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Aminu Ja'afar Adano
Department of Geography, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria

Nengak Danjuma Marcus
Department of Geography, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria

Joshua Ibrahim Magaji
Department of Geography, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria

Obaje Daniel Opaluwa
Department of Chemistry, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria, obajeo@nsuk.edu.ng

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Assessment of Seasonal Variation in Heavy Metal Status of a Lotic Ecosystem in Federal Capital Territory, Abuja, North Central Nigeria

Aminu Ja'afar Adano[1], Nengak Danjuma Marcus[1], Joshua Ibrahim Magaji[1], and Obaje Daniel Opaluwa[2*]

1. Department of Geography, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria
2. Department of Chemistry, Nasarawa State University, Nasarawa State P.M.B 1022, Nigeria

[*]*E-mail: obajeo@nsuk.edu.ng*

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Abstract

The concentrations of Cu, Zn, Fe, Cd, Co, Cr, and Mn and their seasonal variations in water samples from the Wupa River, Abuja, Nigeria, were studied through the atomic absorption spectrophotometric method to determine the suitability of the water for domestic usage and identify potential sources of contamination. Sixty samples were collected during both dry and wet seasons. The respective metal concentrations (in mg/dm^3) in the dry and wet seasons were as follows: Cu (0.023 ± 0.022, 0.023 ± 0.026), Zn (0.104 ± 0.039, 0.158 ± 0.085), Fe (0.350 ± 0.097, 0.3630.103), Cd (not detectable), Co (not detectable), Cr (0.003 ± 0.003, 0.004 ± 0.004), and Mn (0.120 ± 0.132, 0.110 ± 0.099). Among these metals, Cu, Zn, Cr, and Mn occurred in concentrations below the tolerable limits recommended by Nigeria Standard for Drinking Water Quality and WHO, whereas Fe exceeded these limits, and Cd and Co were not detectable. The calculated heavy metal pollution index values (68.22 in the dry season and 63.78 in the wet season) were lower than the critical value (100), indicating low pollution levels in both seasons. The metal index values for both seasons (1.50 for the dry season and 1.55 for the wet season) suggest that the water from the Wupa River was slightly affected by heavy metals. Moreover, no significant differences in metal concentrations existed between the dry and wet seasons. A strong positive correlation occurred between Zn and Fe only during the wet season. Water from the river was polluted with Fe and unsuitable for domestic use. Potential sources of contamination include agricultural areas, industrial effluents, and domestic waste in the wet season, and industrial and domestic sewage in the dry season. To make the river water safe for use, it should be treated and regularly monitored for metal contents, and sources of contamination should be managed appropriately.

Keywords: contamination, heavy metals, pollution, surface water, water

Introduction

Pollution of surface water bodies worldwide has become extremely severe and has therefore raised serious concerns, as life depends on it [1]. Heavy metals are one of the primary pollutants in the environment, particularly in urban and semi-urban areas [2].

Contamination of surface water bodies by heavy metals is attributable to either natural processes or human activities [3]. The discharge of these heavy metals into water bodies poses severe pollution problems because the metals can be toxic even at low concentrations, are non-biodegradable, and can bioaccumulate in biological systems [4]. Heavy metals present in surface water pose significant health hazards, particularly when present in drinking water, as they can be harmful and even enter the food chain [3]. The health challenges associated with these heavy metals include retarded growth and development, reduced haemoglobinhemoglobin levels, damage to internal organs and the nervous system, and in some cases, the effects can be lethal [5, 6].

Heavy metals can exist in water bodies in soluble forms (compounds or free ions) or particulate forms (colloidal or adsorbed to suspended solids). Metals in these different forms exhibit varying degrees of biological toxicity and environmental behavior. For instance, the free hydrate ion of many metals can cause severe metal toxicity in aquatic organisms [5]. In surface aquatic ecosystems, suspended solids feature a higher percentage of heavy metal concentrations. However, constant interaction exists between the particulate-bound form of heavy metals and the soluble or dissolved form. These two forms together contribute to the total metal concentrations in surface water and can be responsible for potential health hazards.

Several researchers have investigated the heavy metal status of surface water bodies. For example, researchers have assessed heavy metal contamination in Saguiling Reservoir water in West Java province, Indonesia [2]; examined seasonal and spatial variations of heavy metals in two typical Chinese rivers, considering concentrations, environmental risks, and possible sources [7]; determined heavy metals in Nairobi Dam waters in Kenya [3]; and evaluated heavy metal pollution of water and sediments in Mada River, Nigeria [8].

Information on the heavy metal load of the Wupa River in the Federal Capital Territory (FCT), Abuja, north-central Nigeria, is limited. The river could be described as an urban river, as it is part of the Jabi watershed and originates from the foot of Aso Rock, flows through the Millennium Park, the city center to Wuye, and beyond, all within FCT, Abuja. Consequently, it serves as the point of discharge for domestic and industrial wastes and runoff from agricultural lands. These wastes and runoff are sources of heavy metals and contribute to elevated levels of metals in the water from the Wupa River. The research aims to assess the heavy metal contents of the water from the river and determine its suitability for domestic and industrial purposes. The specific objectives are to measure the concentrations of heavy metals in water samples and determine whether there are seasonal variations in the levels of these metals between the dry and wet seasons to provide insight into the sources of contamination.

Materials and Methods

Study area. The study area was FCT, Abuja, located in north-central Nigeria. Abuja is situated between latitude 8º58'30" to 9º7'30"N and longitude 7º19'30" to 7º31'30"E. The Wupa River is a part of the Jabi watershed in Abuja, originating from the base of Aso Rock within the city and flowing through the metropolis down to the Idu Industrial Layout (Figure 1). The river receives heavy inflows of waste from both point and non-point sources, particularly during the wet season. Point sources of pollution include the discharge of domestic and industrial sewage and various human activities along the riverbanks, such as those originating from the Wupa sewage treatment plant, industries within the layout, car washes, block molding operations, and auto mechanic workshops. It also receives discharges from numerous unplanned communities along its banks. Non-point sources of pollution are runoff from irrigation and other agricultural farmlands, which are consistently released into the water body.

Sample collection and preparation. Water samples were collected during two seasons: January 2019 for the dry season and September 2019 for the rainy season. A total of 60 water samples were collected from 10 points, each ~0.5 km apart. These samples were taken from a depth of 5.0 cm below the water surface to minimize contamination by surface films. Each sample was carefully

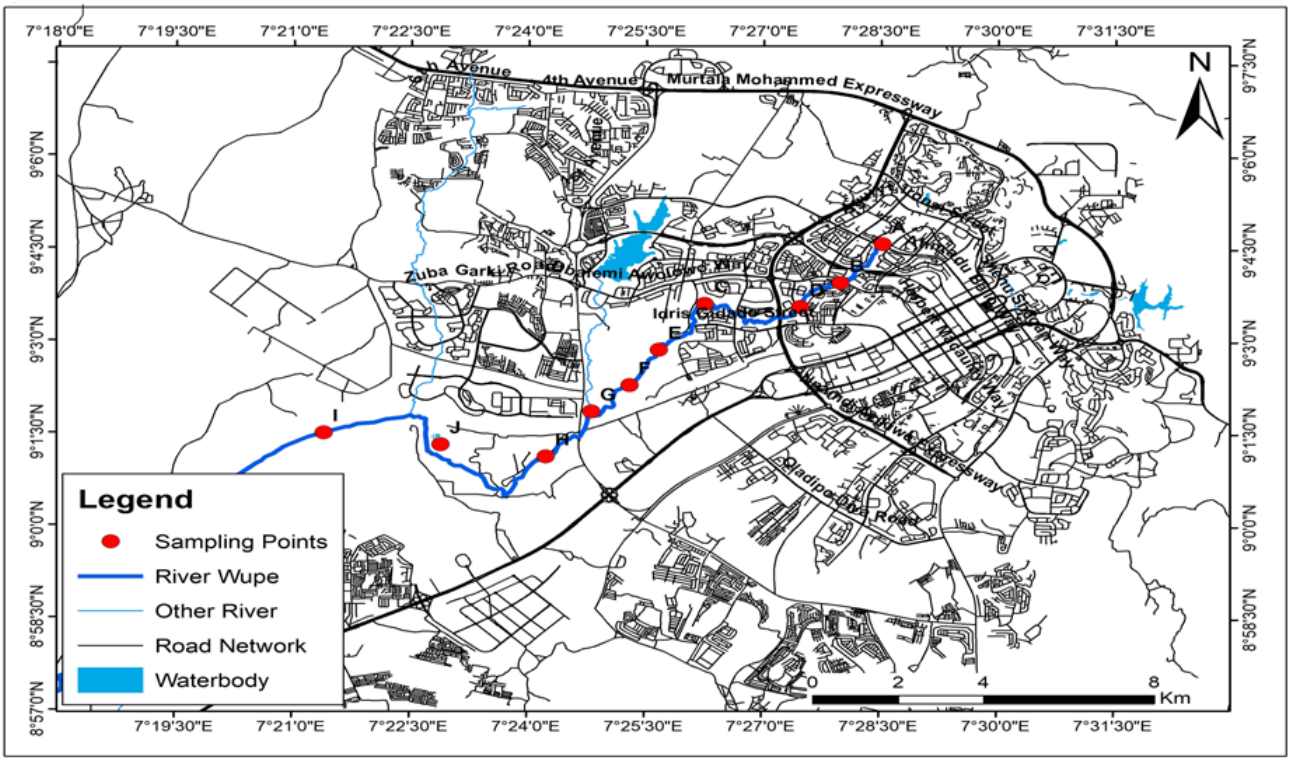

Figure 1. Map of Federal Capital Territory, Abuja, Nigeria, Showing the Wupa River

transferred into prewashed 1.0 dm^3 plastic bottles that had been rinsed with concentrated HNO_3 to prevent the adsorption of metal ions from the water onto the container walls.

To process the samples, they were thoroughly mixed via shaking. Subsequently, 100.00 cm^3 of the sample was measured into a glass beaker, and 5.00 cm^3 of concentrated HNO_3 was added. The beaker was placed on a hot plate and allowed to evaporate until it reduced to about one-fifth of its initial volume (20 cm^3). The beaker was then allowed to cool, and an additional 5.00 cm^3 of concentrated HNO_3 was introduced. The beaker was covered with a watch glass and returned to the hot plate. The heating continued until the solution became light-colored and clear. Then, the sample was brought down and allowed to cool. The sample was then filtered through Whatman No. 1.0 filter paper. The filtrate was adjusted to the specified mark in a 100.00 cm^3 volumetric flask using deionized water and set aside for metal analysis [9, 10].

Determination of metals in water. The concentrations of Cu, Zn, Fe, Cd, Co, Cr, and Mn in the water samples were determined with an atomic absorption spectrophotometer (Model No. AA280FS) manufactured by Agilent Technologies, USA.

Pollution indices. Pollution indices are utilized to assess heavy metal contamination. In this study, the heavy metal pollution index (HMPI) and metal index (MI) were used.

Heavy metal pollution index. Countries, institutions, and organizations typically provide recommended standard values to determine the suitability of water for various uses. These standards are typically established for individual metals, making it challenging to understand the cumulative pollution caused by all metals. However, the HMPI is a comprehensive tool used to assess water quality according to all metals present. The assessment technique involves ranking, to provide information on the influence of each metal on the overall water quality. The ranking scale ranges from 0 to 1 and indicates the relative importance of individual quality considerations, and the ranking scale is inversely proportional to the permissible value (*S*i) for each metal [11].

The stages involved in calculating the HMPI include evaluating the unit weight of the ith parameter, determining the quality rating for each metal, and then summing these sub-indices to obtain the overall index.

$$\mathrm{Wi} = \frac{\mathrm{k}}{\mathrm{Si}} \tag{1}$$

*W*i = unit weight, *S*i = recommended standard for the parameter, and *k* is the proportionality constant. Individual quality rating for each metal is as given below.

$$\mathrm{Qi} = \frac{100 \times \mathrm{Ci}}{\mathrm{Si}} \tag{2}$$

where *Q*i = sub-index of ith parameter, *C*i = concentration of the ith heavy metal, *S*i = permissible limit for the ith parameter, and 100 is the critical pollution index value.

$$\mathrm{HMPI} = \frac{\sum(\mathrm{Qi} \times \mathrm{Wi})}{\sum \mathrm{Wi}} \tag{3}$$

HMPI = heavy metal pollution index, *Q*i = sub-index of the ith parameter; *W*i = unit weight of the ith parameter [11].

Metal index. The MI for potable water proves the possible addictive effect of heavy metals on human health, which is critical in the determination of the overall water quality. MI is expressed as the ratio of the metal concentrations in water samples to the recommended permissible standard limit [11] as given below:

$$MI = \sum \frac{Mi}{Si} \tag{4}$$

where *M*i = mean metal concentration in water samples, and *S*i = maximum recommended standard limit.

When the concentration of metal is higher than the maximum recommended standard limit, the quality of water is worse. MI > 1 is the normal threshold for warning. Evaluation of the metal pollution index helps to ascertain the quality and suitability of water for drinking and industrial purposes.

The MI scale is as follows: < 0.3 = very pure, 0.3–1 = pure, 1–2 = slightly affected, 2–4 = moderately affected, 4–6 = strongly affected and > 6 = seriously affected [11].

Quality control/quality assurance. To ensure accurate results, several measures were implemented. These included the use of blank preparations and the repetition of sample analysis. Blanks were subjected to the same digestion methods for total metal concentrations, with the only distinction being the absence of a sample. This step was essential to validate the digestion method. The repetition of sample analysis involved reanalyzing a sample, for instance, after the analysis of every five samples, the fifth sample was retested. This practice was maintained throughout the entire analysis to determine whether the repeated sample results were consistent with the earlier results, thus testing the validity of the readings obtained from the atomic absorption spectrophotometer. Furthermore, the chemicals used were of analytical grade, and all glassware was washed thoroughly before use.

Results and Discussion

Metal concentrations. Table 1 presents the values of different heavy metal contents in water samples collected from the Wupa River, FCT, Abuja, Nigeria, during both the dry and wet seasons. Table 2 presents the recommended tolerable limits by Nigeria Standard for Drinking Water Quality (NSDWQ) and WHO, along with associated health implications.

During the dry season, the mean copper concentration in the water samples was 0.023 ± 0.022 mg/dm^3, which is lower than the mean value of 0.06 mg/dm^3 observed in the dry season for water from Etche River in Rivers State, Nigeria [12]. Furthermore, the mean copper concentration in this study is significantly below the range of concentrations (0.07 ± 0.01 to 0.23 ± 0.02 mg/dm^3) reported for water sources in Ado Ekiti, Nigeria [13]. In the wet season, the concentration of copper was measured at 0.023 ± 0.026 mg/dm^3. This mean value is lower than the mean values of 0.05 ± 0.01 mg/dm^3 and 0.26 mg/dm^3 recorded for copper in water during the wet season from the Qua-Iboe River, South-South, Nigeria [14], and the Calabar River, Cross River, Nigeria [15], respectively. The copper concentrations in water from the Wupa River in both the dry and wet seasons were low, attributable to the absence of activities that typically lead to elevated copper levels along the river, such as mining, agricultural practices involving the use of pesticides and fungicides, and the wear of automotive brake pads. Moreover, the copper concentrations in both seasons were well below the tolerable limits recommended by NSDWQ and WHO.

The mean concentration of zinc (Zn) in the water samples was 0.104 ± 0.039 mg/dm^3 in the dry season. This mean Zn concentration exceeds the range of values (0.010 ± 0.002 mg/dm^3 to 0.080 ± 0.008 mg/dm^3) reported for water from the Middleton River in the Niger Delta, Nigeria, in the dry season [16]. It also surpasses the range of Zn concentrations (0.0184–0.06 mg/dm^3) observed for water from the Calabar River, Cross River, Nigeria, in the dry season [15]. During the wet season, Zn in the Wupa River water had a mean concentration of 0.158 ± 0.085 mg/dm^3. This mean value is higher than the range values (0.00 ± 0.00 mg/dm^3 to 0.027 ± 0.003 mg/dm^3) recorded for water from the Middleton River, the Niger Delta, Nigeria, during the wet season [16]. However, it is lower than the range values (40.00 ± 11.00 mg/dm^3 to 190.00 ± 47.00 mg/dm^3 and 59.00 ± 18.00 mg/dm^3 to 257.00 ± 152.00 mg/dm^3) for Zn in water during the wet season from Taipu River and Wusong River, both located in China [7]. The Zn content in water from the Wupa River was generally low during both the dry and wet seasons. However, it has the potential to accumulate over time owing to the discharge of domestic wastewater and runoff from irrigation farmlands along the river. The Zn contents of water from the Wupa River fell within the recommended tolerable limits set by regulatory bodies.

The mean concentration of iron (Fe) in the Wupa River water during the dry season was 0.350 ± 0.097 mg/dm^3, which is lower than the mean values of 6.04, 3.97, and 7.73 mg/dm^3 obtained for water samples from three rivers in Nasarawa, Nigeria, during the dry seasons [17]. The range value for Fe in the water from Tanda Dam, Kohat [18] (1.745–2.443 mg/dm^3) was higher than those obtained in this research work. During the wet season, the mean concentration of Fe in the Wupa River water was 0.363 ± 0.103 mg/dm^3. In comparison, the mean values of Fe in water samples from three rivers in Nasarawa, Nigeria, during the wet season were 5.75, 2.41, and 6.73 mg/dm^3 [17]. Additionally, the Fe concentration reached 179.49 ± 21.45 mg/dm^3 in water and associated sediments from the Ajawere River in Oke-Osun farm settlement, Osogbo, Nigeria, during the wet season [19]. These values

Table 1. Heavy Metal Concentrations (mg/dm^3) of Water Samples from the Wupa River, Abuja, in Dry, and Wet Seasons

Parameters	Dry Season					Wet Season					*(p < 0.05)*
	Min.	Max.	Mean	SD	CV (100%)	Min.	Max.	Mean	SD	CV (100%)	
Copper	0.007	0.080	0.023	0.022	97.69	0.008	0.090	0.023	0.026	111.20	0.090
Zinc	0.050	0.190	0.104	0.039	37.43	0.080	0.300	0.158	0.085	53.77	0.496
Iron	0.200	0.500	0.350	0.097	27.77	0.200	0.500	0.363	0.103	28.33	0.217
Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	ND	210.82	0.000
Cobalt	ND	ND	ND	ND	ND	ND	ND	ND	ND	210.82	0.000
Chromium	0.003	0.006	0.003	0.003	73.63	ND	0.012	0.004	0.004	104.10	0.476
Manganese	0.200	0.300	0.120	0.132	109.71	ND	0.300	0.110	0.099	90.40	0.495

SD = Standard Deviation, CV = Coefficient of Variation, ND = Not Detected

Table 2. Mean Heavy Metal Concentrations (mg/dm^3) of Water from the Wupa River and the Recommended Limit by Regulatory Bodies

Parameters	Mean Values from Present Work		NSDWQ [26]	WHO [6]	Health Impact (NSDWQ)
	Dry Season	Wet Season			
Copper	0.023 ± 0.022	0.023 ± 0.026	1.000	2.000	Gastrointestinal disorder
Zinc	0.104 ± 0.039	0.158 ± 0.085	3.000	5.000	None
Iron	0.350 ± 0.097	0.363 ± 0.103	0.300	0.300	None
Cadmium	NA	NA	0.003	0.003	Toxic to the kidney
Cobalt	NA	NA	-	0.100	None
Chromium	0.003 ± 0.003	0.004 ± 0.004	0.050	0.050	Cancer
Manganese	0.120 ± 0.132	0.110 ± 0.099	0.200	0.50	Neurological disorder

are all higher than the mean concentration in our present research. Furthermore, the range values for Fe in the water from Tanda Dam, Kohat [18] (1.745–2.443 mg/dm^3) also exceeded the mean value obtained in our research. The Fe content in water from the Wupa River during both the dry and wet seasons was slightly high, attributable to the presence of Fe-bearing soil or rock along the river's course and the discharge of domestic waste and runoff. The concentrations of Fe in water for both seasons exceed the tolerable limits recommended by NSDWQ and WHO. Consequently, the water can be considered polluted by Fe.

The concentrations of cadmium and cobalt in water from the Wupa River during the dry season were below detection limits. In contrast, Awash River water in Ethiopia displayed concentrations ranging from 0.05 ± 0.02 to 0.24 ± 0.05 mg/dm^3 for cadmium during the dry season [20]. Dams in Plateau State, north-central Nigeria, also had cobalt concentrations in the range of 0.04 ± 0.04 to 0.11 ± 0.10 mg/dm^3 during the dry season [21]. Furthermore, water sources in the South of Najaf City, Iraq, featured mean concentrations of 0.0286 mg/dm^3 for cadmium and 0.0089 mg/dm^3 for cobalt [22]. In the wet season, the concentrations of cadmium and cobalt in water from the Wupa River remained below detection limits. In contrast, the Mada River in Nigeria exhibited a value of 0.007 ± 0.002 mg/dm^3 for cadmium during the wet season [8], and the value for cobalt was below the detection limit in water from the Middleton River, the Niger Delta, Nigeria [16]. Additionally, during the wet season, the Qua-Iboe River in South-South, Nigeria, exhibited mean concentrations of 0.09 ± 0.02 mg/dm^3 for cadmium, and water from dams in Plateau State, Nigeria, displayed cobalt concentrations of 0.01 ± 0.01 to 0.03 ± 0.01 mg/dm^3 [21].

In the dry season, the mean concentrations of chromium and manganese in the Wupa River water were 0.003 ± 0.003 and 0.120 ± 0.132 mg/dm^3, respectively. These values are lower than the mean concentrations of chromium (0.13 ± 0.03) and manganese (0.20 ± 0.12 mg/dm^3) in water from Mada River, Nigeria, during the dry season [8]. Moreover, the mean values for the metals in the present study were lower than the mean values for chromium and manganese (0.187 and 0.755 mg/dm^3, respectively) in water from the Nzhelele River, South Africa [23], during the dry season. In the wet season, the mean concentrations of chromium and manganese in Wupa River water were 0.004 ± 0.004 and 0.110 ± 0.099 mg/dm^3, respectively. For water from the Calabar River, Cross River, Nigeria, during the wet season, chromium was below detection limits, while the mean concentration of manganese was 0.65 mg/dm^3, which is higher than the values obtained in the present study [15]. Furthermore, our mean concentrations for chromium and manganese are lower and higher than the mean concentrations of chromium and manganese (0.04 ± 0.00 mg/dm^3 and 0.07 ± 0.02 mg/dm^3, respectively) recorded during the wet season in water from the Mada River, Nigeria [8]. The concentrations of chromium and manganese in the water during both seasons fall within the tolerable limits recommended by NSDWQ and WHO.

Seasonal variations. Figure 2 displays a bar chart illustrating the seasonal variations in the concentrations of heavy metals determined in water samples from the Wupa River.

No significant difference in copper concentrations existed between the wet season and the dry season, as indicated by the statistical value of 0.090 ($p < 0.05$). This lack of variation is attributable to the continuous indiscriminate discharge of domestic waste, a major source of copper, into the water body. Interestingly, this finding contrasts with the report on copper levels in Awash River, Ethiopia [20].

Furthermore, the results indicated a slight difference in Zn concentrations between the seasons, but this difference

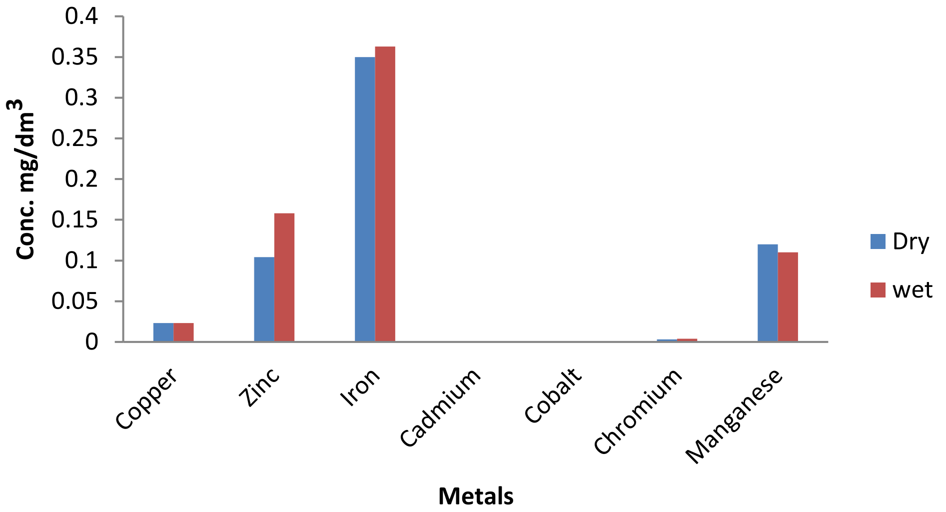

Figure 2. Seasonal Variation in Metal Concentrations of Water from the Wupa River

is not statistically significant, as evidenced by the statistical value of 0.496 ($p < 0.05$). Zinc concentrations during the wet season were slightly higher than those during the dry season, possibly due to runoff from irrigated farmlands and other contaminated areas entering the Wupa River during the wet season. This slight seasonal difference in metal concentrations in this study contradicts the report on Zn (not detected) in water from River Mkomon, Benue State, Nigeria [24].

The results indicated that the Fe concentration in the wet season is slightly higher than that in the dry season, as revealed by the statistical value of 0.217 ($p < 0.05$). This value suggests no significant difference between the dry and wet seasons. However, the slight difference in seasonal metal concentrations, with higher values in the wet season, is attributable to runoff discharged into the river during the season. This higher Fe concentration of water in the wet season than in the dry season aligns with the report on Fe levels in water from the Qua-Iboe River in South-South Nigeria during both wet and dry seasons [14].

In both the dry and wet seasons, the levels of cadmium and cobalt in the water samples from the Wupa River were below detectable limits, indicating that these two heavy metals were present at concentrations below the detection limits.

Chromium concentration in the wet season is slightly higher than that in the dry season. However, the statistical value of 0.476 ($p < 0.05$) indicates that no significant difference existed between the seasons. This minor variation in concentration, with higher values in the wet season, is attributable to runoff discharged into the river during the season. This higher chromium concentration of water in the wet season than in the dry season is consistent with the report on Fe levels in the water from the Qua-Iboe River during both wet and dry seasons [14].

The manganese concentration recorded in the dry season was slightly higher than that in the wet season, possibly because the reduced water volume led to metal ion concentration. However, the differences in metal concentrations between seasons were not significant, as shown by the statistical value of 0.495 ($p < 0.05$). This seasonal difference in metal concentrations, with higher values in the dry season than in the wet season, aligns with the report on the mean metal concentrations of manganese during dry and wet seasons [23].

Pollution indices. Table 3 displays the HMPI for water samples collected from the Wupa River during both the dry and wet seasons, while Table 4 presents the MI for the same water samples. HMPI was used to characterize the water from the Wupa River in both seasons. The results were compared with a critical value to assess the extent of heavy metal pollution in the water body. The calculated HMPI values for the wet and dry seasons were 68.22 and 63.78, respectively, which are lower than the critical value of 100, indicating a low level of heavy metal pollution. The MI values obtained for the dry and wet seasons were 1.50 and 1.55, respectively. These values indicate that the water quality in both seasons was slightly affected by heavy metals, according to the MI scale.

Correlation study. The correlation matrices for metals in the dry and wet seasons are presented in Tables 5 and 6, respectively. For heavy metals in the dry season, no strong correlations existed between the parameters. However, for the wet season, a strong positive correlation existed between Zn and Fe, with a correlation coefficient (r) of 0.729. Water from the Awash River, Ethiopia, exhibited a similar correlation between Zn and Fe [20]. This strong correlation is attributable to the metals sharing a similar oxidation state and reacting similarly in an aqueous environment. These metals possibly coexist in mineral ore and are leached into the aquatic environment during the wet season [25]. Additionally, they may have common sources, such as surface runoff from farmlands with heavy agrochemical and fertilizer use and indiscriminate waste discharge into aquatic systems.

Table 3. Mean HMPI of Water in the Study Area

Metals	Mean Metal Conc. (mg/dm^3)		Highest Permissible Value (Si) (mg/dm^3)	Unit Weight (Wi)	Sub-index Qi		Wi × Qi	
	Dry Season	Wet Season			Dry Season	Wet Season	Dry Season	Wet Season
Copper	0.023	0.023	1.00	1.00	2.30	2.30	2.30	2.30
Zinc	0.104	0.158	5.00	0.20	2.08	3.16	0.42	0.63
Iron	0.350	0.363	0.30	3.33	116.67	121.00	388.51	402.93
Cadmium	ND	ND	0.03	33.33	NA	NA	NA	NA
Cobalt	ND	ND	-	-	NA	NA	NA	NA
Chromium	0.003	0.004	0.05	20.00	6.00	8.00	120.00	160.00
Manganese	0.120	0.110	0.05	20.00	240.00	220.00	4800.00	4400.00
				$\sum Wi = 77.86$			$\sum WiQi = 5{,}311.23$	$\sum WiQi = 4{,}965.86$

HMPI = $\frac{\sum WiQi}{\sum Wi}$; HMPI for Dry Season = 68.22; and HMPI for Wet Season = 63.78

Table 4. Metal Index for Water Samples in Dry and Wet Seasons

Metals	Dry Season	Wet Season
Cu	0.01	0.01
Zn	0.02	0.03
Fe	1.17	1.21
Cd	NA	NA
Co	NA	NA
Cr	0.06	0.08
Mn	0.24	0.22
MI	**1.50**	**1.55**

Table 5. Correlation Matrix for Heavy Metals in Water in Dry Season

	Cu	Zn	Fe	Cd	Co	Cr	Mn
Cu	1.000						
Zn	−0.033	1.000					
Fe	−0.231	−0.142	1.000				
Cd	−0.089	0.493	0.355	1.000			
Co	0.504	−0.187	−0.271	−0.327	1.000		
Cr	0.303	0.437	−0.091	−0.018	0.337	1.000	
Mn	−0.465	0.252	0.174	−0.280	0.120	0.142	1.000

Table 6. Correlation Matrix for Heavy Metals in Water in Wet Season

	Cu	Zn	Fe	Cd	Co	Cr	Mn
Cu	1.000						
Zn	−0.244	1.000					
Fe	−0.491	**0.729**	1.000				
Cd	0.024	−0.417	−0.579	1.000			
Co	−0.077	0.222	0.446	−0.250	1.000		
Cr	0.156	0.035	−0.022	−0.155	0.408	1.000	
Mn	0.292	−0.047	−0.253	−0.318	0.212	0.668	1.000

Conclusions

Heavy metals such as Cu, Zn, Fe, Cd, Co, Cr, and Mn in water samples from the Wupa River during both the dry and wet seasons were analyzed using an atomic absorption spectrophotometer. Cd and Co were not detectable. The concentrations of Cu, Zn, Fe, Cr, and Mn in water samples were below the tolerable limits recommended by NSDWQ and WHO. However, the concentration of Fe was higher, indicating pollution of the river water with Fe. Moreover, no significant differences in metal concentrations existed between the dry and wet seasons. The calculated HMPI values indicated low pollution levels in both seasons, and the MI values for both seasons suggested that the water from the Wupa River was slightly affected by heavy metals. In the correlation study for both the dry and wet seasons, a strong positive correlation existed only between Zn and Fe during the wet season. Considering the location of the river and the activities along its banks, potential sources of contamination include agricultural areas, industrial effluents, and domestic waste during the wet season, and industrial and domestic sewage during the dry season. The water from the Wupa River is not safe for domestic use owing to its high Fe content. Therefore, regular water quality monitoring and treatment are essential before use.

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Conflict of Interest

The authors declared that there is no conflict of interest.

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