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An Investigation of Physicochemical Parameters of Gongola River Corridors in Gombe State, Nigeria

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ABSTRACT

The study investigated the physicochemical parameters of water from Gongola river corridors, Gombe State. In-situ measurements were conducted and the pH ranged between 6.27 ± 0.11 – 7.60 ± 0.02. The pH found in dry season is lower than the recommended limit indicating slightly acidic to a little bit above neutral condition of the river water. Contrarily, the range of Electrical conductivity (EC) (237.50±2.12 - 730.50±25.11µS/cm), Total dissolved solids (TDS) (111.75±1.76mg/L – 365.25±12.55 mg/L), Turbidity (3.25±0.83NTU – 13.39±2.82NTU), Biochemical Oxygen Demand (BOD) (1.91±0.33mg/L – 4.54±0.55 mg/L) and Chemical oxygen demand (COD) (1.91±0.33mg/L – 4.54±0.55 mg/L) found wet and dry season increased significantly in Almakashi and Gwani from the reference location. Furthermore, the range of the mean concentration of the chemical parameters of nitrate, phosphate, sulphate and chloride were 9.33 ± 2.46mg/L-1.18±1.25mg/L, 0.09±0.01 mg/L - 0.80±0.110 mg/L, 5.18 ±3 .16 mg/L-29.80 ± 13.22 mg/L and 37.70±8.45mg/L-168.72 ± 26.30mg/L respectively in which the highest values found in early wet season. The pH decreased from the reference river to the two sampling locations of Almakashi and Gwani rivers. All the chemical parameters examined in the Balanga dam (Reference River) differed significantly compared to the sampling locations of Almakashi and Gwani; though, it is within the recommended limit. There is need for regulation of activities that alters the physicochemical parameters of the water.

Keywords: Physical, Chemical, River Corridors, Gongola River

INTRODUCTION

An extensive analysis of diverse physical and chemical components present in the water revealed the nature of its quality (Huang and Zhang, 2019). This delves into the assessment of both harmless and harmful elements, encompassing parameters such as pH levels, total dissolved solids (TDS), salinity, conductivity, specific ions, nutrients, organic enrichment, dissolved oxygen levels, biocides, trace metals, and compounds known for their potential to disrupt endocrine functions. The tolerance limits of individual organisms also play a crucial role in determining the impact of each variable (Day, & Dallas, 2011) and thus, provide information on physical attributes and chemical constituents of water.

Water pollution refers to any chemical, biological, or physical alteration in water quality that adversely affects living organisms (Bhat *et al*., 2020). Water is deemed polluted when it becomes less suitable or unfit for use. Activities contributing to water quality pollution include inadequate monitoring of sewage effluent, agriculture, intensive irrigation, mining, industrial processes, and densely populated human settlements, especially those lacking proper sanitation facilities (EPA, 2020). Consequently, river water is susceptible to contamination by plant nutrients, chemicals, organo-chlorine and toxic substances such as heavy metals (US EPA, 2024).

Recent observations indicating a decline in both the quantity and size of fish in Northern Nigeria have sparked concerns regarding water quality within the region (Frontiers, (2021). Local artisanal fishermen, who heavily rely on natural water systems for their livelihoods, are particularly vulnerable to shifts in water quality (Oruonye, 2014). Consequently, mitigating water pollution is essential not only for safeguarding the livelihoods of artisanal fishermen but also for preserving the overall health of aquatic ecosystems in Nigeria.

Many studies on physico-chemical parameters in natural water bodies exists; however, no known documented information concerning the physico-chemical analysis of Almakashi, and Gwani river corridors; Thus, worthy of scholarly study. Therefore, the aim of this study was to investigate the physicochemical parameters of some catchments of River Gongola in Gombe State. The objectives were to determine the physical water parameters in dry and wet season along the study area and also to examine the chemical parameters of the sampling sites (namely: Almakashi, Gwani and the reference river). This study will provides valuable information about water quality, helping to identify potential sources of contamination, and inform management decisions for water treatment and environmental protection.

MATERIALS AND METHODS

Study Area

The study sites chosen for this research are located within the Gongola River Complex. The Gongola River, situated in Northeastern Nigeria, stands as the primary tributary of the Benue River. It originates from the eastern slopes of the Jos Plateau, the Gongola flows into the Gongola Basin, following a Northeast trajectory until it reaches Gombe Abba, then Nafada. It takes a southward turn from Nafada, passing through the corridors of the Almakashi landing site and proceeding to the Dadin Kowa Dam, after traversing the Gwani River corridor in the Yamaltu-Deba Local Government of Gombe State (Ighalo *et al.*, 2020).

The Almakashi River is specifically located in the Bajoga Local Government Area of Gombe State, positioned at longitude 10^{o} 44’ 38.15’’N and latitude 11^{o} 30’ 02.13’’E.

The Gongola River passes through the village of Gwani, dividing it into Gwanin Gabar (Eastern Gwani) and Gwanin Yamma (Western Gwani), establishing an essential sub-catchment corridor within the Gongola River complex. The residents of Gwani rely directly on the river water for various domestic activities such as drinking, bathing, cooking, and washing clothes. Gwani is positioned between longitude 10 ^{o} 23’ 47.035’’N and 10 ^{o} 25’ 04.89’’N, as well as latitude 11 ^{o} 31’ 32.013’’ and 11 ^{o} 26’ 40.24’’E.

The reference river of this study is Balanga Dam, situated in the Balanga Local Government Area of Gombe State, is a notable dam characterized by water emerging from beneath the sedimentary rocks. The water flows westward from the dam until it meets River Dogon Daji, ultimately emptying into the lower reaches of the Gongola River, thereby playing a crucial role in replenishing the Gongola River. It is located at longitude 9^{o}35’0” and 10^{o}0ʹ0ʺ N and latitude 11^{o}15’0” and 11^{o}40’0”E.

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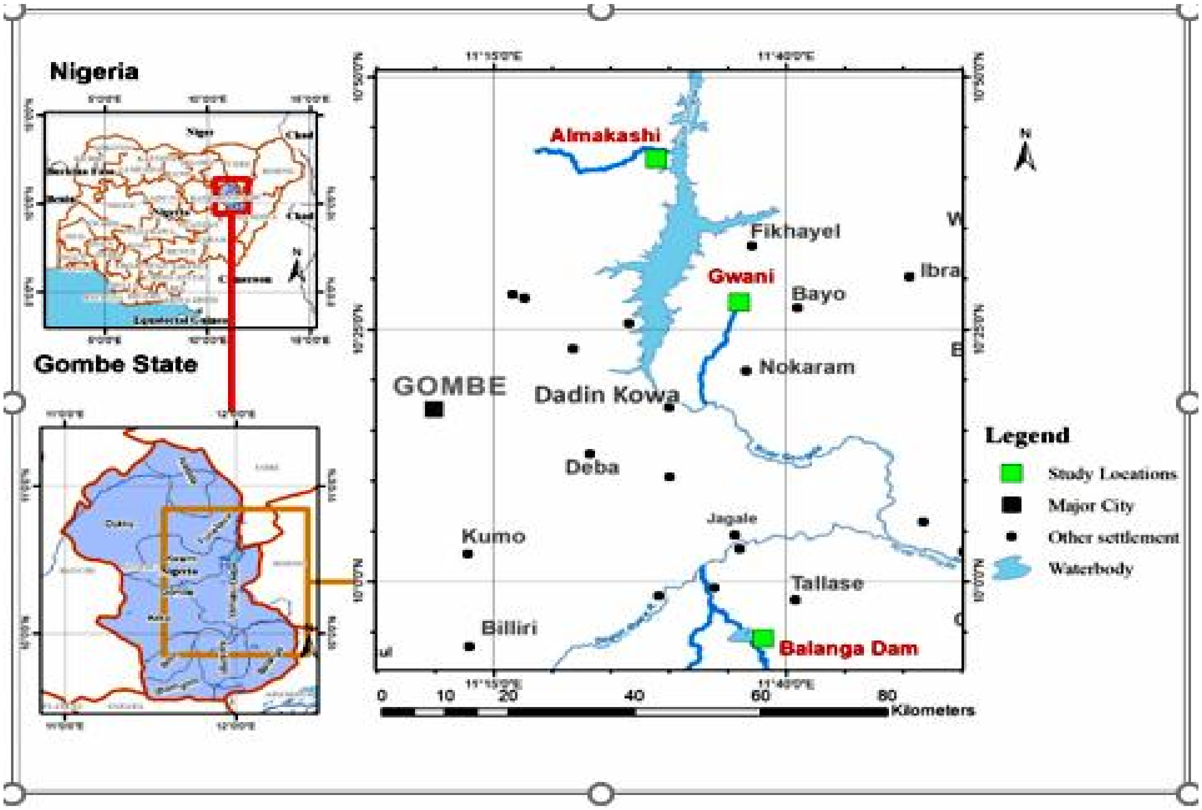

Figure 1: Map of the study area indicating Almakashi, Gwani river catchments of Gongola river complex together with Balanga (the reference dam).

Measurements of Physical and Chemical Water Quality Parameters

In each sampling session, the measurement of physical water quality parameters assessed included pH, oxygen percentage, oxygen concentration (mg/L), total dissolved solutes (TDS), and conductivity. pH was measured using a pH meter, while conductivity, total dissolved salts, Biological Oxygen Demand (BOD) concentration, and Chemical Oxygen Demand (COD) were also recorded. All meters were calibrated to ensure the reliability of the obtained results.

To assess the chemical parameters of the water, samples were collected and subsequently analyzed for nitrate, phosphate, sulfate, and chloride in the Biochemistry laboratory of Gombe State University using a UV spectrophotometer.

Statistical Analysis

The obtained data were analyzed using Statistical Package for the Social Sciences version 22 (SPSS 22) software. Shapiro-wilk test was applied to test the normality of the obtained data. Descriptive statistics was employed to calculate the mean of all the experimental group and the data were presented as mean ± standard deviation (Std dev). This test was utilized to assess whether there was a significant difference between independent and dependent variables in the physicochemical parameters, compared to location, seasons. Values of $p < 0.05$ were considered significant. In cases where differences were observed, *Duncan's post hoc* test was conducted to examine the degree of variation.

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RESULTS

Physical Water Quality Parameters in Relation to Sample Locations

The physical characteristics of the water, including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Turbidity, were examined. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were also assessed in both in-situ and laboratory settings, categorized as physical parameters for this study. The results consistently revealed a pattern of increase from the lowest to the highest values (Reference < Almakashi < Gwani) for all physical parameters, except for pH. Across all measured physical parameters, values increased from the reference river, with higher levels observed during the dry season, except for pH.

Physical Water Quality in Dry and Wet Seasons

Physical water quality at the sampling locations during both the dry and wet seasons was assessed. Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) exhibited a significant increase in Almakashi and Gwani compared to the reference location. Conversely, pH values decreased from the reference river to the two sampling locations. Notably, the pH recorded during the dry season fell below the recommended limit set by WHO (2013).

pH

All examined pH values fell within the acceptable range of 6.50 to 8.50 as stipulated by WHO (2013) and NESREA (2011), except for values obtained in February (6.45±0.29, 6.46±0.10) and April (6.39±0.14, 6.27±0.11) in Almakashi and Gwani, respectively. Additionally, the pH concentration in Gwani during the dry season was slightly acidic (6.42±0.16) (Table 1a). Values obtained during the wet season from all sampling locations were within acceptable limits, except for the mean value of 6.63±0.18 found in May at the Gwani sampling site (Table 1b). The pH concentrations of the reference river in both dry (Table 1a) and wet (Table 1b) seasons were within acceptable values for an unpolluted water body. The lowest was observed in Gwani (6.27±0.11) in April (Table 1a), while the highest value was recorded at Almakashi (7.60±0.02) in August (Table 1b). There was a significant decrease in pH values from the reference dam to the Almakashi and Gwani sampling locations during the dry season. However, there were no significant variations in pH values between the dry and wet seasons. Seasonal analysis of physicochemical parameters indicated that water samples collected in the late dry season months of February, March, and April exhibited the highest acidic values, whereas pH values during the late wet season (August, September, and October) were the lowest acidic values (Table 1b).

Electrical Conductivity and TDS

The electrical conductivity (EC) and total dissolved solids (TDS) in the water from all sampling stations were measured, and mean concentrations were recorded in descending order: Gwani > Almakashi > Reference, with the highest values of EC (730.50±25.11 mg/L) and TDS (365.25±12.55 mg/L) observed in Gwani. This was followed by EC of 666.50 ± 75.11 and TDS of 333.25±37.55 mg/L in Almakashi, obtained in the month of April (late dry season) (Table 1a). The lowest mean values of EC (237.50 ± 2.12 mg/L) and TDS (136.25±23.68 mg/L) were found in October at the reference site (Table 1b). The mean concentrations of EC and TDS in the water of Almakashi and Gwani differed significantly from those of the reference dam ($p < 0.05$).

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Turbidity

Similarly, the mean concentrations of water turbidity obtained from the sampling locations followed a decreasing order of Gwani > Almakashi > Reference, respectively (Table 1a). The highest turbidity mean concentration was 13.39±2.82 mg/L in February, while the lowest was 3.25 ± 0.83 mg/L obtained in the month of August (Table 1b). There is a significant difference between the turbidity concentrations of Almakashi and the reference dam ($p < 0.05$).

Biochemical Oxygen Demand and Chemical Oxygen Demand

The highest mean value of BOD was 4.54±0.55, obtained in February at Gwani (Table 1a), while the lowest was 1.91±0.31 (Table 1b), found in the reference dam in the month of September. Statistically, there was a significant difference between these values ($p < 0.05$). Similarly, COD values of 19.20±1.08 and 5.31±1.49 were the maximum and minimum mean concentrations obtained in Gwani in the month of April (Table 1a) and the Reference dam in the month of September (Table 1b), respectively. There was also a significant difference between Gwani and Almakashi sampling units and that of the reference dam in Balanga.

Table 1a: Monthly Variation in Physical Water Quality in Dry Season at the Sampling Locations

Location	Season	Months	pH	EC	TDS	TUR	BOD	COD
Almakashi	Dry	Apr	6.39±0.14^{b}	710.95±95.34^{a}	355.63±47.52^{a}	12.26±2.46^{a}	4.52±0.53^{a}	18.48±3.40^{a}
		Dec	7.29±0.03^{a}	388.71±44.42^{b}	194.35±22.21^{b}	6.89±0.43^{b}	3.21±0.14	10.32±1.30^{a}
		Feb	6.45±0.29^{b}	488.60±143.87^{b}	244.30±71.93^{b}	10.57±2.17^{a}	4.40±0.57^{a}	12.42±3.67^{a}
		Jan	6.84±0.38^{b}	351.35±79.40^{b}	175.67±39.70^{b}	9.03±4.36^{b}	3.00±0.35	7.66±0.55^{b}
		Mar	6.53±0.14^{b}	470.6±125.45^{b}	235.3±62.72^{b}	9.50±0.94^{b}	4.35±0.52^{a}	12.01±3.15^{a}
		Nov	7.45±0.06^{a}	498.1±29.41^{b}	249.05±14.70^{b}	6.96±0.23^{b}	3.58±0.31^{a}	12.89±0.60^{a}
Gwani	Dry	Apr	6.27±0.11^{b}	730.5±25.11^{a}	365.25±12.55^{a}	12.71±1.95^{a}	3.79±1.15^{a}	19.20±1.08^{a}
		Dec	6.97±0.28^{a}	491.5±71.41^{b}	245.75±35.70^{b}	8.35±1.63^{b}	3.54±0.57^{a}	12.77±1.24^{a}
		Feb	6.46±0.10^{b}	658.12±156.77^{a}	341.56±64.10^{a}	13.39±2.82^{a}	3.80±1.00^{a}	18.31±5.42^{a}
		Jan	6.79±0.65^{b}	441.00±118.79^{b}	220.5±59.39^{b}	11.19±4.31^{a}	4.23±0.16^{a}	11.45±2.96
		Mar	6.42±0.16^{b}	647.00±66.95^{a}	323.5±33.47^{a}	12.82±2.65^{a}	4.13±0.68^{a}	17.31±2.33^{a}
		Nov	7.09±0.20^{a}	581.5±92.63^{a}	290.75±46.31^{a}	5.83±0.48^{b}	4.54±0.55^{a}	15.35±2.95^{a}
Reference	Dry	Apr	6.96±0.18^{a}	358.00±57.23^{b}	179.00±28.61^{b}	5.85±0.59^{b}	3.30±0.34^{b}	9.16±1.75^{b}
		Dec	7.08±0.06^{a}	386.00±100.40^{b}	193.00±50.20^{b}	9.67±0.47^{b}	2.92±0.53^{b}	10.08±3.04^{b}
		Feb	6.94±0.07^{a}	491.5±162.20^{b}	245.75±81.10^{b}	8.69±3.94^{b}	2.95±0.58^{b}	13.21±4.38^{a}
		Jan	7.27±0.08^{a}	223.5±3.53^{c}	111.75±01.76^{c}	8.94±0.26^{b}	2.56±0.05^{a}	7.29±1.25^{b}
		Mar	7.01±0.24^{a}	407.75±131.54^{b}	203.87±65.77^{b}	9.53±1.83^{b}	3.01±0.44^{b}	10.79±3.23^{b}
		Nov	7.06±0.26^{a}	317.5±41.71^{c}	158.75±20.85^{c}	9.22±1.53^{b}	3.17±0.53^{b}	8.22±1.44^{b}
Location			0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Month			0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Location*Month			0.024*	0.225	0.172	0.011*	0.415	0.276

Keywords: Apr= April; Dec= December; Feb= February; Jan= January; Mar= March; Nov= November; pH = Degree of hydrogen ion concentration, EC = Electrical Conductivity, TDS = Total Dissolve Solids; TUR = Turbidity; BOD = Biological Oxygen Demand and COD = Chemical Oxygen Demand. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

Table 1b: Monthly Variation in Physical Water Quality in Wet Season at the Sampling Locations

Location	Season	Months	pH	EC	TDS	TUR	BOD	COD
Almakashi	Wet	Aug	7.60±0.02^{b}	434.9±9.47^{b}	217.45±4.73^{b}	5.98±0.22^{b}	2.10±0.13^{b}	11.73±0.62^{a}
		Jul	6.87±0.42^{a}	503.2±119.02^{b}	251.6±59.51^{b}	8.47±2.38^{b}	3.53±0.84^{a}	13.40±3.56^{a}
		Jun	6.71±0.24^{b}	627.8±43.36^{a}	313.9±21.68^{a}	10.88±1.79^{a}	3.77±0.31^{a}	16.30±1.90^{a}
		May	6.96±0.28^{a}	650.25±57.98^{a}	325.12±28.99^{a}	10.17±1.09^{a}	3.94±0.76^{a}	16.87±1.77^{a}
		Oct	7.33±0.08^{a}	429.97±67.21^{b}	214.99±33.60^{b}	6.02±0.17^{b}	3.29±0.33^{b}	11.01±0.12^{a}
		Sep	7.28±0.09^{a}	424.11±48.21^{b}	212.05±24.10^{b}	6.01±0.67^{b}	2.03±0.11^{b}	10.88±0.75^{a}
Gwani	Wet	Aug	7.08±0.04^{a}	387.00±39.59^{b}	193.5±19.79^{b}	6.08±2.03^{b}	2.82±0.40^{b}	9.99±0.81^{b}
		Jul	6.67±0.44^{b}	618.5±119.66^{a}	309.25±59.83^{a}	9.33±1.11^{b}	3.08±0.38^{b}	16.64±3.76^{a}
		Jun	6.76±0.28^{b}	659.25±45.65^{a}	329.62±22.82^{a}	9.82±1.37^{b}	4.22±0.57^{a}	17.43±1.71^{a}
		May	6.63±0.18^{b}	666.5±75.11^{a}	333.25±37.55^{a}	10.99±1.85^{a}	4.17±0.05^{a}	17.87±2.91^{a}
		Oct	7.16±0.09^{a}	415.75±27.22^{b}	207.87±13.61^{b}	7.20±0.40^{b}	3.80±0.45^{a}	12.97±0.23^{a}
		Sep	7.22±0.09^{a}	441.5±28.99^{b}	220.75±14.49^{b}	5.28±1.54^{b}	2.13±0.10^{b}	11.82±0.75^{a}
Reference	Wet	Aug	7.09±0.02^{a}	308.5±156.27^{c}	154.25±78.13^{c}	3.25±0.01^{b}	2.07±0.27^{b}	8.28±3.35^{b}
		Jul	6.94±0.05^{a}	297.5±143.03^{c}	148.75±71.51^{c}	3.52±1.83^{b}	3.23±0.83^{b}	7.91±3.68^{b}
		Jun	7.07±0.06^{a}	325.00±87.46^{c}	162.5±43.73^{c}	5.31±1.73^{b}	3.38±0.80^{a}	8.55±2.31^{b}
		May	6.99±0.09^{a}	400.75±97.32^{b}	200.37±48.66^{b}	7.85±4.18^{b}	3.29±0.97^{b}	10.40±2.83^{a}
		Oct	7.20±0.01^{a}	237.5±2.12^{c}	136.25±23.68^{c}	8.14±0.28^{b}	2.22±0.09^{b}	5.93±0.16^{b}
		Sep	7.02±0.13^{a}	161.5±84.14^{c}	80.75±42.07^{c}	3.53±3.42^{b}	1.91±0.31^{b}	5.31±1.49^{b}
Location			0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Month			0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Location*Month			0.024*	0.225	0.172	0.011*	0.415	0.276

Keywords: Aug= August; Jul= July; Jun= June; Oct= October; Sep= September; pH = Degree of hydrogen ion concentration; EC = Electrical Conductivity; TDS = Total Dissolve Solids; TUR = Turbidity; BOD = Biological Oxygen Demand; COD = Chemical Oxygen Demand. Same superscript in the same column indicates no significant difference while different values at the same column show significant difference.

Chemical Parameters of the Sampling Locations

In this study, the chemical parameters (nitrate, phosphate, sulfate, and chloride) were analyzed concerning their variations with locations, months, and seasons. Surprisingly, all the chemical parameters examined in the reference river differed significantly from those in the two sampling locations (Almakashi and Gwani) ($p < 0.05$), except for the nitrate concentration found in Gwani (Table 2a). Upon careful observation of the chemical values obtained, all the chemical

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parameters (nitrate, phosphate, sulfate, and chloride) examined in this study did not vary significantly with the sampling seasons of this research.

Nitrate of the sampling locations

The highest and lowest mean values of nitrate recorded were 93.31±24.66 mg/L in the month of April at Almakashi and 11.85±12.55 mg/L in January at the reference dam (Table 2a), respectively. The concentration values obtained in Almakashi differed significantly from the mean values obtained in the reference river ($p < 0.05$).

Phosphate of the sampling locations

The highest phosphate concentration was found in Almakashi River (80.33±11.30 mg/L) in the month of April (Table 2a), and the lowest mean concentration was recorded in the reference dam (9.17±1.39 mg/L) in September during late wet season (Table 2b). The reference river (Balanga dam) differed significantly from Almakashi and Gwani ($p < 0.05$) in terms of phosphate concentrations.

Sulphate of the Sampling Locations

The sulphate concentrations in Balanga dam differed significantly with Almakashi and Gwani ($p < 0.05$). Gwani river site had the highest sulphate concentration of 42.96±7.25 mg/L in the dry season (month of April) (Table 11a), and the lowest mean concentration was recorded during the mid-wet season (July) in the reference river (4.28±1.85 mg/L) (Table 2b). The sulphate concentrations in Balanga dam differed significantly from Almakashi and Gwani ($p < 0.05$).

Chloride of the sampling locations

The highest and lowest mean values of chloride found in the dry (month of April) and wet (month of August) seasons, respectively, were 168.72±26.30 mg/L and 37.70±8.45 mg/L in Almakashi and Reference river (Table 2b), while Gwani, on the other hand, had 159.11±10.92 mean concentrations (Table 2a). There was a significant difference between the concentration values obtained in the reference dam compared to those found in Almakashi and Gwani ($p < 0.05$).

Table 2a: Monthly Analysis of Chemical Parameters in Sampling Locations in Dry Season

Location	Season	Months	Nitrate	Phosphate	Sulphate	Chloride
Almakashi	Dry	Apr	9.33±2.46^a	8.03±1.13^a	28.67±2.13^b	168.72±26.30^a
		Dec	5.88±2.71^b	4.30±0.93^b	10.27±0.76^c	97.55±11.90^b
		Feb	4.61±1.55^b	7.78±0.93^a	26.79±6.49^b	119.97±33.72^b
		Jan	3.39±0.08^c	4.79±0.74^b	20.13±2.43^b	73.09±3.17^c
		Mar	9.14±2.78^a	6.40±1.53^a	29.26±6.42^b	116.69±17.81^b
		Nov	7.11±0.14^a	3.29±1.20^b	13.73±5.21^c	120.21±1.22^a
Gwani	Dry	Apr	1.63±0.50^c	3.68±1.27^b	42.96±7.25^a	159.11±10.92^a
		Dec	2.86±1.04^c	5.99±0.11^a	23.55±11.37^b	109.22±24.26^b
		Feb	1.90±0.35^c	4.04±1.38^b	32.47±2.60^a	152.24±22.52^a
		Jan	3.51±1.85^c	7.16±1.34^a	21.94±4.91^b	114.47±4.42^b
		Mar	1.16±0.27^c	4.77±1.28^b	31.56±12.55^a	140.78±16.93^a
		Nov	3.25±1.13^c	7.03±1.83^a	19.78±12.13^b	119.54±8.03^b
Reference	Dry	Apr	2.49±0.55^c	1.75±0.53^c	4.71±4.60^c	37.26±15.14^c
		Dec	3.30±2.57^c	3.35±3.96^b	4.06±0.09^c	52.56±4.53^c
		Feb	2.71±1.29^c	1.85±0.58^c	5.87±5.36^c	49.27±11.74^c
		Jan	1.18±0.25^c	0.98±0.77^c	4.42±3.98^c	61.12±2.77^c
		Mar	2.62±0.85^c	0.23±1.35^c	3.60±3.91^c	54.99±17.00^c
		Nov	5.21±0.60^b	4.64±1.00^b	6.33±1.81^c	60.34±11.68^c

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Location	0.000*	0.000*	0.000*	0.000*
Month	0.001*	0.005*	0.000*	0.000*
Location*Month	0.000*	0.000*	0.002*	0.000*

Keywords: Keyword: NO_3 = nitrate; PO_4 = phosphate; SO_4 = Sulphate and Cl^- = Chloride. *= significant difference (p value = 0.05); Same superscript in the same column indicates no significant difference while different values at the same column shows significant difference.

Table 2b: Monthly Analysis of Chemical Parameters in the Sampling Locations

Location	Season	Months	Nitrate	Phosphate	Sulphate	Chloride
Almakashi	Wet	Aug	3.91±1.03^{b}	3.45±0.51^{b}	13.27±3.13^{c}	95.37±16.82^{b}
		Jul	5.66±1.07^{b}	5.96±1.49^{a}	25.28±7.17^{b}	123.84±22.40^{a}
		Jun	6.92±1.40^{a}	7.28±1.37^{a}	23.16±3.08^{b}	151.79±14.53^{a}
		May	8.50±5.35^{a}	7.28±1.05^{a}	30.67±5.36^{a}	160.11±18.98^{a}
		Oct	4.51±0.28^{b}	3.63±0.16^{b}	12.92±1.32^{c}	119.49±1.24^{b}
		Sep	2.52±0.04^{c}	3.03±0.45^{c}	13.98±7.46^{c}	101.48±12.86^{b}
Gwani	Wet	Aug	3.96±0.32^{b}	3.78±2.25^{b}	24.68±8.59^{b}	85.33±10.20^{b}
		Jul	2.10±0.37^{c}	5.56±2.04^{a}	42.97±13.97^{a}	140.36±30.86^{a}
		Jun	1.62±0.65^{c}	5.98±0.73^{a}	34.74±15.33^{a}	134.24±18.59^{a}
		May	1.90±0.45^{c}	6.32±1.75^{a}	25.74±5.99^{b}	150.12±17.64^{a}
		Oct	3.37±0.64^{c}	5.99±0.20^{a}	18.40±4.49^{b}	73.86±02.21^{c}
		Sep	4.49±0.34^{b}	4.08±3.32^{b}	11.37±2.70^{c}	87.73±02.34^{b}
Reference	Wet	Aug	3.74±0.27^{c}	13.84±0.62^{c}	8.27±4.01^{c}	37.37±08.45^{c}
		Jul	2.70±0.92^{c}	1.19±6.53^{c}	4.28±1.85^{c}	51.45±10.13^{c}
		Jun	2.38±1.43^{c}	1.60±0.12^{c}	5.54±2.80^{c}	44.92±10.10^{c}
		May	0.28±0.14^{c}	2.00±0.56^{c}	5.00±1.93^{c}	44.01±11.76^{c}
		Oct	3.82±0.35^{b}	1.17±0.07^{c}	5.2±1.85^{c}	46.66±10.30^{c}
		Sep	4.20±0.33^{c}	0.91±0.13^{c}	8.75±0.72^{c}	54.42±10.11^{c}
Location			0.000*	0.000*	0.000*	0.000*
Month			0.001*	0.005*	0.000*	0.000*
Location*Month			0.000*	0.000*	0.002*	0.000*

Keywords: NO_3 = nitrate; PO_4 = phosphate; SO_4 = Sulphate and Cl^- = Chloride.*= significant effect (p value = 0.05); Same superscript in the same column indicates no significant difference while different values at the same column shows significant difference.

DISCUSSION

Physical Water Quality Parameters

pH

pH is considered an important parameter that determines the suitability of water for various purposes. The pH of water holds great significance for biotic communities since the majority of aquatic creatures are adapted to an average pH. In the present investigation pH ranges between 6.27±0.11 – 7.60±0.02. The NESREA (2011) and WHO (2013) limits the pH of drinking water between the range of 6.5–8.5. So, it can definitely be said from water pH point of view that, the water of river Gongola corridors is still in the limit of drinking purpose, but care should be taken to retain the acceptable limit of pH.

The mean pH concentration of the studied water of Almakashi, Gwani and the reference ranged from 6.27±0.11 – 7.60±0.02. This range was more acidic and less alkaline than 6.38 to 7.85 values obtained by Muhammad, (2022) in Dadin kowa reservoir. The range obtained in that study was higher than 4.70 - 6.50 reported by Akpan, (2013) in Imo river estuary. The level of pH is favourable to support optimal aquatic life including fish and thus is in line with the observation of Alam *et al*, (2014). The reported range is also within the acceptable limit of 6.5 – 8.5 by NESREA (2011). Consequently, the human activities within the studied rivers may not have affected the pH levels of these water corridors of Gongola River. Hence, the pH of these water bodies may not affects neither the aquatic nor consumers that are exposed to the water ecosystem.

Higher value of pH (slightly alkaline condition) observed in August (mid or late wet season) (Table 1b) may be due to increase in penetration of fertilizers from farmlands as a result of surface run-off into the rivers. This result is contrary to the findings of Muhammed *et al*., (2022) who observed alkaline condition in dry season. The lowest pH value was found in the month of June (Early wet season) (Table 1b). This result is similar to the findings of Muhammed *et al*. (2022) who observed that acidity of the water in wet season. Low pH may be as a result of the penetration of chemicals such as nitrate, sulphate and chloride ions in the water body from Agricultural lands or domestic activities. Mean concentrations of pH values in this study is contrary to the findings of Akintunde and Bamgbose, (2020) who found 5.51 ± 0.16 to 6.46 ± 1.27 in dry season. This is probably as a result of chemicals released by farmers during dry season Agricultural activities because the level of water greatly reduced during dry season and farmers farmed their product within the river side. The pH range of this study is lesser than the report of Patra *et al.*, (2010) who found concentrations of 7.60±0.53 - 8.67±0.18 higher than the WHO recommended limits of pH values ranged (6.5 - 8.65) in Mansoon season in India. Similarly, the lowest and highest pH of 7.18 -8.41 were recorded by Smith *et al*, (2012) in the Olive River in South Africa, though it is within the recommended acceptable limit of 6.5 – 8.5 by WHO (2013) but slightly alkaline condition. The higher pH value was attributed to higher sediment loads in the river.

Electrical Conductivity/Total Dissolve Solids

The mean concentration of Electrical conductivity (EC) ranges between 237.50±2.12 -730.50±25.11µS/cm in August (late wet season) and April (late dry season) respectively. Highest value obtained in April (late dry season) may probably be as a result of reduction in movement of water due to low amount of wind speed. This range value was lower than 443.35-574.13µS/cm found by Ebong and John (2021) in Niger Delta river estuary as well and also lower than 1,047µS/cm obtained by Smith (2012) in the samples collected in 2009 from Olive River. Nevertheless, the mean values of EC obtained in all the sampling locations of this research were lower than the 1000.0µS/cm limit recommended for unpolluted water by NESREA (2011). Hence, monthly (or seasonal) variation in EC of the studied water channels may not affect the water quality of the sampling locations and its biota such as (*O. niloticus* and *C. gariepinus*).

Total Dissolved Solids (TDS)

The levels of total dissolved solids (TDS) in all the studied river corridors and the reference dam ranged between 178.72±65.14 - 178.72±65.14 mg/L. The range values found was slightly higher than the values of 120.00 – 143.7mg/l reported by Ebong and John (2021) who attributed it to human activities within that water bodies may have elevated their TDS levels. The mean value obtained in this research was lower than 500.0 mg/L recommended for the maximum acceptable water body by NESREA (2011).

The range of the mean concentration of total dissolve solids (TDS) was 111.75±1.76mg/L and 365.25±12.55mg/L both in late wet (August) and late dry (April) seasons respectively. The concentrations found are lower than the NESREA (2011) recommended limit of 500 mg/L for unpolluted water body. This report is similar to the findings of Muhammad *et al*., (2022) who obtained highest conductivity values in early wet season 275.82±77.02mg/L. Similarly, Akintunde and Bamgbose, (2020) reported higher concentration of (TDS) values within the range of 246.67 ± 4.24 mg/L to 1402.50 ± 3.21mg/L in the dry seasons; while lower values in range of 275.00 ± 2.50 mg/L to 294.33 ± 4.74mg/L were observed in the rainy seasons. There was no significant difference observed between seasons in this research, at $p \leq 0.05$ confidence limit, implies no seasonal pattern in variation. Increase in TDS results, in increase in EC and turbidity and all these were found in the month of April, this is because there is less amount of wind speed in circulation during extreme dry season of the year. High level of evaporation occur which lead to reduction in water volume. This agrees with findings made by Adakole (2015) in river Kubanni, Zaria who observed higher mean conductivity during dry season and attributed to higher concentration effect due to reduce water volume from their main tributaries. High electrical conductivity of the water surface indicated trophic status and productivity (Akphan, 2016).

Turbidity

The values of mean concentration for turbidity recorded in this study varied from 3.25±0.83 NTU to 13.39±2.82 NTU obtained in August and February respectively in the study locations of River Gongola. The mean concentration obtained was lower than 94.16±14.69 NTU (ranged values of 74.80 to 110.36 NTU) by Ebong and John (2021) and also lower than 76.00 – 96.70 NTU ranged obtained by Ebigwai *et al*., (2014). The mean concentrations obtained especially late dry season of this study (February, March and April) was also higher than the standard acceptable limit of 5.0 NTU stipulated by NESREA (2011) and slightly higher than 10.0 limits set by WHO (2013) for an open water bodies.

Consequently, the anthropogenic activities in the study area may have attributed to the increase levels of turbidity reported. The slightly high turbidity found may be harmful to sampling specimens exposed to these water bodies because according to Reza and Singh (2010) increase turbidity in water is directly related to increase in disease-causing microorganisms. As a consequence of this, these water bodies may not be suitable for drinking and bathing based on their high levels of turbid substance.

There was no significant difference between the months of the study but higher values were found in dry season at Gwani in ascending order of April < March < February which included: 12.71±1.95, 12.82±2.65 and 13.39±2.82 NTU respectively. Additionally, 12.26±2.46 NTU was the highest mean concentration found in April at Almakashi. On the other hand, the lowest values in ascending order were 3.25±0.83 NTU, 3.52±1.83 NTU, and 3.53±3.42 NTU respectively, in August< July<September, obtained in the reference site. Another reason may be because the volume of the water has greatly reduced, thus the flow rate that may wipe-away turbid substance may equally be reduced but human's activity increases due to high demand of the perennial water system for domestic, dry season agricultural and industrial activities (Dilshod *et al*., 2021).

Biological Oxygen Demand (COD) /Chemical Oxygen Demand (COD)

Biochemical Oxygen Demand (BOD) of a water channel indicates the level of oxygen required by microorganisms to decompose organic waste under aerobic conditions. The highest and the lowest range of BOD mean

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concentration found in the reference dam (1.91±0.33 mg/L) and Gwani (4.54±0.55 mg/L) in September (late wet) and November (early dry) season respectively. All the Biological Oxygen Demand values obtained across the months of this study fall within the 6.0 mg/L NESREA (2011) acceptable limits for an un-polluted water body. This finding agrees with the values of 2.23 – 3.95 mg/L obtained in dry months of November and January by Muhammad (2021) at Dadin kowa dam. Conversely, Nguyen and Huynh, (2022) reported that BOD in the wet (rainy) season months (May–September) fluctuated more than that in the dry season months. The BOD value obtained by Akintunde and Bamgbose, (2020) were 549.00±3.44 to 759.00±3.94 in dry season and 519.70±1.21 to 817.50±4.59mg/L in wet season at the point of discharge of effluent into water ways, quite higher than both the values obtained in this study and also that of NESREA, (2011) recommended value of 6.0 mg/L.

On the other hand, Chemical Oxygen Demand (COD) also had a quite significant lowest value of 5.31±1.49 mg/L in September (late wet season) at the reference site compared to the highest value of 19.20±1.08 mg/L in April (late dry season) at Gwani Sampling site (Table 10a). Both the low and higher values obtained were less than 30.0 mg/L, the standard acceptable limit of COD for unpolluted water by WHO (2013). The values obtained were less than that of Akintunde and Bamgbose, (2020) who reported the high range of mean concentration of 1208.00±3.30 - 1670.67±3.72 in dry season and 1142.93±3.16 - 1798.77 during wet season of the study period in Lagos, Nigeria.

Water Chemical Parameters of studied Sites

Nitrate

The level of nitrate in the studied water corridors in Gombe State was analysed and the mean range value obtained were 9.33±2.46 mg/L in the month of November at Almakashi and 1.18±1.25mg/L in April at the reference dam respectively. The concentrations values obtained in Almakashi differed significantly with the mean values obtained in the reference river ($p < 0.05$). The level of nitrate in all the sampling rivers was below the W.H.O and NESREA recommended limit of 10 mg/L and 40mg/L respectively. Thus, is below 36.77±5.90 mg/L mean values reported by Ebong and John (2021).

All the nitrate values reported in all the sampling sites including the reference dam were higher than ranged values of 0.33-2.35mg/L obtained by Muhammad *et al*., (2021) in wet season (from July to September) at Dadin Kowa dam and 4.2 – 5.7 mg/L values obtained by Simeon *et al*., (2019) from ?. The mean concentrations obtained in the reference dam differed significantly with the mean values obtained in the two river corridors (Almakashi and Gwani) ($p < 0.05$). The increase in nitrate between the sampling areas reported may be linked to runoff of nitrogenous fertilizers from farm lands along routes of the sampling locations as a result of anthropogenic activities (Kuffour *et al*., 2021).

Wireko (2015) also attributed nitrate levels in surface water to increase in surface runoff, bare areas and leaching of nitrogenous fertilizers from nearby farmlands. A study by Maghanga *et al*. (2013) concluded that, nitrogen fertilizer application contributed to an increase in nitrate levels in surface water through surface run. Another reason for the elevation of nitrates found between the reference dam and the river corridors may also be due to the released of the nitrate from the sediments during decomposition of organic matter. Increase in in Nitrate in the month of November (early dry season) could be attributed to concentration effect due to reduction in water volume and this is contrary to the findings of Muhammad *et al*. (2021) who reported highest value in dry season.

Muhammad *et al*. (2021) reported that low nitrate values signifies period of late dry season or early onset of rains and the period preceding the first upsurge of phytoplankton growth, Lymer *et al*. (2014) observed that concentration of nitrate could be reduced by plankton and macrophytes uptake during the period. Hence, exposure to these water corridors may lead to disease conditions in living organisms such as *O. niloticus* and *C. gariepinus* (Speijers, 1996). The high nitrate content of these water channels may lead to eutrophication of water body because of the damning construction that slows the rate of flow of the aquatic ecosystem (Adeolu *et al*., 2016).

Phosphate

The highest phosphate concentration was found in Almakashi River (0.80±0.110 mg/L) in the month of July and the lowest mean concentration was recorded in the reference dam (0.09±0.01 mg/L) in April during late dry season. The mean concentrations observed in this study were below the phosphate maximum recommended limits of 3.5mg/l sets by NESREA (2011). There is significant amount of phosphate in the reference site compared to the two sampling locations of Almakashi and Gwani ($p < 0.05$). The reported range is lower than 2.144 to 9.741mg/l by Isiuku and Enyoh (2020). The mean value of phosphate recorded by Ebong and John (2021) was 2.45±0.77 mg/L higher than all the reported values from all the sampling locations of this study and also lower than the limit recommended for unpolluted water (3.5 mg/l) by NESREA (2011). This is an indication that, the natural and anthropogenic activities within the Gongola river of Gombe State may not have affected the phosphate content significantly. Hence, the phosphate content of the studied water catchments may not have serious impact on both *O. niloticus* and *C. gariepinus* and aquatic animals exposed to these aquatic ecosystems.

Sulphate

Sulphate concentrations in the studied rivers of the reference dam (Balanga) and corridors (Almakashi and Gwani) of Gongola river complex varied respectively in an ascending order of 3.60±3.91 mg/L, 29.26±6.42mg/L and 42.97±13.97 mg/L. These values are higher than 0.05 – 23.19mg/l reported by Ebigwai *et al*. (2014). However, the mean value of sulphate of all the study sites was lower than 86.40±13.29 mg/L obtained by Ebong and John (2021). Thus, lower than 200.0 mg/L and 500.0 mg/l recommended for unpolluted water by WHO (2004) and NESREA, (2011). Therefore, the levels of sulphate in the studied water bodies may not be harmful to both *Oreochromis niloticus* and *Claria gariepinus* and other aquatic life.

Chloride

Although the Chloride mean values differs significantly between the reference dam (37.70±8.45mg/L in August) and that of Almakashi (168.72±26.30mg/L) in April and Gwani (159.11±10.92 mg/L) river corridors but all values were found within acceptable chloride water values sets by WHO (2004) and NESREA (2011) was 250mg/L and 500mg/L respectively. The highest concentration of chloride observed in the April (dry season) may be attributed to the rise in temperature and low water level.

This is similar to the findings of Majumder (2014) that found highest value in summer and the minimum value (76.91±27.13 mg/L) in late wet (autumn). Conversely, the low concentration of Chloride ion was also observed in winter by Sahni and Yadav (2012) at Bharawas pond in Haryana and also by Shiddamallaya and Pratima (2008) in fresh water body of tank water in Bhalki town of Bidar. Venkatesharaju *et al*. (2010) observed the higher concentration of Chloride ion in the summer; and assumed that the higher concentration may be due to the increased temperature and also due to the low level of water during summer.

CONCLUSION

Most of the physical and chemical parameters obtained from Almakashi and Gwani river catchments deviates from the mean concentrations obtained from the reference river of Balanga dam though falls within the standard recommended values. It is therefore recommended that, there is need for careful monitoring and regulation of anthropogenic activities in the sampling areas. Additionally, there is need for identifying the anthropogenic activities that are affecting the water quality of these ecosystems.

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