status of seven heavy metals (Cd, Co, Cr, Fe, Mn, Ni, and Zn) in sediments from River Gwagwalada, Nigeria. Sediment samples were collected from twelve stations during the wet and dry seasons and analyzed using Atomic Absorption Spectrophotometry (AAS). Mean metal concentrations (mg/kg) were Cd (0.52), Co (17.46), Cr (11.43), Fe (1643.67), Mn (350.03), Ni (11.16), and Zn (23.26), with generally higher concentrations observed at downstream locations. Analysis of variance (ANOVA) revealed significant seasonal variations for Cd ($p = 0.032$), Fe ($p < 0.001$), and Ni ($p = 0.002$), whereas Co, Cr, Mn, and Zn showed no significant seasonal differences ($p > 0.05$). Contamination factor (CF) and pollution load index (PLI) were used to evaluate sediment quality. Cadmium exhibited moderate contamination (CF = 1.73), while the remaining metals showed low contamination levels (CF < 1). The overall PLI (0.25) indicated that the sediments were generally unpolluted. These findings provide baseline information for environmental monitoring and sustainable management of River Gwagwalada.*

Keywords: Heavy metals; River sediments; Spatial distribution; Seasonal variation; River Gwagwalada

1 Introduction

River sediments perform a critical influence on aquatic systems by operating as both long-term sinks and remobilization sources of heavy metals. As a result of their high surface area and strong sorption capacity, sediments readily accumulate metals transported from natural weathering mechanisms and anthropogenic activities (Li et al., 2013; Miller et al., 2004). In many developing countries, river sediments exposed to mining, industrial discharge, agricultural runoff, and urban waste inputs show elevated concentrations of heavy metals, reflecting long-term pollution histories (Abdel-Ghani & Elchaghaby, 2007; Masindi & Muedi, 2018). These accumulated metals can become remobilized as environmental conditions shift, posing persistent ecological risks.

Heavy metals are sourced from both natural and anthropogenic origins. Natural inputs involve rock weathering, volcanic emissions, forest fires, sea-salt sprays, and wind-borne soil particles (Konietzny et al., 2014; Olowojuni et al., 2025). However, anthropogenic contributions from industries, mining, wastewater discharge, agriculture, fossil fuel combustion, and vehicular emissions often exceed natural fluxes and dominate environmental contamination pathways (Masindi & Muedi, 2018; H. Wang et al., 2013). Metals such as chromium, cadmium, nickel, cobalt, zinc, and lead are commonly associated

with industrial effluents, fertilizers, pesticides, and sewage sludge, and are frequently detected in river sediments at concentrations capable of causing ecological harm (Abdel-Ghani & Elchaghaby, 2007; Islam et al., 2015).

The fate and behavior of heavy metals in sediments are governed by physicochemical processes such as sorption, precipitation, dissolution, and redox reactions (Atkinson et al., 2007). Environmental parameters including pH, temperature, dissolved oxygen, and hydrodynamic disturbance strongly influence metal mobility and bioavailability (Balali-Mood et al., 2021; Li et al., 2013). Under acidic conditions or low dissolved oxygen levels, sediment-bound metals may flux into the overlying water, increasing exposure risks to aquatic organisms. Physical disturbances such as dredging or flooding have been shown to mobilize metals more rapidly than biological processes, underscoring the importance of sediment studies in pollution assessment (Atkinson et al., 2007).

Sediment-associated heavy metals pose serious ecological threats, particularly to benthic organisms, which may accumulate metals directly from sediments and transfer them through the food web (Miller et al., 2004). Chronic exposure has been linked to reduced biodiversity, altered community structure, and long-term ecosystem degradation. Recent studies emphasize that sediment quality assessment is a more reliable signal of cumulative contamination than water analysis alone, as sediments integrate contamination over extended periods (Varol, 2020; Zhang et al., 2021).

River Gwagwalada flows through zones characterized by quarrying, agriculture, domestic settlements, and minor industrial activities. Sediments along the river channel receive continuous inputs from surface runoff, tributary inflows, and direct waste discharge. Downstream sections are particularly susceptible to metal accumulation due to reduced flow velocity and increased deposition (Badamosi et al., 2024). Despite the ecological importance of sediments in controlling river health, detailed information with respect to heavy metal distribution and contamination levels in River Gwagwalada deposits remain scarce.

This research therefore assesses the concentration, spatial dispersion, and seasonal range of selected heavy metals in River Gwagwalada sediments. The findings provide insight into sediment-associated pollution, potential ecological risks, and baseline data necessary for effective river management and environmental protection.

2 Materials and Methods

2.1 Study Area

River Gwagwalada is a major fluvial system within the Federal Capital Territory (FCT), Nigeria, originating from River Usuma in Bwari Area Council and flowing through several urban and peri-urban settlements before reaching Gwagwalada. The river basin lies within Gwagwalada Area Council, which covers approximately 1,043 km² and has a population exceeding one million inhabitants. The area is geographically located between latitude 7°57′N and longitude 7°07′E and forms part of the floodplain of River Gurara at an average elevation of about 70 m above sea level (Badamosi et al., 2024; Ekpo & Haruna, 2022). The river sediments are continuously influenced by domestic waste disposal, agricultural activities, sewage discharge, industrial runoff, and sand mining, making them potential sinks for heavy metal accumulation.

2.2 Description of Sediment Sampling Sites

Twelve sediment sampling stations were established along River Gwagwalada, corresponding to locations influenced by varying anthropogenic activities. The sites included upstream reference points, urban bridges, agricultural zones, industrial inflow areas, confluence points, and densely populated riverbanks. Major activities observed included refuse dumping, discharge of sewage and industrial effluents, runoff from mechanic workshops, poultry and piggery waste discharge, and commercial sand fetching. The locations of the sampling stations are illustrated in Figure 1, with their geographical coordinates and elevations provided in Table 1 (Badamosi et al., 2024).

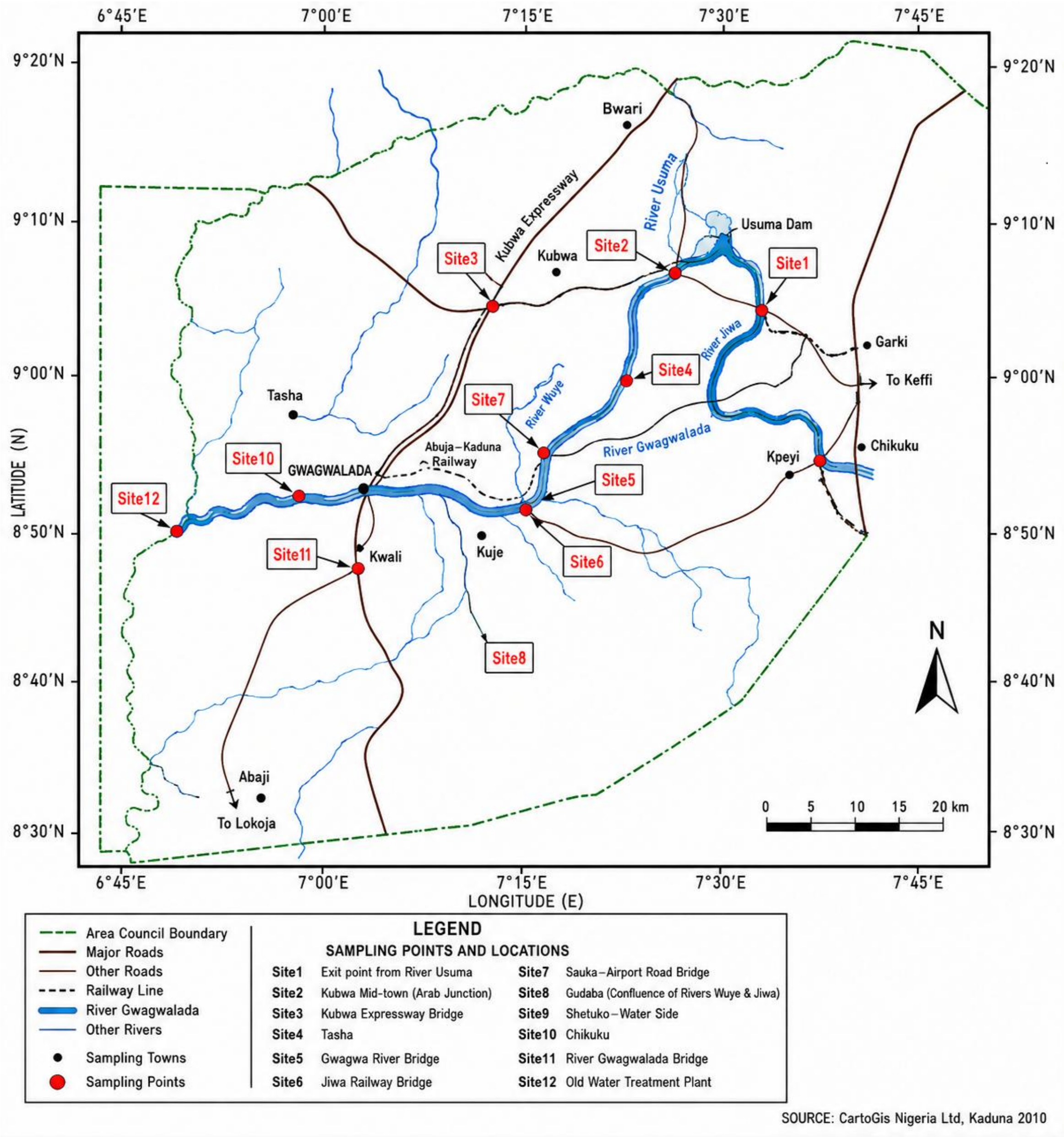

Figure 1: Sampling stations of the River Gwagwalada with adjoining cities, initial map (*adopted from (Badamosi et al., 2024)*

Table 1: Sampling sites of River Gwagwalada with their geographical coordinates.

Sampling site code	Name of sampling site	Latitude-N	Longitude-E	Elevation from sea level (M)
S_1	Exit point from River Usuma	9^{O} 9’9.39’’	7^{O} 20’56.84”	190
S_2	Kubwa Midtown Bridge by Arab	9^{O} 12’9.32”	7^{O} 23’32.45”	170
S_3	Kubwa Express- way bridge	9^{O} 9’22.20”	7^{O} 20’34.97”	230
S_4	Tasha	9^{O} 19’2.63”	7^{O} 5’11.83”	200
S_5	Gwagwa bridge	9^{O} 5’13.48”	7^{O} 18’41.98”	200
S_6	Juwa	8^{O}59’33.27”	7^{O}16’32.57”	210
S_7	Airport road bridge by Sauka	8^{O} 56’49.60”	7^{O} 15’37.42”	290
S_8	Gudaba	8^{O} 56’.07”	7^{O} 16’36.90”	380
S_9	Shetuko	8^{O} 53’37.20”	7^{O} 12’25.73”	310
S_{10}	Chikuku	8^{O} 52’56.27”	7^{O} 13’42.15”	
S_{11}	Gwagwalada bridge	8^{O} 56’14.33”	7^{O} 5’36.17”	250
S_{12}	Old water treatment plant Gwa-gwalada	8^{O} 56’14.33”	7^{O} 5’36.17”	250

2.3 Sediment Sampling Procedure

Twelve sampling stations were established along River Gwagwalada. One sediment sample was collected from each station during both the rainy and dry seasons, resulting in a total of twenty-four observations for statistical analysis. Approximately 500 g of sediment was sampled from each sampling station at a depth of about 50–60 cm adjacent to the riverbank. The samples were transferred to labeled polyethylene bags and conveyed to the laboratory for further analysis.

2.4 Preparation and Digestion of Sediment Samples

At the laboratory, sediment samples were air-dried for 72 hrs, crushed using a ceramic mortar, and screened using a 75-µm mesh to collect the fine sediment fraction. The sediments were thoroughly homogenized prior to digestion. Complete digestion was performed using the aqua regia method, where 3 g of each collected sediment was digested with 20 mL of aqua regia (HNO_3: HCl, 1:3 ratio) in a conical flask and heated at 80–150 °C for 4–5 hours. Distilled water was added intermittently to prevent dryness. Total digestion was confirmed by the formation of a clear solution. The digest was cooled prior to filtration through Whatman No. 42 filter paper, and made up to 100 mL with deionized water.

2.5 Determination of Heavy Metals in Sediments

The concentrations of cadmium (Cd), nickel (Ni), cobalt (Co), iron (Fe), chromium (Cr), manganese (Mn), and zinc (Zn) in sediment samples were analyzed using a Thermo Scientific iCE 3000 series Atomic Absorption Spectrophotometer (AAS). All analytical determinations were carried out in triplicate to ensure reliability of results.

2.6 Instrument Calibration and Quality Assurance

Quality assurance and quality control (QA/QC) procedures were implemented throughout sample preparation and analysis to ensure data reliability. Instrument calibration was performed using certified multi-element standard solutions, and only calibration curves with correlation coefficients ($R^2 \geq 0.990$) were accepted. Analytical quality control measures included reagent blanks, instrument blanks, duplicate analyses, and triplicate measurements to evaluate precision, accuracy, and potential contamination. Instrument performance was periodically verified during analysis to minimize analytical drift and ensure the consistency of measured metal concentrations (Correia & Rasteiro, 2025).

3 Results and Discussion:

3.1 Heavy Metals in River Gwagwalada Sediments

3.1.1 Distribution of Heavy Metals in Sediments

Mean concentrations, ranges, and comparisons with WHO and USEPA sediment quality recommended values are presented in Table 2. Sediment metal concentrations decreased in the order:

Fe > Mn > Zn > Co > Cr > Ni > Cd

Sediments consistently showed higher metal concentrations than water, confirming their role as long-term sinks for heavy metals (Ellaway et al., 1982; Liu et al., 2024; Wakawa, 2012; Yousef et al., 1994).

Table 2: Comparison of heavy metals in River Gwagwalada sediments with known standards

Metal (mg/kg)	Range	Mean	WHO	USEPA
Cd	0.02 – 0.99	0.52	6	0.6
Co	5.6 – 39.85	17.46	20	-
Cr	1.8 – 27.10	11.43	25	25
Fe	1391.18 – 1836.26	1643.67	-	30
Mn	94.67 – 1488.86	350.03	-	30
Ni	1.00 – 14.78	11.16	20	16
Zn	3.44 – 46.91	23.26	123	110

3.1.2 Cadmium (Cd) in Sediments

Cadmium concentrations varied from 0.02 to 0.99 mg/kg, with a mean value of 0.52 mg/kg (Figure 2 and Table 2). These values exceeded WHO (World Health Organization, 2011) sediment guidelines and were higher than values reported by Ugwu et al. and Mustapha et al.(Aminu et al., 2024; *Comparative Study of Heavy Metal Pollution of Sediments in Odo-Owa and Yemoji Streams, Ijebu-Ode Local Government Area, Sw Nigeria*, n.d.; Ugwu et al., 2011). Elevated Cd levels may be associated with refuse dumping, sewage sludge discharge, agricultural runoff, and leachates from Kyami dumpsite. Similar Cd enrichment has been reported for urban rivers in Ghana and Iraq (Duncan et al., 2018; Salah et al., 2012). Seasonal distribution showed slightly higher concentrations during the rainy season (Figure 3), reflecting enhanced surface runoff and soil erosion that transport Cd-contaminated particulates into the riverbed. This pattern is consistent with previous studies in West African river sediments, where rainy-season hydrology intensifies Cd accumulation in depositional zones (Amponsah et al., 2022).

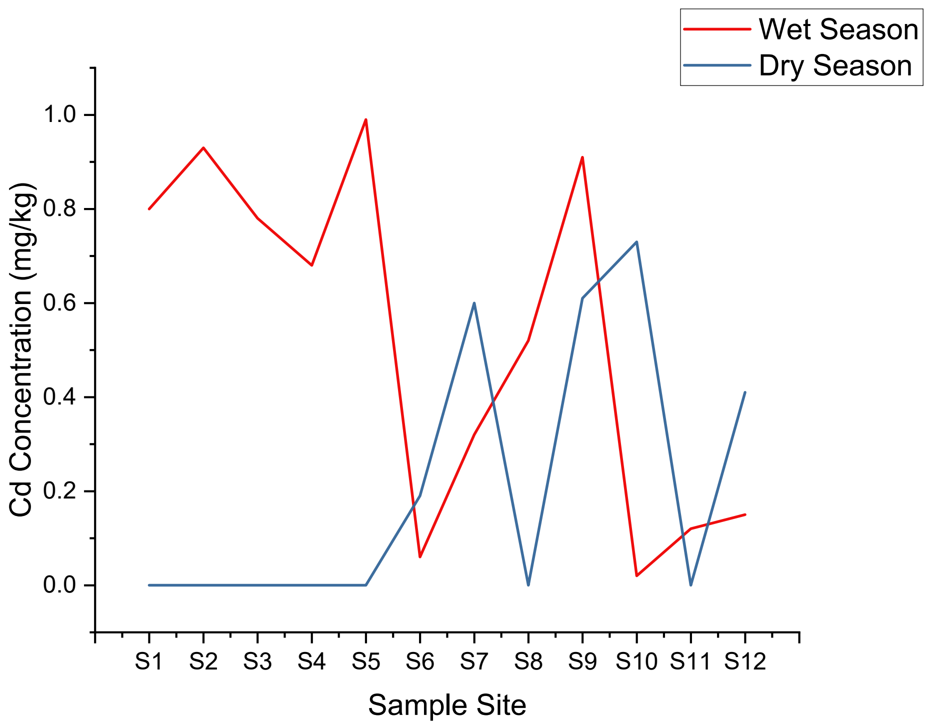

Figure 2: Variation of Cadmium concentration in sediment sample along the River Gwagwalada course

3.1.3 Cobalt (Co) in Sediments

Cobalt concentrations varied from 5.6 to 39.85 mg/kg, with a mean value of 17.46 mg/kg (Figure 3 and Table 2). Although the mean value is below WHO (World Health Organization, 2011) limits, several sites exceeded guideline values, particularly near highways and airport corridors. Comparable Co concentrations have been reported for River Euphrates and River Ganga sediments (Salah et al., 2012; Viers et al., 2009). Figure 3 revealed that there was a pronounced rainy-season enrichment at traffic-dominated and downstream sites. The seasonal increase suggests stormwater-mediated transport of Co-bearing particulates derived from vehicular emissions, soil erosion, and urban runoff. Similar seasonal Co accumulation has been reported in sediments of urban rivers influenced by road traffic and surface runoff processes (Nguyen et al., 2020).

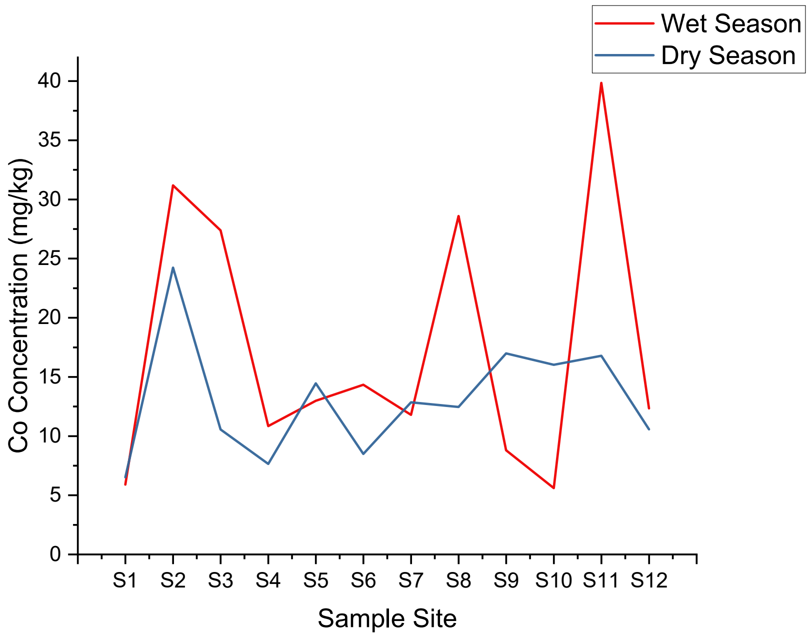

Figure 3: Variation of Cobalt concentration in sediment sample along River Gwagwalada course

3.1.4 Chromium (Cr) in Sediments

Chromium concentrations varied from 1.8 to 27.10 mg/kg, with a mean value of 11.43 mg/kg (Figure 4). Except for isolated sites, Cr levels were below WHO and USEPA limits. These values are substantially lower than those reported for River Nzoia (Kenya) and River Euphrates (Iraq), indicating moderate Cr contamination (S. Omutange et al., 2022; Salah et al., 2012). Figure 4 displayed mixed seasonal behavior characterized by rainy-season peaks upstream and dry-season accumulation downstream. This spatial–seasonal variability suggests combined effects of runoff-driven Cr inputs during rainfall and sediment remobilization or concentration during low-flow conditions. Comparable dual-season Cr dynamics have been observed in sediments of rivers affected by agricultural and urban activities (Patil et al., 2025).

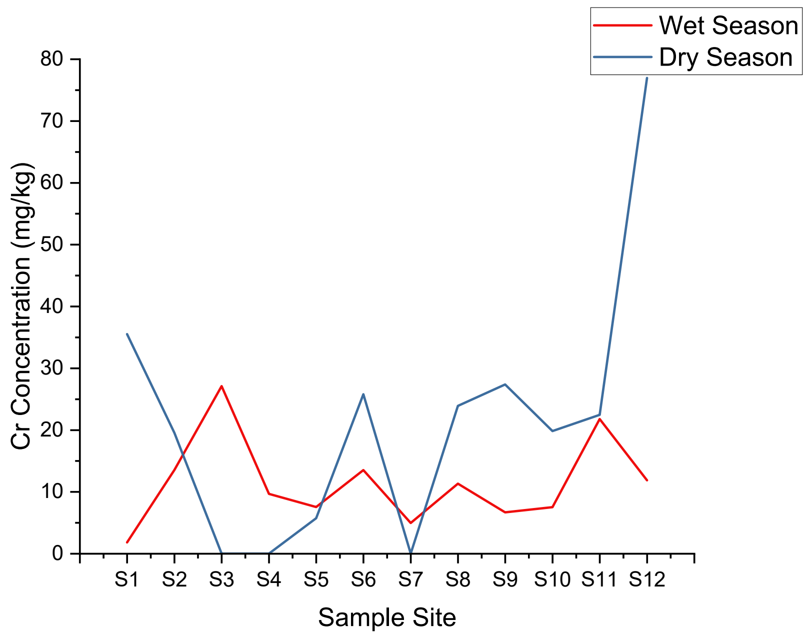

Figure 4: Variation of Chromium concentration in sediment sample along River Gwagwalada course

3.1.5 Iron (Fe) in Sediments

Iron concentrations ranged from 1391.18 to 1836.26 mg/kg, with a mean value of 1643.67 mg/kg (Table 2 and Figure 5). High Fe levels reflect natural geological sources combined with anthropogenic inputs. Comparable Fe concentrations have been reported for River Pra (Ghana) and Lake Edku (Iran) (Duncan et al., 2018; Saeed & Shaker, 2008). Figure 5 and Table 3 showed significant seasonal variation ($p < 0.001$), with increased values during the dry season. The dry-season enrichment reflects reduced flow velocity and enhanced sediment deposition, while rainy-season dilution lowers apparent concentrations. Elevated Fe levels are note-worthy indicators of erosion, quarrying, and urban drainage impacts, in line with results from similar riverine sediment studies (Liu et al., 2024)

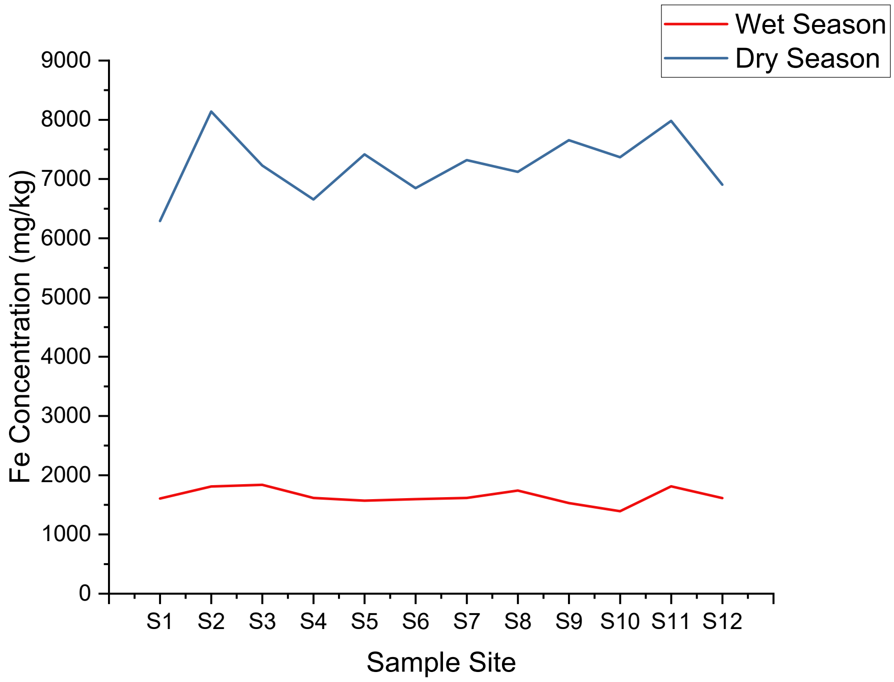

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Figure 5: Variation of Iron concentration in sediment sample along River Gwagwalada course

3.1.6 Manganese (Mn) in Sediments

Manganese showed pronounced enrichment, ranging from 94.67 to 1488.86 mg/kg, with a mean value of 350.03 mg/kg (Figure 6 and Table 2). These values exceed USEPA (Verovšek et al., 2020) limits, indicating heavy Mn pollution. Similar Mn bioaccumulation trends have been reported in heavily urbanized river systems (Duncan et al., 2018; Salah et al., 2012). Figure 6 and Table 3 showed pronounced rainy-season peaks. The elevated rainy-season Mn reflects intensive runoff and mobilization of Mn-rich soils and wastes into the sediment matrix. Similar Mn enrichment during high-flow periods has been widely reported in sediment studies of tropical river systems (Varol, 2020).

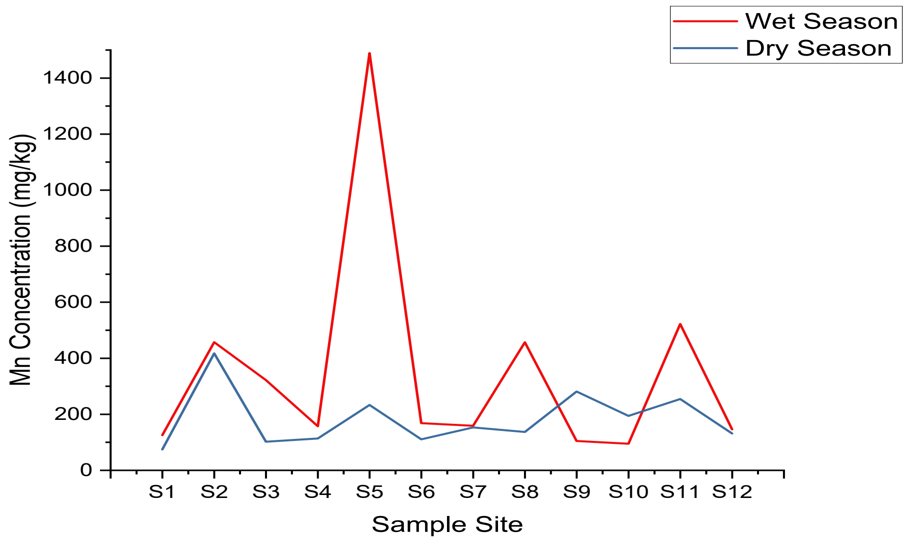

Figure 6: Variation of Manganese concentration in sediment sample along River Gwagwalada course

3.1.7 Nickel (Ni) in Sediments

Nickel concentrations varied from 1.00 to 21.72 mg/kg, with a mean value of 11.16 mg/kg (Figure 7 and Table 2). Most sites were below WHO and USEPA limits, indicating minimal Ni pollution. These values are lower than those reported for River Euphrates and River Yangtze (Kassim et al., 1997; Rabee et al., 2009, 2011; Raju et al., 2012; Wang et al., 2011). However, Figure 7 and Table 3 depicted higher concentrations during the rainy season. This pattern suggests runoff-driven transport of Ni from surrounding soils and anthropogenic surfaces, consistent with seasonal sediment Ni enrichment reported in rivers influenced by mixed land-use activities (Varol, 2020).

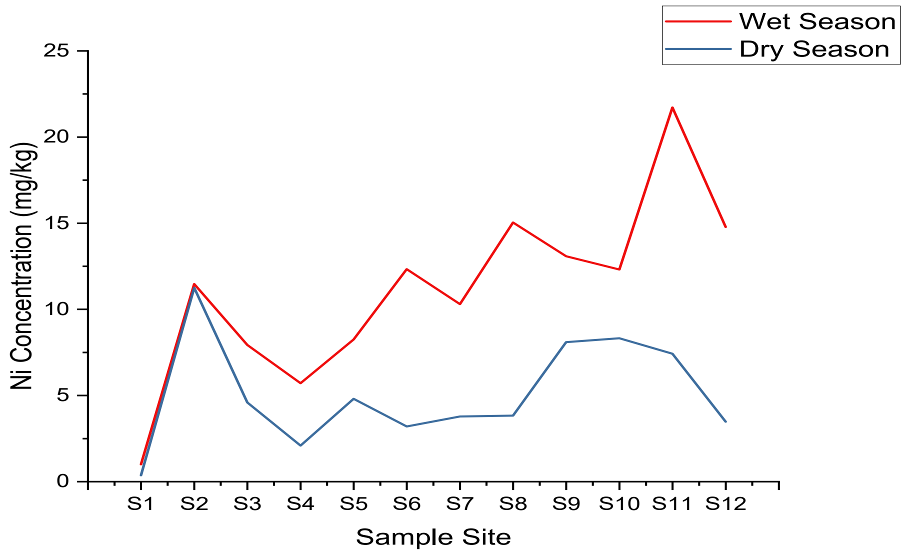

Figure 7: Variation of Nickel concentration in sediment sample along River Gwagwalada course

3.1.8 Zinc (Zn) in Sediments

Zinc concentrations ranged from 3.44 to 46.91 mg/kg, with a mean value of 23.26 mg/kg (Table 2 and Figure 8), remaining below WHO and USEPA limits. These values are less than those reported for River Pra and River Nzoia (Duncan et al., 2018; S. Omutange et al., 2022). Table 3 and Figure 8 showed that both rainy and dry-season maxima occurring at quarry-influenced sites. The relatively moderate Zn levels indicate limited industrial input, while its persistence across seasons reflects strong sediment binding and localized anthropogenic influence. Similar Zn behavior has been documented in sediments of less industrialized river systems (Duncan et al., 2018).

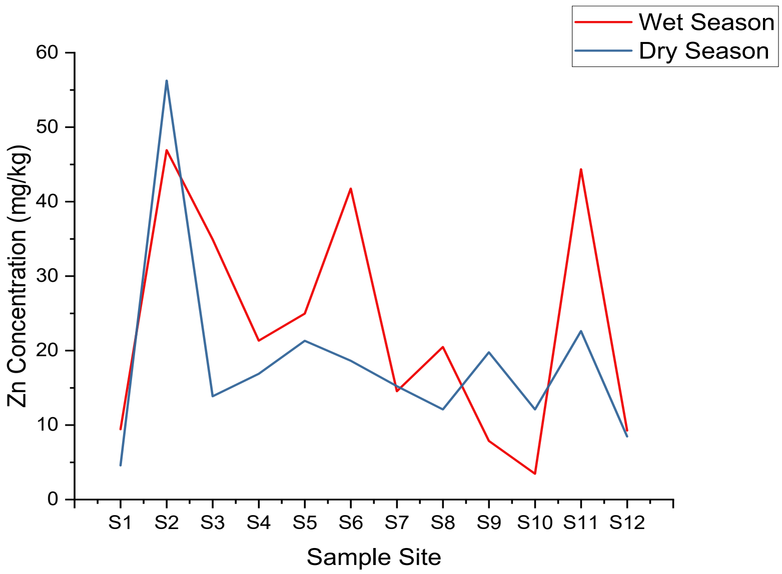

Figure 8: Variation of Zinc concentration in sediment sample along River Gwagwalada course

3.2 Seasonal Variability of Heavy Metals in Sediments

ANOVA results (Table 3) revealed statistically significant seasonal variations for Cd ($p = 0.032$), Fe ($p < 0.001$), and Ni ($p = 0.002$), whereas Co, Cr, Mn, and Zn showed no significant seasonal differences ($p > 0.05$). The higher dry-season Fe concentrations may be attributed to reduced dilution and enhanced sediment accumulation during periods of low river discharge, while elevated rainy-season Ni concentrations may be associated with increased surface runoff, catchment inputs, and sediment resuspension processes (Aderinola et al., 2009; Saeed & Shaker, 2008). The significant seasonal variation observed for Cd may similarly reflect fluctuations in runoff intensity and anthropogenic inputs between seasons.

Table 3: ANOVA test results for seasonal variability of heavy metals in sediments of River Gwagwalada

		Sum of Squares	Df	Mean Square	F	Sig.
	Inter-Groups	.583	1	.583	5.249	.032
Cd	Intra-Groups	2.443	22	.111		
	Total	3.025	23			
	Inter-Groups	112.927	1	112.927	1.493	.235
Co	Intra-Groups	1664.529	22	75.660		
	Total	1777.455	23			
	Inter-Groups	597.882	1	597.882	2.380	.137
Cr	Intra-Groups	5526.631	22	251.210		
	Total	6124.513	23			
	Inter-Groups	188159328.001	1	188159328.001	1253.062	.001
Fe	Intra-Groups	3303512.710	22	150159.669		
	Total	191462840.711	23			
	Inter-Groups	166798.359	1	166798.359	2.060	.165
Mn	Intra-Groups	1781183.403	22	80962.882		
	Total	1947981.762	23			

		Sum of Squares	Df	Mean Square	F	Sig.
	Inter-Groups	220.342	1	220.342	12.037	.002
Ni	Intra-Groups	402.728	22	18.306		
	Total	623.070	23			
	Inter-Groups	6466.262	1	6466.262	.796	.382
Zn	Intra-Groups	178704.772	22	8122.944		
	Total	185171.034	23			

3.3 Sediment Contamination Classification

The mean concentrations of Cd, Co, Cr, Fe, Mn, Ni, and Zn were compared with the adopted sediment quality criteria (Table 4). The results indicated that the concentrations of Fe, Ni, and Zn were within permissible limits and therefore did not suggest sediment pollution. Although variations were observed among the metals, the overall concentration levels were generally low, indicating limited contamination within the study area. The downstream increase in metal concentrations may be associated with sediment transport, depositional processes, and localized anthropogenic activities along the river corridor.

Table 4: USEPA sediments contamination guidelines (mg/kg)

Metal	Not polluted	Fairly Polluted	Severely Polluted	Current study Conc. Level
Cd	--	--	> 6	0.02 - 0.99
Co	--	--	--	5.60 - 39.05
Cr	< 25	25-75	> 75	1.80 – 27.10
Fe	< 1700	1700-2500	> 2500	1391.18-1830.26
Mn	< 300	300-500	> 500	94.67-1488.86
Ni	< 20	20- 50	> 50	1.00-14.78
Zn	< 90	90-200	> 200	3.44-46.91

3.4 Contamination Factor (CF) and Pollution Load Index (PLI)

To provide a more comprehensive assessment of sediment quality, the Contamination Factor (CF) and Pollution Load Index (PLI) were calculated using average shale background concentrations proposed by Turekian & Wedepohl, (1961). These indices have been widely used in both classical and recent studies of sediment contamination (Popoola, 2023; S. Omutange et al., 2022; Tomlinson et al., 1980; Yozukmaz & Yabanlı, 2023). The contamination factor (CF) was computed as the ratio of the measured metal concentration to its corresponding background concentration, while the pollution load index (PLI) was determined as the geometric mean of the contamination factors for all analyzed metals. The degree of contamination was classified as low (CF < 1), moderate (1 ≤ CF < 3), considerable (3 ≤ CF < 6), and very high (CF ≥ 6). Similarly, PLI values less than 1 indicate unpolluted sediments, a value of 1 represents baseline pollution levels, and values greater than 1 indicate polluted conditions. The use of CF and PLI provides a quantitative evaluation of both individual metal contamination and the overall pollution status of the sediment environment (Tomlinson et al., 1980; Turekian & Wedepohl, 1961).

$$Contamination\ Factor\ (CF) = \frac{C_{sample}}{C_{background}} \quad (1)$$

Where Csample is the concentration of the metal measured in your sediment sample (mg/kg).

and $C_{background}$ is the natural concentration of the metal before anthropogenic influence.

$$Pollution\ Load\ Index\ (PLI) = (CF1 \times CF2 \times \ldots\ldots\ldots\ldots \times CFn)^{1/n} \quad (2)$$

Table 5: Contamination Factor (CF) and Pollution Load Index (PLI) of the Heavy Metals

Metal	Mean (mg/kg)	Background (mg/kg)	CF	Pollution Status
Cd	0.52	0.30	1.73	Moderate contamination
Co	17.46	19.00	0.92	Low contamination
Cr	11.43	90.00	0.13	Low contamination
Fe	1643.67	47200.00	0.035	Low contamination
Mn	350.03	850.00	0.41	Low contamination
Ni	11.16	68.00	0.16	Low contamination
Zn	23.26	95.00	0.25	Low contamination

The Overall PLI is 0.25, which is unpolluted

Contamination factor (CF) and pollution load index (PLI) were employed to further evaluate the contamination status of River Gwagwalada sediments (Table 5). Cadmium exhibited moderate contamination (CF = 1.73), whereas Co, Cr, Fe, Mn, Ni, and Zn showed low contamination levels (CF < 1). The moderate enrichment observed for cadmium suggests possible anthropogenic inputs within the river catchment, while the low CF values of the remaining metals indicate minimal enrichment relative to their background concentrations. Furthermore, the overall PLI value of 0.25 was less than unity, indicating that the sediments are generally unpolluted with respect to the combined heavy metal burden. These findings are consistent with the concentration-based assessment presented in Table 4 and agree with previous studies that reported low overall sediment pollution despite localized enrichment of specific metals using CF and PLI approaches(Popoola, 2023; Yozukmaz & Yabanlı, 2023).

4. Conclusion

The analysis of sediments from River Gwagwalada revealed a general increase in heavy metal concentrations from upstream to downstream locations, suggesting the influence of sediment transport, depositional processes, tributary inputs, and localized anthropogenic activities within the river catchment. Contamination factor (CF) analysis indicated moderate contamination by cadmium (CF = 1.73), whereas Co, Cr, Fe, Mn, Ni, and Zn exhibited low contamination levels (CF < 1). Furthermore, the overall Pollution Load Index (PLI = 0.25) indicated that the sediments were generally unpolluted with respect to the combined heavy metal burden. Although the current contamination levels are relatively low, the accumulation of heavy metals in sediments may potentially pose ecological concerns if inputs increase over time.

To minimize future contamination, public awareness programmes should be implemented to educate residents on the environmental implications of heavy metal pollution and encourage responsible waste disposal practices. Collaboration with regulatory agencies such as National Environmental Standards and Regulations Enforcement Agency (NESREA) and Abuja Environmental Protection Board (AEPB) is essential for effective pollution control and sustainable river management. Future studies should include sediment sampling at multiple depths and assess additional potentially toxic elements such as arsenic, mercury, lead, vanadium, and copper to provide a more comprehensive evaluation of sediment quality and contamination status.

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