



ASSESSMENT OF HEAVY METAL CONTAMINATION AND SEASONAL VARIATION IN RIVER GWAGWALADA, NIGERIA

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ABSTRACT

Heavy metals are among the most persistent pollutants in aquatic environments due to their toxicity, persistence, and potential for accumulation. Rivers receiving discharges from industrial, domestic, and agricultural activities are particularly vulnerable to contamination. This study investigated the concentrations and seasonal variations of seven heavy metals (Cd, Cr, Co, Fe, Mn, Ni, and Zn) in River Gwagwalada, Abuja, Nigeria. Water samples were collected from twelve sampling stations during the rainy and dry seasons and analyzed using Atomic Absorption Spectrophotometry (AAS). The mean concentrations (mg/L) were Cd (0.06), Co (0.114), Cr (0.19), Fe (1.71), Mn (0.29), Ni (1.14), and Zn (0.01). Comparison with WHO (2011) drinking-water guidelines revealed that Mn and Zn were within permissible limits, whereas Cd, Co, Cr, Fe, and Ni exceeded the recommended values. Analysis of variance (ANOVA) showed significant seasonal variations in the concentrations of Co, Cr, Fe, Mn, and Ni, while Cd and Zn exhibited no significant differences between the rainy and dry seasons. The observed spatial and seasonal variations suggest that anthropogenic activities, including agricultural practices, domestic waste disposal, sewage discharge, and urban runoff, contribute to heavy metal contamination in the river. The findings highlight the need for regular water-quality monitoring and effective pollution-control measures to support the sustainable management of River Gwagwalada.

Keywords: Heavy Metals; River Water Quality; Seasonal Variation; River Gwagwalada; Public Health Risk

INTRODUCTION

Heavy metals are naturally occurring elements in the environment characterized by high atomic weight and densities at least fivefold greater than that of water. Although they are typically present in trace concentrations in natural waters, many heavy metals remain toxic even at very low concentrations, making them a major concern in aquatic environments (Olowojuni et al., 2025). Increasing industrialization, urban expansion, and agricultural intensification have significantly elevated heavy metal loads in surface waters worldwide, largely due to the discharge of untreated or poorly treated industrial effluents, sewage, and agricultural runoff (Edokpayi et al., 2017; Kawser Ahmed et al., 2016). Rivers are particularly vulnerable because they act as natural receivers of contaminants from multiple point and non-point sources, including stormwater runoff, leaching from dumpsites, and atmospheric deposition (Diarra & Prasad, 2021; Förstner, 2012).

Some metals, such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), are essential for biological processes in humans and aquatic organisms; however, excessive concentrations can disrupt metabolic functions and become toxic (Järup, 2003; Kawser Ahmed et al., 2016). Non-essential metals such as cadmium (Cd), mercury (Hg), arsenic (As), and lead (Pb) are toxic even at very low concentrations and have no known biological benefits (Angon et al., 2024; Järup, 2003). Prolonged exposure to contaminated water may result in bioaccumulation and biomagnification through the food chain, leading to adverse health effects including kidney failure, neurological disorders, reduced fertility, developmental impairment, and cancer (Hughes et al., 1988; Santhosh et al., 2024). Recent studies have further shown that chronic exposure to metal-contaminated drinking water remains a significant public health issue in many developing regions due to weak regulatory enforcement and limited water

treatment infrastructure (Briffa et al., 2020; Gupta et al., 2020).

Rivers serve critical ecological and socio-economic functions, including water supply, irrigation, fisheries, and groundwater recharge (Stephens et al., 2020; Zoumis et al., 2001). However, physicochemical conditions of river water vary seasonally, influencing the mobility, solubility, and bioavailability of heavy metals (Pasricha et al., 2021; Singh et al., 2010). Seasonal rainfall patterns often enhance surface runoff and pollutant transport, while dry seasons may concentrate dissolved metals due to reduced dilution. Metals entering rivers may exist as free ions, soluble complexes, or adsorbed onto suspended particulates, making them readily available for uptake by aquatic organisms and humans (Islam et al., 2015; Jamshed & VAmrit, 2017).

River Gwagwalada, with River Usuma as its major tributary, traverses rapidly urbanizing and agriculturally active areas within the Federal Capital Territory, Nigeria. Along its course, the river receives effluents from domestic settlements, quarry activities, agricultural lands, and small-scale industrial operations. The upper catchment is dominated by quarrying and household discharges; the middle catchment by intensive agricultural activities and agrochemical use; and the lower catchment by additional domestic waste and agricultural runoff. Despite the reliance of surrounding communities on the river for domestic, irrigation, and commercial purposes, comprehensive data on heavy metal contamination in the river water remains limited.

In view of the adverse effects posed by heavy metals and their potential health implications, a systematic assessment of their concentrations and seasonal behavior in the River Gwagwalada water is essential. This study, therefore, evaluates the concentrations of selected heavy metals from the river water, examines seasonal variations, and assesses conformity with international water quality regulations to

support evidence-based water resource management and human health protection.

MATERIALS AND METHODS

Study Site

River Gwagwalada constitutes a major surface water body within the FCT, Nigeria. It originates from River Usuma in the Bwari Area Council and flows through Gwagwa, Kubwa, Gudaba, and Gwagwalada before discharging downstream. Gwagwalada Area Council occupies an estimated land area of 1,043 km² and has a population exceeding one million residents (Badamosi et al., 2024). The area lies in the southwestern part of the FCT and shares boundaries with Kuje, Kwali, and Niger State. The river basin is located within the floodplain of River Gurara, flowing at an average elevation of approximately 70 m above sea level and geographically positioned between latitude 7°57'N and longitude 7°07'E (Ekpo & Haruna 2022). Increasing urbanization, domestic wastewater discharge, agricultural effluents, and industrial activities along the river corridor make River Gwagwalada particularly vulnerable to surface water contamination.

Description of Water Sampling Sites

Twelve water sampling stations were established along the course of River Gwagwalada to capture variations in land use, anthropogenic activities, and potential sources of pollution. Sampling was conducted during both the rainy (July-August) and dry seasons (November-December), resulting in twelve

water samples per season from locations extending from the upstream exit point of River Usuma to the downstream section near the old Gwagwalada water treatment plant. Prior to sample collection, a reconnaissance survey was undertaken to identify representative stations based on the intensity of human activities and potential contamination sources. The selected stations included Site 1 (Exit Point from River Usuma), Site 2 (Kubwa Midtown Bridge by Arab Junction), Site 3 (Kubwa Expressway Bridge), Site 4 (Tasha), Site 5 (Gwagwa River Bridge), Site 6 (Juwa Railway Bridge), Site 7 (Sauka Airport Road Bridge), Site 8 (Gudaba, at the confluence of Rivers Wuye and Jiwa), Site 9 (Shetuko Waterside), Site 10 (Chikuku), Site 11 (River Gwagwalada Bridge), and Site 12 (Old Water Treatment Plant, Gwagwalada). These stations were influenced by diverse anthropogenic activities, including refuse dumping, sewage discharge, agricultural runoff, car-wash effluents, runoff from mechanic workshops, quarrying and rock-blasting activities, industrial emissions, sand mining, poultry and fish-farm effluents, and domestic wastewater discharges. The upstream stations were predominantly affected by quarrying activities, urban runoff, and refuse disposal, whereas the midstream and downstream stations were characterized by intensive agricultural practices, sewage inputs, industrial runoff, fish-farm discharges, sand mining activities, and increasing residential influences. The spatial distribution of the sampling stations is presented in Figure 1, while their geographical coordinates and elevations are summarized in Table 1 (Badamosi et al., 2024).

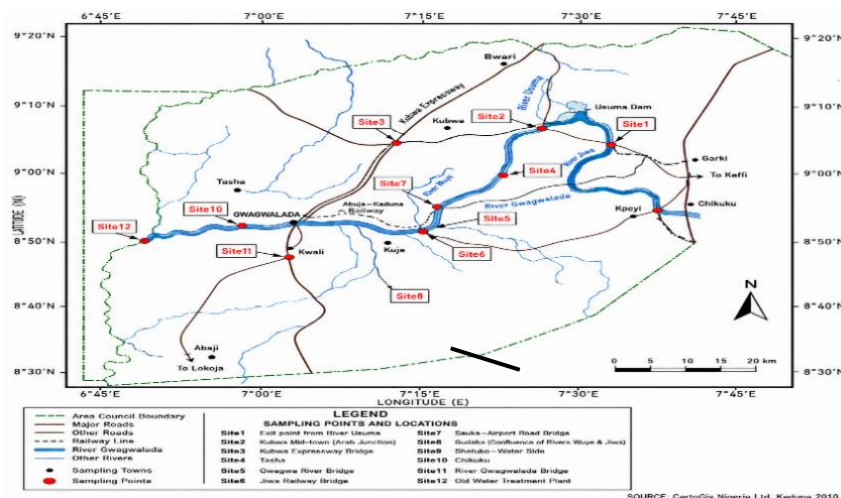


Figure 1: Sampling Stations Of The River Gwagwalada With Adjoining Cities, Initial Map Adopted From (Badamosi et al., 2024)

Table 1: Sampling Sites of River Gwagwalada with Their Geographical Coordinates

Sampling site code	Name of collection site	Latitude-N	Longitude-E	Elevation from sea level (M)
S ₁	Exit point from River Usuma	9° 9'9.39"	7° 20'56.84"	1900
S ₂	Kubwa midtown bridge by Arab	9° 12'9.32"	7° 23'32.45"	1700
S ₃	Kubwa Express- way bridge	9° 9'22.20"	7° 20'34.97"	2300
S ₄	Tasha	9° 19'2.63"	7° 5'11.83"	2000
S ₅	Gwagwa bridge	9° 5'13.48"	7° 18'41.98"	2000
S ₆	Juwa	8°59'33.27"	7°16'32.57"	2100
S ₇	Airport road bridge by Sauka	8° 56'49.60"	7° 15'37.42"	2900
S ₈	Gudaba	8° 56'.07"	7° 16'36.90"	3800
S ₉	Shetuko	8° 53'37.20"	7° 12'25.73"	3100
S ₁₀	Chikuku	8° 52'56.27"	7° 13'42.15"	
S ₁₁	Gwagwalada bridge	8° 56'14.33"	7° 5'36.17"	2500
S ₁₂	Old water treat- ment plant Gwa-gwalada	8° 56'14.33"	7° 5'36.17"	2500

Water Sampling Procedure

Immediately after collection, each water sample was preserved by acidification with 5 mL of concentrated hydrochloric acid (HCl) to minimize metal adsorption onto container walls, inhibit microbial activity, and maintain dissolved metals in solution during storage and transportation prior to analysis. The preserved samples were transported to the laboratory and stored at 4 °C until analysis. For digestion, 50 mL of each composite water sample was transferred into a clean beaker, and 5 mL of concentrated nitric acid (HNO₃) was added. The mixture was heated on a hot plate until the volume was reduced to approximately 20 mL. Additional nitric acid was added intermittently, and the digestion process continued until a clear solution was obtained, indicating complete digestion of the sample matrix. The digested sample was allowed to cool to room temperature, rinsed with deionized water, quantitatively transferred into a 50 mL volumetric flask, and diluted to the mark with deionized water following standard procedures for trace metal analysis (Singh et al., 2010).

Preparation of Water Samples

The concentrations of cadmium (Cd), chromium (Cr), cobalt (Co), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) in the water samples were determined using a Thermo Scientific iCE 3000 Series Atomic Absorption Spectrophotometer (AAS). All samples were analyzed in triplicate, and the mean values were used for subsequent statistical analyses. Appropriate hollow cathode lamps and analytical wavelengths were employed for each metal according to the manufacturer's specifications. Metal concentrations were expressed in milligrams per litre (mg/L).

Quantification of Heavy Metals in Water

The concentrations of cadmium (Cd), chromium (Cr), cobalt (Co), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) in the water samples were determined using a Thermo Scientific iCE 3000 Series Atomic Absorption Spectrophotometer (AAS). All samples were analyzed in triplicate, and the mean values were used for subsequent statistical analyses. Appropriate hollow cathode lamps and analytical wavelengths were employed for each metal

according to the manufacturer's specifications. Metal concentrations were expressed in milligrams per litre (mg/L).

Instrument Calibration and Quality Control

Instrument calibration was performed using certified standard solutions prepared at multiple concentration levels covering the expected concentration ranges of the target metals. Calibration curves were generated prior to sample analysis, and acceptable linearity was achieved with regression coefficients (R²) of at least 0.990 for all analytes (Shi et al., 2025; Verovšek et al., 2020). Reagent blanks and Procedural blanks were analyzed alongside the samples to monitor potential contamination during sample preparation and analysis. All analyses were conducted in triplicate to ensure analytical precision and reproducibility.

Descriptive statistics, including mean, standard deviation, and concentration ranges, were computed for each heavy metal. Prior to inferential statistical analysis, data normality was assessed using the Shapiro–Wilk test, while homogeneity of variance was evaluated using Levene's test. Seasonal differences in heavy metal concentrations between the rainy and dry seasons were examined using one-way analysis of variance (ANOVA) at a significance level of $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics software.

RESULTS AND DISCUSSION

Heavy Metals in River Gwagwalada Water

Concentration of Heavy Metal in Water

The results obtained from this study present the spatial and seasonal dispersion of selected heavy metals in the River Gwagwalada water. Mean concentrations, ranges, and comparisons with World Health Organization (WHO, 2011) (World Health Organization, 2011, 2022) potable water guidelines are summarized in Table 2. The overall abundance of the metals occurred in the order:

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

This trend reflects both geogenic inputs and increasing anthropogenic pressures along the river course, including urban runoff, refuse dumping, agricultural activities, quarrying, and sewage discharge. Subsequently, the results will be considered on an elemental basis.

Table 2: Mean Concentration of Heavy Metal Levels In Water (Mg/L)

Metals	Mean concentration (mg/l)	Range (mg/l)	WHO 2011 limits (mg/l)
Cadmium (Cd)	0.06	0.04 - 0.1	0.003
Cobalt (Co)	0.114	0.05 - 0.2	0.05
Chromium (Cr)	0.19	< 0.13 – 0.43	0.05
Iron (Fe)	1.71	0.9 – 3.17	1.00
Manganese (Mn)	0.29	0.25 – 0.32	0.4
Nickel (Ni)	1.14	1.02 – 1.27	0.006
Zinc (Zn)	0.01	< 0.01 – 0.02	0.01

Cadmium (Cd) in Water

Cadmium concentrations varied from 0.04 to 0.10 mg/L, with a mean value of 0.06 mg/L (Table 2). These values exceeded the World Health Organization (2011) (World Health Organization, 2011, 2022) permissible limit of 0.003 mg/L at all sampling locations (Figure 2), indicating widespread Cd contamination. Elevated concentrations are consistent with inputs from rock blasting activities between Sites 1 and 2, leachates from the Kyami dump site (Site 7), agricultural

runoff, and indiscriminate disposal of metal-containing wastes. Similar elevated Cd levels above WHO limits have been reported for Gurara Reservoir and other Nigerian surface waters impacted by urbanization (Aboujassoum & Costa, 2012; Gezahegn et al., 2024; Iliya et al., 2019). Furthermore, Seasonal analysis revealed no statistically significant difference between wet (rainy) and dry seasons ($p = 0.772$, see Table 3), indicating continuous and persistent Cd input rather than seasonally driven variability.

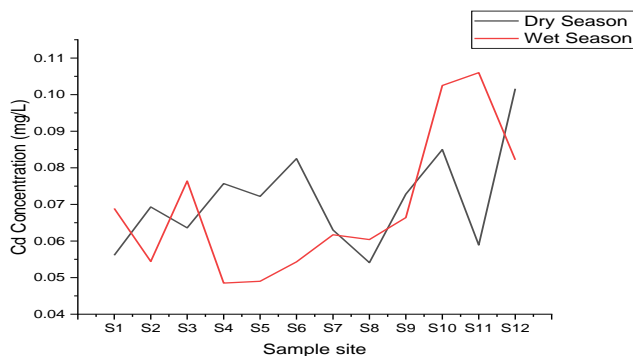


Figure 2: Variation of Cadmium Concentration in Water Sample along River Gwagwalada Course

Cobalt (Co) in Water

Cobalt concentrations varied from 0.05 to 0.25 mg/L, with a mean of 0.14 mg/L. Except for Site 3, all locations surpassed the WHO (2011) standard of 0.05 mg/L (Figure 3). Higher concentrations downstream reflect cumulative pollutant loading from sewage discharge, vehicular emissions, car wash effluents, and agricultural runoff. Comparable Co-enrichment in urban rivers has been reported in recent studies across West Africa, attributed mainly to traffic emissions and waste

disposal (Salah et al., 2012). Contrarily, Figure 3 and Table 3 showed significant seasonal variation ($p < 0.001$), with elevated concentrations recorded during the rainy season, particularly at downstream and traffic-influenced locations. This pattern indicates enhanced surface runoff during rainfall events, which mobilizes Co-bearing particulates from road dust, agricultural soils, and urban wastes into the river system (Han et al., 2022; Zhu et al., 2025).

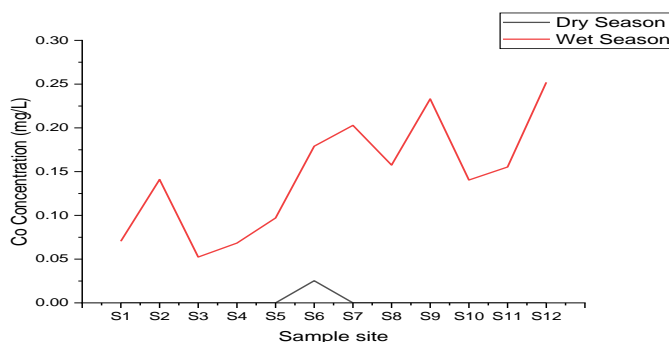


Figure 3: Variation of Cobalt Concentration in Water Sample along River Gwagwalada Course

Chromium (Cr) in Water

Chromium concentrations varied between <0.13 and 0.43 mg/L, with a mean of 0.19 mg/L, exceeding WHO (2011) limits at most sites (Figure 4). Low values at upstream sites (Sites 1 and 2) suggest minimal initial contamination, while increasing concentrations downstream indicate anthropogenic enrichment from sewage, piggery effluents, fertilizer runoff, and dumpsite leachates. These findings agree with Auta et al. (Iliya et al., 2019), who reported Cr concentrations between

0.08 and 0.39 mg/L in Gurara Reservoir. Figure 4 and Table 3 also revealed that seasonal variation was significant ($p < 0.001$), with increased concentrations observed during the dry season in comparison with the rainy season. This trend is linked to reduced river discharge and limited dilution during dry periods, which enhances the concentration of Cr from continuous point sources such as sewage discharge, piggery effluents, and fertilizer runoff (Asamoah et al., 2021; Debnath et al., 2024).

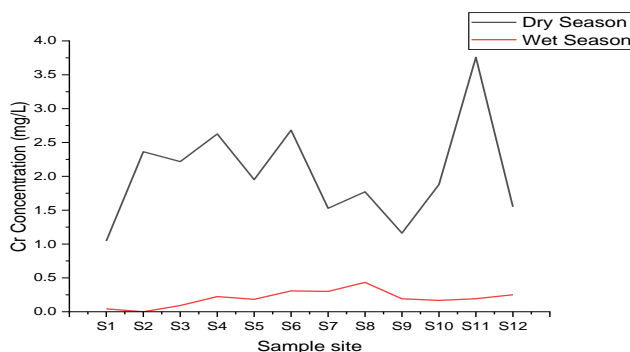


Figure 4: Variation of Chromium Concentration in Water Sample along River Gwagwalada Course

Iron (Fe) in Water

Iron concentrations varied from 0.16 to 3.17 mg/L, with a mean of 1.71 mg/L, exceeding WHO (2011) limits at most sites (Figure 5). Elevated Fe levels are linked to rock weathering, quarrying activities, refuse dumping, and runoff from farmlands. Similar Fe enrichment in surface waters near quarry zones has been reported by Ogunfowokan et al. (2013). Figure 5 and Table 3 indicate that seasonal variation in Fe concentrations was statistically significant ($p = 0.043$),

suggesting that seasonal factors influenced iron levels in River Gwagwalada. Higher concentrations during one season may be associated with variations in runoff, erosion processes, river discharge, and anthropogenic inputs. The lowest concentrations observed at sand-excavation sites suggest localized sediment removal effects. Similar Fe enrichment has been widely reported in rivers influenced by mining, construction activities, and urban runoff in developing regions (Adewumi & Laniyan, 2021; Ag, 2022)

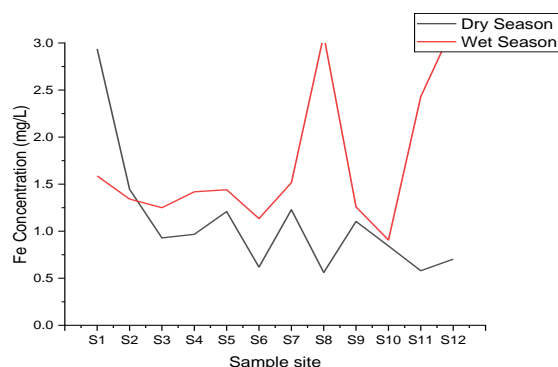


Figure 5: Variation of Iron Concentration in Water Sample along River Gwagwalada Course

Manganese (Mn) in Water

Manganese concentrations varied from 0.25 to 0.32 mg/L, with a mean of 0.29 mg/L, remaining below the WHO (2011) limit of 0.4 mg/L at all sites (Figure 6). These relatively low concentrations may be attributed to biological uptake by aquatic organisms and moderate natural background levels. Comparable Mn concentrations below guideline limits have been reported for similar tropical rivers (World Health Organization & World Health Organization, 2006). However,

Figure 6 and Table 3 revealed that there was a significant seasonal difference ($p < 0.001$). Higher Mn levels were recorded during the dry season, likely as a result of reduced dilution, higher sediment–water interaction, and possible release of Mn from bottom sediments under low-flow conditions. Similar seasonal Mn behavior has been observed in tropical rivers, where dry-season hydrodynamics promote metal accumulation in the water column (Kouassi et al., 2022).

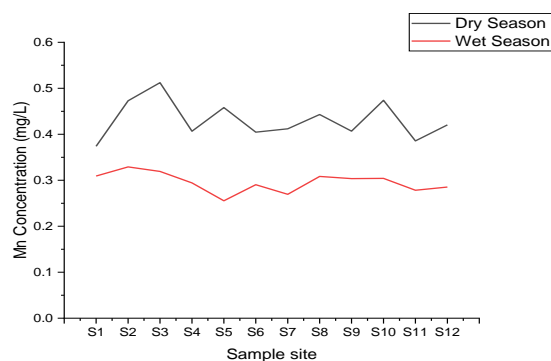


Figure 6: Variation of Manganese Concentration in Water Sample along River Gwagwalada Course

Nickel (Ni) in Water

Nickel concentrations ranged from 1.02 to 1.27 mg/L, with a mean of 1.14 mg/L, significantly exceeding the WHO (2011) limit of 0.006 mg/L (Figure 7). High Ni levels are associated with rock blasting, soil leaching, sewage discharge, and industrial runoff. Similar exceedances have been reported for rivers in Nigeria, Ghana, and India affected by urban and industrial activities (Rabee et al., 2009, 2011; Venkatesha et al., 2012; Wang et al., 2011). Figure 7 and Table 3 also

indicated that seasonal variation was significant ($p < 0.001$), with increased concentrations recorded during the rainy season, suggesting runoff-driven inputs from soils, rock blasting sites, and anthropogenic surfaces. The pronounced rainy-season enrichment reflects enhanced transport of Ni-laden particulates into the river during storm events, a pattern consistent with findings from river systems impacted by urbanization and land disturbance (Aderinola et al., 2009).

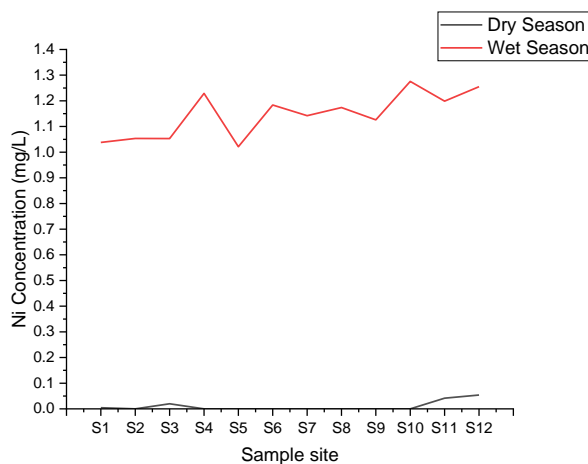


Figure 7: Variation of Nickel Concentration in Water Sample along River Gwagwalada Course

Zinc (Zn) in Water

Zinc concentrations varied from <0.01 to 0.02 mg/L, with a mean of 0.01 mg/L, which is within the WHO (2011) permissible limits (Figure 8). This suggests that River Gwagwalada water is not significantly polluted by Zn, likely due to rapid biological uptake and limited industrial discharge sources. Comparable findings have been reported for other Nigerian rivers (Akan et al., 2010). Seasonal variation was not

significant (See Figure 8 and Table 3, p = 0.203), indicating relatively stable Zn levels throughout the year. This stability may be attributed to Zn’s strong adsorption to sediments and its rapid geochemical stabilization in aquatic systems, limiting its mobility in the water column. Similar low and seasonally stable Zn concentrations have been reported in rivers with limited industrial discharge (Boral et al., 2020)

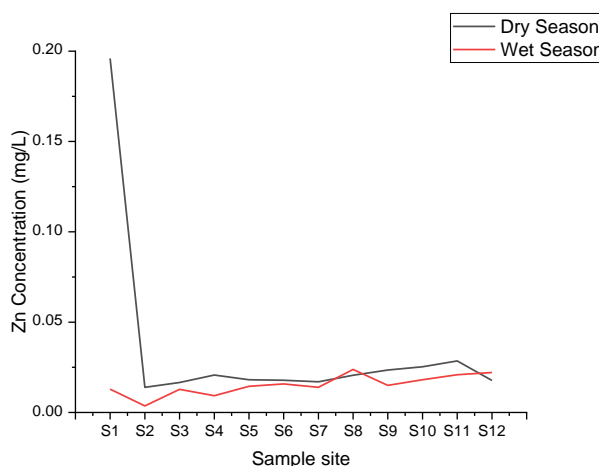


Figure 8: Variation of Zinc Concentration in Water Sample along River Gwagwalada Course

Seasonal Variation of Heavy Metals in Water

ANOVA results (Table 3) indicate statistically significant seasonal variation for Co, Cr, Mn, and Ni (p < 0.05), while Cd, Fe, and Zn showed insignificant seasonal variation. Increased concentrations during the dry season for Cr and Mn

reflect reduced dilution and increased evaporation, while elevated rainy-season Ni and Co concentrations are linked to surface runoff and flooding effects. Similar seasonal trends have been reported in tropical river systems (Aderinola et al., 2009; Akan et al., 2010).

Table 3: ANOVA Results for Seasonal Variation of Heavy Metals in Water Samples of River Gwagwalada

		Sum of Squares	df	Mean Square	F	Sig.
Cd	Between Groups	.000	1	.000	.086	.772
	Within Groups	.006	22	.000		
	Total	.006	23			
Co	Between Groups	.124	1	.124	58.086	.000
	Within Groups	.047	22	.002		
	Total	.171	23			
Cr	Between Groups	20.431	1	20.431	70.574	.000

		Sum of Squares	df	Mean Square	F	Sig.
	Within Groups	6.369	22	.289		
	Total	26.800	23			
Fe	Between Groups	2.290	1	2.290	4.634	.043
	Within Groups	10.870	22	.494		
	Total	13.160	23			
Mn	Between Groups	.110	1	.110	102.169	.000
	Within Groups	.024	22	.001		
	Total	.133	23			
Ni	Between Groups	7.752	1	7.752	1917.452	.000
	Within Groups	.089	22	.004		
	Total	7.841	23			
Zn	Between Groups	.002	1	.002	1.720	.203
	Within Groups	.029	22	.001		
	Total	.031	23			

CONCLUSION

This study assessed the concentrations and seasonal variations of selected heavy metals in River Gwagwalada, Abuja, Nigeria. The results revealed that the river is contaminated with several heavy metals, with the mean concentrations of Cd, Co, Cr, Fe, and Ni exceeding the World Health Organization (WHO, 2011) permissible limits for drinking water, while Mn and Zn remained within the recommended limits. Spatial variations in metal concentrations were observed across the sampling stations, reflecting the influence of diverse anthropogenic activities, including agricultural practices, domestic waste disposal, sewage discharges, sand mining, car-wash operations, mechanic workshop runoff, and other urban activities occurring along the river course.

Statistical analysis showed significant seasonal variations in the concentrations of Co, Cr, Mn, Ni, and Fe between the rainy and dry seasons, indicating that seasonal factors such as surface runoff, dilution effects, sediment resuspension, and fluctuations in anthropogenic inputs influence the distribution of these metals in the river system. The elevated concentrations of several metals above guideline values suggest ongoing environmental pressure on the river and highlight the need for effective pollution control and watershed management strategies.

To improve water quality and reduce further contamination, regular monitoring programmes should be established by relevant environmental regulatory agencies, including the National Environmental Standards and Regulations Enforcement Agency (NESREA), the Abuja Environmental Protection Board (AEPB), and the Gwagwalada Area Council. Efforts should focus on controlling indiscriminate waste disposal, regulating effluent discharges, and promoting sustainable land-use practices within the watershed. Future studies should incorporate increased sampling frequency, broader spatial coverage, and the inclusion of additional priority metals such as Pb, Hg, As, and Cu to provide a more comprehensive assessment of heavy metal contamination in River Gwagwalada. Furthermore, future investigations should include formal testing of statistical assumptions and long-term monitoring programmes to strengthen the evaluation of temporal variations and support evidence-based management of the river system.

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