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Heavy Metal Contamination in Water and Sediments of the Gongola River Complex, Nigeria: A Seasonal and Spatial Assessment

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ABSTRACT

Heavy metal contamination poses a significant threat to aquatic ecosystems globally. This study investigates the presence and seasonal variations of heavy metals (Cd, Cr, Pb, Ni, Fe, Cu, As, Mn) in water and sediment samples from two anthropogenically impacted corridors (Almakashi and Gwani) of the Gongola River, Nigeria, using Balanga Dam as a reference site. Water and sediment samples were collected over a 12-month period covering dry and wet seasons and analyzed using Atomic Absorption Spectrophotometry. Results indicate that while most metal concentrations in water and sediments were within permissible limits set by NESREA and WHO, spatial and seasonal variations were significant. Almakashi corridor exhibited the highest mean concentrations for most metals in water, notably Cd (5.07 µg/L) and Ni (9.10 µg/L), while the highest Fe concentration (50.57 µg/L) was found at Balanga Dam. Sediment analysis revealed higher accumulations of Ni, As, and Mn in the river corridors compared to the dam, with concentrations peaking during the dry season. Statistical analysis ($p < 0.05$) confirmed significant differences in contamination levels between the reference dam and the river corridors. The study concluded that the elevated metal concentrations in Almakashi and Gwani signal growing anthropogenic pressure,

1. INTRODUCTION

Heavy metal contamination in aquatic environments is a global concern due to its toxicity, persistence, and potential for bioaccumulation [1]. Rivers are vital resources, but urbanization, industrial activities, and agricultural runoff introduce heavy metals into these systems, posing risks to environmental and human health [2]. The Gongola River, a major tributary of the Benue River in northeastern Nigeria, supports diverse ecological and human activities. The Gongola River, situated in northeastern Nigeria, stands as the primary tributary of the Benue River. The upper course of the river and most of its tributaries are characterized by seasonal streams that swiftly fill up in August and September [3].

The river exhibits a seasonal flow pattern that is influenced by rainfall, with high water levels during the rainy season and low flow during the dry season). During the rainy season, the Gongola River often overflows its banks, creating extensive floodplains that support agriculture and diverse ecosystems. These floodplains are crucial for local agriculture, providing fertile soil for crops [4].

The river and its floodplains are extensively used for irrigation and agriculture, supporting crops like rice, maize, and vegetables. The fertile soils of the floodplains are crucial for local food production. Furthermore, The seasonal floodplains provide critical habitats for many species. Generally, the Gongola River basin is home to diverse flora and fauna, including aquatic species, riparian vegetation, and terrestrial wildlife [4].

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The Almakashi and Gwani corridors within this complex are of particular interest due to potential pollution from surrounding agriculture, industry, and domestic waste [5], [6].

Anthropogenic activities in the region, including farming with agrochemicals and discharge of domestic and industrial effluents, contribute pollutants to the river corridors [7], [8]. These activities have been linked to a decline in fish catches, raising concerns about the health of the aquatic ecosystem [6], [9]. Despite its importance, there is limited research on heavy metal contamination in the Gongola River, specifically in the Almakashi and Gwani corridors [3], [5].

This study was undertaken to investigate the presence and seasonal variations of heavy metals in water and sediment from these corridors compared to Balanga Dam. The justification is to establish baseline contamination levels in order to inform conservation efforts, policy-making, and future scientific investigations.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Gongola River basin in northeastern Nigeria. The river originates from the Jos Plateau and flows into the Benue River. The climate is characterized by distinct dry (November-April) and wet (May-October) seasons. Three locations were selected:

- Almakashi Corridor (10°44'38.15"N, 11°30'02.13"E): A major fish landing site influenced by agricultural and industrial runoff.
- Gwani Corridor (approx. 10°24'N, 11°29'E): Impacted by domestic waste from Gombe metropolis and villages.
- Balanga Dam (approx. 9°47'30"N, 11°27'30"E): Chosen as a reference site due to its relatively pristine conditions and internal water source [3], [10].

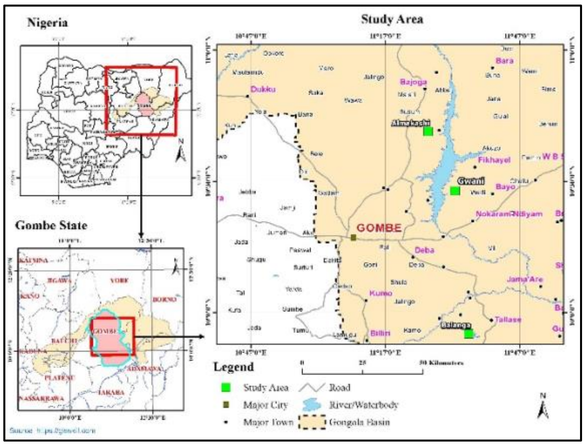

Fig. 1. Gongola River Complex Indicating the Study River Corridors and Balanga Dam

2.2 Sample Collection and Analysis

Sampling was conducted from February 2020 to July 2021. Each water body was divided into three stations (I, II, III) for consistency.

Water Samples: Collected in clean polypropylene bottles, frozen, later thawed, filtered (0.45µm), and analyzed for heavy metals (Cd, Cr, Pb, Ni, Fe) using a Buck-205 Flame Atomic Absorption Spectrophotometer (AASP) following APHA guidelines [11].

Sediment Samples: Collected in polypropylene bottles, dried, ground, and digested with a 3:1 $HCl:HNO_3$ mixture. The digestate was filtered and analyzed for metals (Cu, Cd, Cr, Pb, Ni, As, Mn, Fe) using AASP [11].

Quality Control: Accuracy was checked using Standard Reference Material (NIST 1946) with a recovery range of 95-110% [12]. Results were compared with Nigerian (NESREA) and World Health Organization (WHO) guidelines [13], [14].

2.3 Statistical Analysis

Data were analyzed using SPSS version 22. Normality was tested with the Shapiro-Wilk test. Descriptive statistics (mean ± standard deviation) were computed. One-way ANOVA and Duncan's post hoc tests were used to compare means between locations and seasons. A p-value < 0.05 was considered statistically significant.

3. Results

The metal concentrations of heavy metals in water and sediment were analysed and the results were provided in Tables 1- 4.

3.1 Heavy Metal Concentrations in Water

The heavy metals concentrations found in water column of Almakashi, Gwani and Balanga were Cadmium, Chromium, lead, nickel and Iron and the mean concentrations were given in Table (1, 2 and 3) respectively.

3.1.1 Cadmium (Cd)

In Almakashi, the lowest cadmium concentration ranged from 0.4±0.8 µg/L in May to a highest of 5.07±3.20 µg/L in March (Table 1). In Gwani, the cadmium concentration ranged from a lowest value of 0.55±0.73 µg/L in November to a highest mean of 4.00±5.65 µg/L in January (Table 2). In Balanga dam, the cadmium concentration ranged from a lowest mean of 0.1±0.14 µg/L in January and March to a highest mean of 2.65±3.64 µg/L in the dry season month of April (Table 3). Generally, the highest and lowest mean values of cadmium recorded were 5.07±3.20 µg/L in March at Almakashi (Table 1) and 0.10±0.14 µg/L in January at Balanga dam (Table 3), respectively. The concentration values obtained in Almakashi and Gwani differed significantly from the mean values obtained in Balanga dam ($p < 0.05$).

3.1.2 Chromium (Cr)

The lowest concentration of chromium found in Almakashi was 0.6±0.56µg/L in the month of September while the highest concentration was 8.35±9.35µg/L found in January (Table 1).In Gwani, the lowest concentration of chromium was 0.17±0.35µg/L in the month of February while the highest concentration was 8.9±2.26µg/Lin January (Table 2). The lowest concentration of chromium found in Balanga was 0.05±0.07µg/L in the month of December while the highest concentration was 3.65±6.52µg/L found in June (Table 3). Water samples collected from the Gwani sampling location had the highest chromium concentration in the dry month of January during the study period with 8.90±2.26 µg/L (Table 2), while

0.05±0.07 µg/L was the lowest mean concentration obtained in December (Early dry Season) of the study period at Balanga (Table 3). The concentration values obtained in Almakashi and Gwani differed significantly from the mean values obtained in the reference river ($p < 0.05$).

3.1.3 Lead (Pb)

The lead concentrations in Almakashi ranged from 0.18±0.31 µg/L in July, 0.25±0.28 µg/L in April (Table 1). In Gwani, the lead concentrations were 0.15±0.30 µg/L in July to 1.25±1.94 µg/L in April, and 0.30±0.60 µg/L in June (Table 2). In Balanga, the detected lead concentrations were 0.10±0.14 µg/L in April, 0.52±0.86 µg/L in July, and 0.90±1.14 µg/L in June (Table 3).

Generally, the highest lead concentration was found in Almakashi River corridor (1.25±1.94 µg/L) in April, while most of the months of the study had no recorded value of lead (denoted as 00±00), especially in the dry season. No lead value was detected in Balanga dam in the dry season except the lowest recorded mean concentration of 0.10±0.14 µg/L found in April during late dry season (Table 3). The reference dam of Balanga differed significantly from Almakashi and Gwani ($p < 0.05$) in terms of lead concentrations.

3.1.4 Nickel (Ni)

The range of nickel means value found in Almakashi were 1.90±0.84- 9.10±4.89µg/L in November and March respectively (Table 1). The range of Lead means value in Gwani found was 2.30±0.28-6.35±1.48µg/L in December and November respectively (Table 2).

The lowest and highest mean concentration of nickel was obtained in Balanga sampling location was 1.40±0.42 and 7.2±7.21µg/L in January (dry season) and November (dry season) (Table 3). In general, Almakashi river corridor had the highest nickel concentration of 9.10±4.89 µg/L in the dry season (March) (Table 2), and the lowest mean concentration was recorded during the early-dry season (January) in the reference dam of Balanga (1.40±0.42 µg/L) (Table 3). The nickel concentrations in the reference dam differed significantly from Almakashi and Gwani ($p < 0.05$).

3.1.5 Iron (Fe)

The lowest and highest mean concentration of Iron (Fe) was obtained in Almakashi sampling location was 0.8±0.42µg/L and 23.87±27.39 µg/L in October (late wet season) and July (wet season) (Table 1). The lowest and highest mean concentration of Fe obtained in Gwani sampling location was 2.2±0.92 and 22.67±19.07µg/L in March (late dry season) and May (wet season) respectively (Table 2). Both the lowest and highest mean concentration of iron (Fe) was obtained in Balanga sampling location that ranged from2.4±0.28 µg/Lin January (dry season) to50.57±37.83µg/L in May (wet season) (Table 3).

In general, the highest and lowest mean values of iron was found in early-wet (May) and late-wet (October) seasons respectively, with values of 50.57±37.83 µg/L and 0.80±0.42 µg/L in Balanga dam (Table 3) and Almakashi (Table 1), while Gwani, on the other hand, had 22.67±19.07µg/L in µg/L mean concentrations in May (Table 2). There was a significant difference between the concentration values obtained in the Balanga dam compared to those found in Almakashi and Gwani ($p < 0.05$).

Table 1. Heavy Metals Parameters in Water Column of Almakashi (February, 2020 - July, 2021)

Location	Season	Months	Cd (µg/L)	Cr (µg/L)	Pb (µg/L)	Ni (µg/L)	Fe (µg/L)
Almakashi	Dry	Apr, 2020 and 2021	$4.5±3.07^b$	$7.00±9.09^a$	$1.25±1.94^a$	$5.60±1.57^b$	$5.42±4.02^b$
		Dec, 2020	$1.4±1.97^b$	$1.06±3.35^b$	$0.8±1.13^a$	$3.75±1.62^b$	$6.1±1.27^b$
		Feb, 2020 and 2021	$1.00±1.28^b$	$5.54±5.80^a$	$0.00±0.00^a$	$2.9±1.39^b$	$4.65±2.37^b$
		Jan, 2021	$0.00±0.00^b$	$4.17±2.95^a$	$0.00±0.00^a$	$2.8±0.84^b$	$3.35±1.76^b$
		Mar, 2020 and 2021	$5.07±3.20^b$	$3.30±4.15^b$	$0.00±0.00^a$	$9.10±4.89^a$	$5.42±1.01^b$
		Nov, 2020	$2.55±2.90^b$	$1.06±0.75^b$	$0.00±0.00^a$	$1.90±0.84^b$	$2.35±1.62^b$
	Wet	Aug, 2020	$2.00±2.82^b$	$2.61±4.75^b$	$0.00±0.00^a$	$7.00±5.93^b$	$9.20±0.42^b$
		Jul, 2020 and 2021	$0.92±0.70^b$	$1.77±1.40^b$	$0.18±0.31^a$	$3.80±1.80^b$	$23.87±27.39^a$
		Jun, 2020 and 2021	$0.45±0.9^b$	$5.88±6.07^b$	$0.45±0.90^a$	$3.45±2.23^b$	$21.67±22.57^b$
		May, 2020 and 2021	$0.4±0.8^b$	$8.35±9.35^a$	$0.72±1.45^a$	$4.30±2.67^b$	$9.02±5.25^b$
		Oct, 2020	$0.00±0.00^b$	$1.00±1.00^b$	$0.00±0.00^a$	$8.95±1.06^a$	$0.8±0.42^b$
		Sep, 2020	$0.00±0.00^b$	$0.6±0.56^b$	0.00±0.00a	$4.20±1.55^b$	$5.75±1.34^b$

Keywords: Cu= Copper; Cd= Cadmium; Pb = lead; Ni= Nickel; As= Arsenic; Mn= Manganese; Fe= Iron, 0.000= below detectable limit, NESREA = National Environmental Standard and Regulation Enforcement Agency. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

Table 2. Heavy Metal Parameters in Water Column in Gwani Sampling Location in 2020 and 2021

Location	Season	Months	Cd (µg/L)	Cr (µg/L)	Pb (µg/L)	Ni (µg/L)	Fe (µg/L)
Gwani	Dry	Apr, 2020 and 2021	1.42 ± 2.02^{b}	5.62 ± 5.88^{a}	0.25 ± 0.28^{a}	5.7 ± 4.47^{b}	6.6 ± 4.23^{b}
		Dec, 2020	0.00 ± 0.00^{b}	3.6 ± 1.41^{b}	0.00 ± 0.00^{a}	2.30 ± 0.28^{b}	19.45 ± 13.75^{a}
		Feb, 2020 and 2021	1.07 ± 1.12^{b}	0.6 ± 0.73^{b}	0.00 ± 0.00^{a}	5.35 ± 3.23^{b}	3.47 ± 3.08^{b}
		Jan, 2021	4.00 ± 5.65^{b}	8.9 ± 2.26^{a}	0.00 ± 0.00^{a}	4.10 ± 0.56^{b}	5.95 ± 5.02^{b}
		Mar, 2020 and 2021	2.02 ± 2.39^{b}	1.27 ± 2.55^{b}	0.00 ± 0.00^{a}	3.50 ± 1.29^{b}	2.2 ± 0.92^{b}
		Nov, 2020	0.55 ± 0.77^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}	6.35 ± 1.48^{b}	16.35 ± 21.28^{a}
	Wet	Aug, 2020	0.00 ± 0.00^{b}	2.75 ± 3.88^{b}	0.00 ± 0.00^{a}	5.75 ± 1.20^{b}	7.5 ± 5.65^{b}
		Jul, 2020 and 2021	1.23 ± 2.38^{b}	0.17 ± 0.35^{b}	0.15 ± 0.30^{a}	3.22 ± 1.08^{b}	6.77 ± 3.05^{b}
		Jun, 2020 and 2021	1.42 ± 1.70^{b}	5.8 ± 6.70^{b}	0.30 ± 0.60^{a}	4.32 ± 1.89^{b}	22.5 ± 22.87^{b}
		May, 2020 and 2021	1.15 ± 0.98^{b}	8.67 ± 9.60^{a}	0.00 ± 0.00^{a}	2.95 ± 1.78^{b}	22.67 ± 19.07^{b}
		Oct, 2020	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}	2.7 ± 1.13^{b}	4.75 ± 1.90^{b}
		Sep, 2020	1.55 ± 0.21^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}	3.05 ± 2.89^{b}	5.65 ± 2.19^{b}

Keywords: *= Significant effect, Cu= Copper; Cd= Cadmium; Pb = lead; Ni= Nickel; As= Arsenic; Mn= Manganese; Fe= Iron, 0.000= below detectable limit, NESREA = National Environmental Standard and Regulation Enforcement Agency. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

Table 3. Heavy Metal Parameters in Water Column Collected from Balanga dam in 2020 and 2021

Location	Season	Months	Cd (µg/L)	Cr (µg/L)	Pb (µg/L)	Ni (µg/L)	Fe (µg/L)
Balanga	Dry	Apr, 2020 and 2021	2.65 ± 3.64^{b}	0.75 ± 0.99^{b}	0.1 ± 0.14^{a}	5.72 ± 2.21^{b}	17.15 ± 6.54^{a}
		Dec, 2020	1.15 ± 1.62^{b}	0.05 ± 0.07^{b}	0.00 ± 0.00^{a}	6.50 ± 3.11^{b}	8.35 ± 4.03^{b}
		Feb, 2020 and 2021	1.35 ± 0.36^{b}	1.32 ± 1.52^{b}	0.00 ± 0.00^{a}	3.92 ± 2.52^{b}	23.72 ± 13.21^{a}
		Jan, 2021	0.1 ± 0.14^{b}	0.4 ± 0.56^{b}	0.00 ± 0.00^{a}	1.40 ± 0.42^{b}	2.4 ± 0.28^{b}
		Mar, 2020 and 2021	0.1 ± 0.20^{b}	1.6 ± 1.31^{b}	0.00 ± 0.00^{a}	5.55 ± 2.51^{b}	15.82 ± 15.15^{a}
		Nov, 2020	0.65 ± 0.91^{b}	1.15 ± 1.62^{b}	0.00 ± 0.00^{a}	7.2 ± 7.21^{a}	3.3 ± 0.28^{b}
	Wet	Aug, 2020	0.7 ± 0.98^{b}	2.05 ± 2.89^{b}	0.00 ± 0.00^{a}	2.15 ± 1.62^{b}	6.8 ± 1.55^{b}
		Jul, 2020 and 2021	1.22 ± 1.65^{b}	0.5 ± 0.70^{b}	0.52 ± 0.86^{a}	3.07 ± 2.52^{b}	8.43 ± 8.98^{b}
		Jun, 2020 and 2021	0.92 ± 0.97^{b}	3.65 ± 6.52^{b}	0.9 ± 1.14^{a}	4.05 ± 2.77^{b}	15.1 ± 11.35^{b}
		May, 2020 and 2021	0.3 ± 0.60^{b}	1.7 ± 2.00^{b}	0.00 ± 0.00^{a}	5.25 ± 3.49^{b}	50.57 ± 37.83^{a}
		Oct, 2020	0.7 ± 0.98^{b}	1.9 ± 2.68^{b}	0.00 ± 0.00^{a}	2.7 ± 0.28^{b}	46.35 ± 43.48^{a}
		Sep, 2020	0.00 ± 0.00^{b}	1.3 ± 1.41^{b}	0.00 ± 0.00^{a}	4.35 ± 3.88^{b}	12.65 ± 15.20^{b}

Keywords: *= Significant effect, Cu= Copper; Cd= Cadmium; Pb = lead; Ni= Nickel; As= Arsenic; Mn= Manganese; Fe= Iron, 0.000= below detectable limit, NESREA = National Environmental Standard and Regulation Enforcement Agency. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

3.2 Heavy Metal Concentrations in Sediments

The metal concentrations in sediments were analysed in this research, in which the range of Copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), arsenic (As), manganese (Mn), and Iron (Fe) were found in this research. Moreover, the mean accumulation in the sediments of Balanga dam significantly increased compared to the river catchments of Almakashi and Gwani, except for the concentration ranges of cadmium and chromium obtained in the sediments of the study location (Table 4).

Table 4. Heavy Metals (mg/kg) in the Sediments Column of the Sampling Locations Collected in 2020 and 2021

Location /Season	Cu	Cd	Cr	Pb	Ni	As	Mn	Fe
Almakashi – Dry	0.06 ±0.04	0.03 ±0.02	0.06 ±0.01	0.02 ±0.00	3.85 ±2.32	0.15 ±0.06	4.23 ±1.84	1.43 ±1.06
Almakashi – Wet	0.01 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.43 ±0.26	0.03 ±0.03	0.39 ±0.17	0.03 ±0.01
Gwani – Dry	0.02 ±0.01	0.01 ±0.00	0.02 ±0.03	0.02 ±0.00	9.27 ±5.33	0.14 ±0.04	2.01 ±1.14	2.52 ±2.07
Gwani – Wet	0.01 ±0.00	0.01 ±0.00	0.00 ±0.00	0.00 ±0.00	0.78 ±0.50	0.09 ±0.02	0.34 ±0.09	0.02 ±0.01
Balanga – Dry	0.00 ±0.00	0.01 ±0.00	0.02 ±0.01	0.00 ±0.00	1.41 ±1.07	0.02 ±0.04	0.00 ±0.00	0.00 ±0.00
Balanga – Wet	0.01 ±0.00	0.00 ±0.00	0.02 ±0.02	0.00 ±0.00	0.70 ±1.08	0.03 ±0.03	0.59 ±0.46	0.00 ±0.00

Keywords: Cu= Copper; Cd= Cadmium; Cr= Chromium; Pb = lead; Ni= Nickel; As= Arsenic; Mn = Manganese; Fe= Iron, 0.000= below detectable limit, NESREA = National Environmental Standard and Regulation Enforcement Agency. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

3.2.1 Copper (Cu)

The mean values of Copper (Cu) metal in sediments at the study locations were approximately 0.06±0.04mg/kg in the dry season at Almakashi, followed by 0.02±0.01mg/kg in the dry season at Gwani, while it was 0.01±0.00mg/kg in the wet season across all sampling locations (Almakashi, Gwani, and the Balanga site). There was no copper concentration detected in the dry season at the Balanga site (Table 4). Significant differences were observed between Balanga dam and the sampling locations of Almakashi and Gwani, as well as between the dry and wet seasons ($p < 0.05$).

3.2.2 Cadmium (Cd)

Cadmium (Cd) in sediments from Almakashi in the dry season had the highest mean concentration of 0.03±0.02 mg/kg while Gwani and Balanga had of 0.01±0.00 mg/kg (Table 4).

Both the wet samples from Almakashi and the dry and wet sediment samples from Gwani had concentrations of 0.01±0.00 mg/kg (Table 4). No significant difference was recorded between sampling locations across the seasons of this study.

3.2.3 Chromium (Cr)

The highest mean range values of chromium obtained in the dry season at Almakashi were 0.06±0.00 mg/kg, and the lowest recorded value was 0.02±0.01 mg/kg found in the sediments in the dry season at the reference location. No value was found in the wet season for the two river corridors (Almakashi and Gwani) (Table 4). There was no significant difference between all the measured sampling locations and between wet and dry seasons ($p < 0.05$).

3.2.4 Lead (Pb)

The mean concentration of Lead (Pb) in sediments from the studied rivers of Almakashi and Gwani in the dry season was 0.02±0.00 mg/kg (Table 4). No values were detected in all seasons of the reference river and in the wet season of Almakashi and Gwani. A significant difference was found between the Balanga dam and the two river corridors (Almakashi and Gwani), and between the dry and wet seasons.

3.2.5 Nickel (Ni)

The maximum and minimum range values of nickel (Ni) obtained from the three sampling locations was 9.27±5.33mg/kg and 0.43±0.26mg/kg in the dry season at Gwani and the wet season in Almakashi, respectively (Table 4). However, the mean value obtained is lower than the 20.0 mg/kg recommended for unpolluted sediment by [13]. There was a significant difference between the sediments present in Balanga sampling station and the river catchments of Almakashi and Gwani. Moreover, dry season sediments varied significantly from those in the wet season ($p < 0.05$).

3.2.6 Arsenic (As)

The highest and lowest mean accumulation values of arsenic in the sediment samples collected from Almakashi in the dry season were 0.15±0.06mg/kg, and the reference site in the dry season had 0.02±0.04mg/kg (Table 4). There was a significant difference between the mean values of the reference location and the two river corridors of Almakashi and Gwani. Furthermore, dry season sediments varied significantly from those in the wet season ($p < 0.05$).

3.2.7 Manganese (Mn)

The highest manganese concentration was obtained in Almakashi in the dry season with 4.23±1.84mg/kg, while the lowest mean concentration was 0.34±0.09 mg/kg in the wet season at the Gwani sampling location (Table 4). No value was recorded in the dry season at the reference site. There was a significant difference between the mean values of the reference location and the two river corridors of Almakashi and Gwani. Similarly, dry season sediments varied significantly from those in the wet season ($p < 0.05$).

3.2.8 Iron (Fe)

The Iron (Fe) concentrations in sediments from the studied rivers ranged from the highest mean concentrations of 2.52±2.07mg/kg in the dry season at Gwani location to the lowest value of 0.02±0.01mg/kg in the wet season at Gwani (Table 4), and this is less than the WHO recommended limit. There values from the sediments of the Balanga dam were below detectable limit. There was a significant difference between the mean values of the reference location and the two river corridors of Almakashi and Gwani. There is a significant difference also between dry season sediments with those in the wet season ($p < 0.05$).

4. DISCUSSION

Heavy metals are group of metals or metalloids that have relatively high density and are toxic or poisonous at low concentrations [15]. Bioaccumulation of heavy metals is used for environmental monitoring basically because aquatic biotas are directly connected with the contaminated water [16]. Heavy metals accumulate in fishes through water, sediments, and food such upon which food, web trophic interaction between herbivorous, carnivorous, and omnivorous fish specimens occurs [17].

Difference in the absorption of heavy metals depends on the heavy metal affiliation, the fish species, and the physical and chemical properties of water [18]. Living creatures accumulate heavy metals when the rate of uptake and storage surpasses the rate at which they are broken down (metabolized) or excreted. These metals find their way into the water supply through industrial and consumer materials, as well as through the breakdown of soils by acidic rain, releasing heavy metals into streams, lakes, rivers, and groundwater.

The three environmental heavy metals; Chromium (Cr), lead (Pb), and copper (Cu) are considered critically important for monitoring in aquatic environments due to their toxicity, persistence, bioaccumulation potential, and ecological and human health risks [19]- [20], have been reported in this study, but some other heavy metals can also badly affect the environment. Heavy metal toxicity has been reported to be caused by different means for instance, from contamination of drinking water (Pb pipes), high ambient air concentrations near emission sources, or from the food chain [1].

Metals such as copper, arsenic, and manganese were found in the water column but not detected in the study area's sediments. They might be diluted due to high water flow rates, especially in large bodies of water like rivers or estuaries. In these environments, the residence time of metals in the water column may be sufficient for them to remain suspended before settling into the sediments. High turbulence or water movement can also prevent sedimentation [2].

The sediment-water interface is a dynamic region where the diffusive exchange of solutes occurs. In certain cases, metals such as copper, arsenic, and manganese can be present in the water column because they are being desorbed from the sediments or are actively released due to changes in environmental conditions, such as changes in pH, salinity, or biological activity [21]. The presence of suspended particulate matter in the water can also facilitate the transport of metals without them being permanently sequestered in the sediments.

4.1 Copper (Cu) concentration in sediments

In the present results, copper was not found in the sampling water. Conversely, the highest mean concentration of Copper (Cu) metal in sediments of the study locations was 0.06±0.04 mg/kg in the dry season at Almakashi sampling location (Table 1), while the lowest mean concentration was 0.01±0.00 mg/kg found in the wet season at all three sampling locations of Almakashi, Gwani, and Balanga dam. The range found was lower than 1.20–13.56 mg/kg reported by [22] in the River Nun estuary around Akassa, Niger Delta, Nigeria. The mean obtained was also lower than the 25.0 mg/kg recommended limit for Cu in unpolluted sediment by [14]. The level of copper in the sediments could not be regarded as a pollutant and therefore may not affect the life of O. niloticus and C. gariepinus at the sampling locations.

4.2 Cadmium concentration in water and sediments

The result of the variations of metal in the water column of the sampling areas in relation to seasonal variations depicts that Cadmium (Cd) is highest in the late dry month of March (5.07±3.20 µg/L) (Table 1), while the least value was recorded in the month of January (early dry season) (0.06±0.09 µg/L) (Table 3). In sediments samples, a range value of 0.03±0.02 mg/kg in dry season at Almakashi while 0.01±0.00 mg/kg was obtained in the wet season of at all the sampling sites (Table 4). In either way, there was no significant elevation in the mean concentrations of cadmium from Balanga Dam to the two river corridors of Almakashi and Gwani ($P>0.05$). However, the mean values relatively increased because of increased in anthropogenic activities in the study river corridors. Metals are naturally occurring in aquatic ecosystems or as a result of human activities. However, their toxicity depends on their concentrations and physiological behaviour [23]. This metal has no known useful properties that support life and there is no evidence that it is either biologically necessary or beneficial [24]-[25]. The presence of cadmium in these water bodies may be attributed to anthropogenic activities such as chemicals used in fishing activities by the local fishermen, herbicides and fertilizers from farms. Furthermore, industrial wastes and domestic waste from Gombe Township are discharged into these water bodies, which may also contribute to the presence of Cadmium. Cadmium is found at trace concentrations in fresh waters and mostly as a result of industrial activity. The result of this study is in contrast to that reported by [26] in southern Vietnam. However, [27] recorded Cadmium (Cd) levels of 0.2 µg/L in Yangtze River, China. Similarly, [28] also documented a value of 23.15 µg/L in river of Kruger National Park, South Africa, which is in accordance with the result of this study. The presence of high Cd values observed in the late dry season months of April may be due to the reduction in volume of the water as well as low water flow [29].

The minimum and maximum mean concentrations of Cadmium (Cd) in sediments from the Almakashi, Gwani, and Balanga dam ranged from 0.01±0.00 mg/kg in the wet season at Almakashi, and in both wet and dry seasons at Gwani, to 0.03±0.02 mg/kg in the dry season at Almakashi and Gwani, respectively (Table 4). This range is lower than the 0.04-0.65 mg/kg reported in sediments from the Niger Delta Region of Nigeria by **[30]**. The range of Cd values obtained was also lower than the 3.0 mg/kg recommended limit for sediment by **[14]**. Thus, Cd may not be regarded as a pollutant in sediments from the studied aquatic environments.

4.3 Chromium (Cr) concentration in water and sediments

Chromium is one of the essential trace elements involved in glucose metabolism and functions as an insulin co-factor. It plays a vital role in increasing protein and amino acid uptake by cells [31] Chromium is an unusual metal, and its incidence and amounts in aquatic ecosystems are typically very low **[32]** (Smith et al., 2021). Furthermore, hexavalent chromium (Cr^{6+}) is considered toxic due to its powerful oxidative potential and ability to cross cell membranes [33]. When observing chromium in the water samples collected in the present study, the highest Cr value of 8.90±2.26 µg/L was observed in the month of May (early wet season) (Table 4), which may be due to early rain causing runoff of materials into the river that had experienced a significant reduction in water volume before the onset of the wet season due to high evaporation rates. The values reported in this study are lower than those observed by

[34] from the Yangtze River, who reported a Cr value of 29.66 µg/L. Similarly, chromium (Cr) mean accumulation in sediment of 0.06±0.02 mg/kg obtained in Almakashi in the dry season was within the acceptable limit. There was no significant elevation of chromium between location and season. The low value of Cr observed may be related to the runoff of materials from nearby farms as most inhabitants of the sample sites are peasant farmers. The presence of Cr could also be a natural source such as weather of chromium-rich bedrock and soils, atmospheric deposition [35]. Long-term release of such contaminants might affect fish and other animals present in aquatic environments.

4.4 Lead (Pb) concentration in water and sediment

The highest lead concentration in the water was found in Almakashi river corridor (1.25±1.94µg/L) in the month of April while most of the months of the study had no recorded value of lead (denoted as 00±00) especially in dry season. No record of lead value was detected in Balanga (the reference) dam in dry season except the lowest recorded mean concentration of 0.10±0.14µg/L found in April during late dry season. Balanga dam differed significantly with Almakashi and Gwani ($p < 0.05$) in terms of lead concentrations. This may be because of less human activities in Balanga dam.

The highest concentration of lead (Pb) in sediments from the studied river corridors was 0.02±0.00 mg/kg, observed during the dry season at both Almakashi and Gwani. This is lower than 12.43 – 36.65 µg/g and ranged between 2.34 and 6.33 mg/kg obtained in sediments from the Niger Delta Area of Nigeria by [36] respectively. The range value recorded from all the study locations was lower than 10.0 mg/kg recommended limit for Pb in unpolluted sediment by [14]. Therefore, Pb in the studied sediments may not be regarded as a pollutant; however, constant monitoring is required because of its high toxicity to C. gariepinus, O. niloticus and other living organisms.

Lead (Pb) is an essential indicator that should be periodically monitored. It was observed that Pb concentration is highest at late dry months of April with 1.25±1.94µg/L (Table 1). From this result it can be deduced that Pb fall within the allowable limit of the [13]. [23] reported a higher value of 0.02mg/L in southern Vietnam which exceed the acceptable limit. Interestingly, the Pb value observed in this study is similar to the one reported by [30], with 3.14 µg/L mean value in river of Kruger National Park, South Africa. Anthropogenic activities are said to be the major sources of Pb in the aquatic environment; these activities may include precipitation, fallout of Pb dust, and Pb emissions from gasoline-powered motor vehicles. This may also include industrial and municipal wastewater discharge; mining, milling, and smelting of Pb and metals associated with Pb, such as Zn, Cu, silver, As, and antimony; and combustion of fossil fuels [37].

4.5 Nickel (Ni) concentration in water and sediments

The mean concentration of nickel observed in this study ranges from 9.10±4.89 µg/L in the late dry season month of March to 1.40±0.42 µg/L in the early dry season month of January. The results observed in this study agree with those of [38], who also reported a Ni value of 4.00µg/L from open drainage channels in Nairobi, Kenya. These values are below WHO recommended limits for nickel in open water. Nickel is readily soluble in water environments and, consequently, can be easily absorbed by living organisms. The accumulated heavy metals in the sediments indicated significant increase in Nickel concentration in dry season compared to wet season and this is attributed to hydrodynamics due to reduction in water level and thus, is similar to the findings of [39].

There was a variation in the range of mean values of nickel (Ni) in sediments obtained from the sampling locations. It ranged from 0.43±0.26 mg/kg in the wet season at Almakashi to 9.27±5.33 mg/kg in the dry season at Gwani. The obtained range is higher than the 0.4 – 2.3 mg/kg reported in the region by **[40]**. However, the mean value obtained is lower than the 20.0 mg/kg recommended for unpolluted sediment by [37]. Therefore, nickel in the sediments could not be regarded as pollutant despite the fact that the level of nickel was comparatively elevated from Balanga dam to the two sampling locations (Almakashi and Gwani) and between the seasons of this study. This potential connection may be attributed to the fact that Almakashi and Gwani receive waste materials from nearby industries and municipalities, as well as fertilizers and chemicals from nearby farms.

4.6 Arsenic (As) concentration in water and sediments

Health problems related to the exposure of Arsenic (As) continue to raise global concern because of the wide variety of its adverse health effects, such as cancerous effects of many internal, cardiovascular and neurological effects [41]. This is similar to the chronic exposure to high levels of As, primarily from drinking water, sediments and food [42]. No arsenic concentration was recorded in water of the sampling sites of this study; however, it was found in sediments of the sampling sites.

The range of arsenic accumulation found in this study was 0.02±0.04mg/kg - 0.15±0.06 mg/kg of arsenic in the sediment samples collected in dry season from the lowest in Balanga dam to the highest in Almakashi. There was a significant elevation in the sampling river corridors of Almakashi and Gwani suggesting that, a faster flow rate in river corridors could result in increased levels of arsenic compounds compared to the slower flow rate downstream of the dam. Furthermore, dry season sediments varied significantly with that of the wet season ($p <0.05$). This range concentration was lower than the average arsenic concentrations of 11 ± 80 and 13 ± 10 mg/kg found in surface sediments and soils from streams, respectively.

On the other hand, high average arsenic levels were observed, with the highest concentration pattern in the northern part of La Paz lagoon. [43] determined the trace element content of sediments from La Paz lagoon and from the mouth of adjacent streams. [41] examine the sediment quality guidelines reported that the probable effect level value for the protection of aquatic life in freshwater and marine environments is 17.0 mg/kg which is higher than the mean concentration of the sediments obtained in the present study. Therefore, the level of arsenic found in sediments may not affect C. gariepinus and O. niloticus as well as other aquatic organism present in the study area.

4.7 Manganese (Mn) concentration in water and sediments

Sediments, soil, and all rocks except igneous rocks are sources of manganese. Furthermore, manganese is used as an additive micro-nutrient in fertilizers applied to farms [30]. In this research, no manganese concentration was recorded in water media of this study. However, the highest manganese concentration in sediments was obtained in Almakashi in the dry season, with 4.23±1.84 mg/kg. A significant increase in manganese concentration was observed in Almakashi and

Gwani sampling locations compared to Balanga Dam. Additionally, there was a significant difference in the mean concentration of manganese between the dry and wet seasons ($p < 0.05$). This could be attributed to surface runoff and leaching of chemicals and other pollutants from nearby farmlands during the wet season. Manganese exposure may lead to the death of cells in organisms, resulting in necrosis [44]. Severe effects on the lifespan and reproduction of nematodes have been observed when exposed to manganese concentrations ranging from 75µmol/L to 200µmol/L for 2 days [45]. An elevation in manganese was also reported to induce apoptosis in Nephrops norvegicus [46].

4.8 Iron (Fe) concentration in water and sediments

The highest value of iron in both seasons of this study was 50.57±37.83 µg/L found in the early wet month of May. The presence of iron reported in this study could be from the sedimentary rocks where the source of the reference water is gorging out. [30] reported a value of 65.25 µg/L of iron from two rivers in Kruger National Park, which is relatively greater than that of this study. Previous studies have suggested that iron in the aquatic environment may originate from natural sources (acid sulfate soils) or industrial wastewater [26],[47],[48]. Thus, the presence of iron in surface waters is a common problem observed in all sample seasons of this period. Effluents from industrial processes and urban areas can contribute to the rise in iron concentrations in the water corridors.

Iron (Fe) concentrations in sediments from the studied rivers ranged from 0.02±0.01 mg/kg in the wet season at Gwani to 2.52±2.07 mg/kg in Gwani from the samples collected in the dry season. The obtained range is lower than the 6914.0 – 7543.0 µg/g reported in sediments by [49] in the upper reaches of the Sombriero River, Niger Delta, Nigeria. However, the mean obtained in this study was lower than the 30.0 mg/kg recommended for Fe in unpolluted sediment by [37]. The accumulated heavy metals in the sediments indicated significant increase in iron concentrations in dry season compared to wet season and this is attributed hydrodynamics due to reduce in water level and is similar to the findings of [39].

Iron may not pose a risk to the organisms living in the studied aquatic ecosystem as high levels of the metal could be released into these water channels. This low level of Fe in the studied locations could be attributed to less natural and anthropogenic influence leading to the low level of the iron in wet season. However, the Iron concentration in the sediments showed a notable rise during the dry season compared to the wet season. This increase is attributed to the agitation of sediments (hydrodynamics), which influences the variation in metal concentrations across different seasons. Therefore, reduced water flow allows iron particles to accumulate in sediment. This observation aligns with the findings of [39], who investigated the accumulation of essential heavy metals in Caulerpa racemosa, seawater, and marine sediments on Bintan Island, Indonesia.

In general, most of the contaminants in water and sediments were found in late dry season and the major reason of this high contaminant concentration observed during this season may be associated with extreme evaporation rate during the high-temperature season in the water bodies [50]. Similarly, [51] revealed an excessive increase in the concentration of metals in the eastern part of Lake Qaroun in water and sediments samples, with the maximum absorption during the summer season. This agrees with the result of the present study as more concentration of metals was observed during the late dry season.

The location and seasonal variations of heavy metals in water and sediments have important implications for assessing contamination levels, identifying pollution sources, evaluating ecological risks, and understanding the fate and behaviour of these pollutants in aquatic ecosystems [52], [53].

5. Conclusion

Heavy metal analysis reveals that all sites are within the normal range, but Almakashi has the highest mean concentrations for most metals. Iron concentrations are highest at Balanga dam, while there is significant rise in iron concentrations in the sediment samples examined. There are significant differences in contamination levels between Balanga dam and the river corridors, although all values are within acceptable limits. There is need to conduct further studies to assess the health status of fish populations, particularly focusing on histopathology, haematology and biochemical indices. This can help in understanding the long-term impacts of environmental stressors on fish health. Moreover, this study promotes integrated water resource management strategies that consider the interactions between agricultural practices, water quality, and aquatic ecosystems. Collaborative efforts among stakeholders, including farmers, local communities, and government agencies, are essential for sustainable resource management.

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