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Spatio-Temporal Assessment of Physicochemical Parameters in River Benue at Jimeta-Yola

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Abstract- ***This study evaluated the spatio-temporal variation of physicochemical water quality in River Benue along the Jimeta-Yola axis, Adamawa State, Nigeria. Water samples were collected monthly during the dry and rainy seasons of 2024 from three stations representing the upstream, midstream, and downstream reaches. Physicochemical parameters were analyzed using standard methods, and the data were subjected to two-way analysis of variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) test at P < 0.05. Significant spatial and seasonal variations were observed for all measured parameters. Water temperature was higher during the dry season (28.2°C), whereas turbidity increased from 15.00 to 22.67 NTU during the rainy season. The downstream station recorded the highest turbidity (22.5 NTU), nitrate (4.75 mg/L), and biochemical oxygen demand (4.70 mg/L), while dissolved oxygen declined to 6.20 mg/L. Significant site × season interactions for temperature, dissolved oxygen, nitrate, and biochemical oxygen demand indicated intensified pollutant loading downstream during the rainy season. Although most parameters remained within World Health Organization and Nigerian drinking water guideline limits, the downstream Damare-Geriyo reach showed clear evidence of cumulative impacts from urban wastewater and agricultural runoff. Continuous water quality monitoring and improved watershed management are therefore recommended to protect the ecological health and water resource value of River Benue.***

Index Terms- River Benue, Physicochemical Water Quality, Spatio-Temporal Variation, Seasonal Dynamics, Anthropogenic Pollution, Watershed Management.

I. INTRODUCTION

Water is an essential natural resource that supports human health, economic development, food production, and ecosystem functioning [1, 2]. Growing population, urbanization, industrialization, and agricultural expansion have increased the global demand for freshwater while reducing the availability of clean water resources [3, 4]. In many developing countries, including Nigeria, maintaining adequate water quality remains a significant challenge because of inadequate wastewater treatment, weak environmental regulation, and increasing anthropogenic pollution [1, 5]. River Benue, the second largest river in Nigeria, serves as a major source of domestic water supply, irrigation, fisheries, transportation, and other socio-economic activities for communities within the Jimeta-Yola metropolitan area and surrounding settlements [3, 6, 7]. However, increasing urban development and population growth have intensified pressure on the river through the discharge of untreated domestic wastewater, industrial effluents, agricultural runoff, and solid waste, resulting in progressive deterioration of water quality [8-10].

Surface water quality is influenced by the interaction of natural environmental processes and human activities. Weathering of rocks, hydrological conditions, and seasonal variations contribute to the natural composition of river water, whereas urban wastewater, agricultural chemicals, and industrial discharges alter its physicochemical characteristics beyond acceptable environmental limits [3, 5, 11]. Physicochemical parameters such as pH, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), turbidity, nitrate, and phosphate provide valuable information on ecosystem health, pollution status, and the suitability of water for domestic, agricultural, and ecological uses [6, 12, 13]. Previous investigations within the Jimeta-Yola reach of River Benue reported elevated turbidity, nitrate, and other water quality parameters above recommended limits established by the World Health Organization and other regulatory agencies, indicating moderate

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pollution associated with urban runoff, abattoir discharges, and irrigation return flows [3, 14-17].

Seasonal hydrological conditions strongly influence pollutant transport and water quality in tropical rivers. During the rainy season, increased runoff transports sediments, nutrients, pathogens, and agricultural chemicals into rivers, resulting in higher turbidity and nutrient concentrations ([3, 8, 18]. In contrast, reduced river discharge during the dry season limits dilution and promotes the accumulation of dissolved ions, nutrients, and trace metals [1, 9, 14]. Elevated concentrations of nitrate and phosphate contribute to eutrophication, excessive algal growth, depletion of dissolved oxygen, and degradation of aquatic habitats, while excessive nitrate in drinking water poses serious public health risks, particularly for infants [19-21]. These seasonal variations highlight the importance of continuous water quality monitoring to support effective environmental management and reduce risks to human health.

The spatial distribution of pollutants within river systems generally reflects surrounding land use and cumulative anthropogenic activities. Water quality commonly deteriorates from upstream locations with limited human influence toward downstream reaches receiving municipal wastewater, agricultural drainage, and industrial discharges [3, 18]. Similar patterns have been reported along the Jimeta-Yola section of River Benue, where downstream locations influenced by urban settlements and the Geriyo irrigation scheme exhibit poorer water quality than upstream reference sites [6, 14]. Although previous studies have evaluated selected physicochemical parameters or specific pollution sources within the study area, comprehensive assessments that simultaneously investigate both spatial and seasonal variations using integrated statistical approaches remain limited. This gap restricts a complete understanding of pollution dynamics and limits the development of effective water resource management strategies for the Upper River Benue.

This study therefore aims to assess the spatio-temporal variation of selected physicochemical parameters, including pH, temperature, turbidity, dissolved oxygen, biochemical oxygen demand, nitrate, and phosphate, in River Benue within the Jimeta-Yola metropolitan area. The study applies appropriate statistical analyses to evaluate the effects of sampling location, season, and their interaction on water quality. The findings will provide an updated baseline for monitoring environmental change, support evidence-based management of surface water resources, and contribute to the protection of public health and aquatic ecosystems in northeastern Nigeria.

II. METHODOLOGY

A. Study Area

The study was conducted along the Upper River Benue within the Jimeta axis of Yola North Local Government Area, Adamawa State, northeastern Nigeria (Figure 1) [6]. The study area lies between latitudes 9°15′ N and 9°20′ N and longitudes 12°25′ E and 12°29′ E, at an average elevation of approximately 135 m above sea level [22]. The region experiences a tropical semi-arid climate characterized by two distinct seasons, namely the rainy season from April to October and the dry season from November to March [1, 3]. Mean annual air temperature is approximately 28°C, while high evapotranspiration rates prevail during the dry season, influencing river discharge and water quality [1]. Figure 1. Location of the study area showing the three sampling stations (Station A, Upstream; Station B, Midstream; and Station C, Downstream) along the Upper River Benue within the Jimeta-Yola metropolitan area, Adamawa State, northeastern Nigeria.

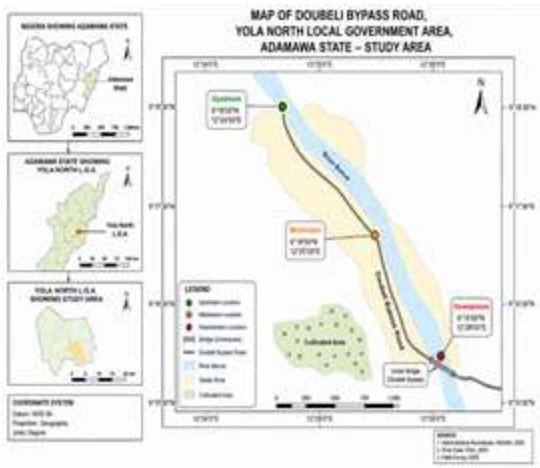

Figure 1: Doubeli By-pass Road, Yola-North Local government area, Adamawa state

B. Sampling Stations and Sample Collection

Three sampling stations were established along River Benue using purposive sampling to represent a longitudinal gradient of anthropogenic activities within the study area [6, 19]. The stations were selected based on surrounding land use, accessibility, and potential pollution sources. Station A (Upstream) was located near the Custom Office and served as the reference station because it is subject to relatively limited anthropogenic influence before the river enters the urban area. Station B (Midstream) was situated approximately 1 km downstream of Station A within the central section of the river and represented mixed water quality conditions resulting from cumulative upstream inputs and urban activities. Station C (Downstream) was located approximately 1.5 km downstream of Station B near the Damare and Geriyo axis, where the river receives runoff from irrigated agricultural fields, municipal drainage, and other urban discharges, making this station representative of the most impacted section of the study area [3, 6].

Water samples were collected once every month during the rainy and dry seasons of 2024 to capture seasonal variations in physicochemical characteristics. At each sampling station, samples were collected from approximately 30 cm below the water surface using pre-cleaned, acid-washed 1 L high-density polyethylene (HDPE) bottles following the procedures described in the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) Standard Methods for the Examination of Water and Wastewater, 24th edition [23]. Samples designated for heavy metal determination were preserved immediately after collection by acidifying them with concentrated nitric acid (HNO_3) to a pH below 2, in accordance with APHA Method 3030B [23]. All samples were stored in insulated ice chests at approximately 4°C and transported to the laboratory within six hours for physicochemical analysis in accordance with APHA sample preservation and handling guidelines [23].

C. Laboratory and In Situ Analysis

Physicochemical parameters were determined following the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) Standard Methods for the Examination of Water and Wastewater (24th ed.) [23]. Water temperature, pH, electrical conductivity (EC), and dissolved oxygen (DO) were measured in situ using calibrated portable multiparameter meters immediately after sample collection. Turbidity was determined in nephelometric turbidity units (NTU) using a calibrated portable nephelometric turbidometer in accordance with APHA Method 2130 B [23].

Laboratory analyses were conducted immediately after sample preservation and transportation. Total dissolved solids (TDS) and total suspended solids (TSS) were determined using the gravimetric method following APHA Methods 2540 C and 2540 D, respectively. Biochemical oxygen demand (BOD_5) was determined using the five-day incubation method at 20°C (APHA Method 5210 B), while nitrate (NO_3^-) and phosphate (PO_4^{3-}) concentrations were analyzed using UV-Visible spectrophotometry following APHA Methods 4500-NO_3^- and 4500-P, respectively. Instrument calibration, reagent blanks, duplicate samples, and standard solutions were used as quality assurance measures to ensure the accuracy and reliability of the analytical results [23].

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D. Statistical Analysis

Data were analyzed using descriptive statistics to compute the mean and standard deviation of all physicochemical parameters. Pearson correlation analysis was performed to determine relationships among the measured water quality variables [9, 18, 24]. A two-way analysis of variance (ANOVA) was used to evaluate the effects of sampling location (Upstream, Midstream, and Downstream), season (Rainy and Dry), and their interaction on the measured physicochemical parameters. Where significant differences were detected at $P < 0.05$, Tukey's Honestly Significant Difference (HSD) test was applied for mean separation. All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA) and R software version 4.3.0.

III. RESULTS AND DISCUSSION

The physicochemical characteristics of the River Benue at Jimeta-Yola indicate that most measured parameters comply with national and international water quality standards, except turbidity as shown table 1. The recorded pH (6.67 to 7.10) and nitrate concentrations (4.75 to 5.23 mg/L) fall within the WHO and Nigerian permissible limits of 6.5 to 8.5 and ≤50 mg/L, respectively, indicating low direct health risks [1, 6, 9]. In contrast, turbidity values (15.00 to 22.67 NTU) exceed the recommended limit of 5 NTU, reflecting the influence of sediment resuspension, surface runoff, and agricultural activities (World Health Organization, 2022; [3, 8]. Dissolved oxygen concentrations (6.13 to 6.53 mg/L) remain above the minimum 5.0 mg/L required to sustain aquatic life, while BOD_5 (4.70 to 4.87 mg/L) and phosphate (0.375 to 0.400 mg/L) indicate moderate organic and nutrient loading. The BOD_5 values are slightly higher than those reported in previous studies, suggesting increasing anthropogenic pressure from urban and domestic waste discharges [8]. Overall, the river maintains acceptable ecological conditions, although the elevated turbidity highlights the need for adequate treatment before domestic use [1, 3].

The two-way analysis of variance (ANOVA) demonstrated that sampling site and season significantly influenced all measured physicochemical parameters of River Benue at Jimeta-Yola as indicated in table 2. Significant site × season interactions were also observed for temperature, dissolved oxygen (DO), nitrate, and biochemical oxygen demand (BOD), indicating that seasonal hydrological conditions modified the spatial distribution of these variables. These findings demonstrate that water quality in the study reach is controlled by the combined effects of natural seasonal processes and anthropogenic inputs, emphasizing the need to consider both spatial and temporal variability when evaluating river health and designing water quality management strategies.

Table 1. Comparison of measured physicochemical parameters of River Benue with WHO (2022) and NSDWQ (2015) guideline limits

Parameter	Unit	Measured Value (This Study)	WHO (2022) Guideline	NSDWQ (2015) Guideline	Status
pH	-	6.67 to 7.10	6.5 to 8.5	6.5 to 8.5	Within limit
Temperature	°C	24.5 to 28.2	Not specified	Not specified	Reference only
Turbidity	NTU	15.00 to 22.67	≤ 5	≤ 5	Exceeds limit
Dissolved Oxygen (DO)	mg/L	6.13 to 6.53	Not specified*	Not specified	Satisfactory for aquatic life*
Biochemical Oxygen Demand (BOD_5)	mg/L	4.70 to 4.87	Not specified	Not specified	Reference only
Nitrate (NO_3^-)	mg/L	4.75 to 5.23	≤ 50	≤ 50	Within limit
Phosphate (PO_4^{3-})	mg/L	0.375 to 0.400	Not specified	Not specified	Reference only

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Table 2. Two-way analysis of variance for the physicochemical water-quality parameters

Parameter	Site F	p-value	Season F	p-value	Site × Season F	p-value
pH	6.50	0.012	84.50	<0.001	0.50	0.619
Temperature (°C)	13.50	0.001	6160.50	<0.001	73.50	<0.001
Turbidity (NTU)	84.50	<0.001	264.50	<0.001	3.50	0.063
DO (mg/L)	14.00	0.001	72.00	<0.001	6.00	0.016
Nitrate (mg/L)	234.50	<0.001	2244.50	<0.001	9.50	0.003
Phosphate (mg/L)	100.42	<0.001	700.96	<0.001	0.12	0.892
BOD (mg/L)	45.50	<0.001	338.00	<0.001	30.50	<0.001

Note. Site and Site × Season effects were tested with $F(2, 12)$, while Season was tested with $F(1, 12)$. The total sample size was 18. Values reported as 0.000 in the source output are presented as $p < 0.001$. DO = dissolved oxygen; BOD = biochemical oxygen demand. Statistical significance was evaluated at $p < 0.05$.

Table 3. Tukey HSD mean separation for site, season, and site-by-season effects on the water-quality parameters

Effect/level	pH	Temperature (°C)	Turbidity (NTU)	DO (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	BOD (mg/L)
SITE (n = 6)							
Upstream	7.00 a	26.50 a	15.0 c	6.50 a	3.50 c	0.2767 c	4.15 c
Midstream	6.85 ab	26.35 ab	19.0 b	6.30 b	4.10 b	0.3267 b	4.45 b
Downstream	6.80 b	26.20 b	22.5 a	6.20 b	4.75 a	0.3750 a	4.70 a
SEASON (n = 9)							
Dry season	7.100 a	28.2 a	15.000 b	6.533 a	3.000 b	0.2511 b	4.000 b
Rainy season	6.667 b	24.5 b	22.667 a	6.133 b	5.233 a	0.4011 a	4.867 a
SITE × SEASON (n = 3)							
Upstream × Dry	7.2 a	28.0 b	12 e	6.8 a	2.5 f	0.2033 f	3.5 d
Midstream × Dry	7.1 a	28.2 ab	15 d	6.5 b	3.0 e	0.2500 e	4.0 c
Downstream × Dry	7.0 ab	28.4 a	18 c	6.3 bc	3.5 d	0.3000 d	4.5 b
Upstream × Rainy	6.8 bc	25.0 c	18 c	6.2 c	4.5 c	0.3500 c	4.8 a
Midstream × Rainy	6.6 c	24.5 d	23 b	6.1 c	5.2 b	0.4033 b	4.9 a
Downstream × Rainy	6.6 c	24.0 e	27 a	6.1 c	6.0 a	0.4500 a	4.9 a

Note. Each value is the arithmetic mean followed by its Tukey grouping letter(s). Within a given effect (Site, Season, or Site × Season) and within the same parameter column, means that do not share a letter differ significantly at the 5% level. Site × Season interaction was not significant for pH, turbidity, or phosphate; those interaction means are retained only to reproduce the complete source output. DO = dissolved oxygen; BOD = biochemical oxygen demand.

A. Hydrogen Ion Concentration (pH) and Temperature

The pH ranged from 6.67 during the rainy season to 7.10 during the dry season, with significantly higher values recorded at the upstream station than downstream (Table 3). Despite the observed seasonal decline, all values remained within the recommended range of 6.5 to 8.5 for drinking water established by the World Health Organization [15] and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). The lower pH during the rainy season is attributed to increased runoff carrying organic debris and dissolved carbon dioxide, which forms weak carbonic acid during microbial decomposition. The gradual decline in pH toward the downstream station further suggests the cumulative influence of municipal wastewater and organic discharges entering the river. Similar observations have been reported for River Benue by [1] and [9], although the values obtained in this study were lower than those reported by [6], reflecting spatial differences in watershed characteristics and pollution intensity. The maintenance of near-neutral pH indicates that the river retains adequate buffering capacity despite increasing anthropogenic pressure.

Water temperature varied significantly between seasons, averaging 28.2°C during the dry season and 24.5°C during the rainy season as shown in table 3. Elevated dry-season temperatures are consistent with increased solar radiation, lower cloud cover, and reduced river discharge, while rainfall and increased flow contributed to lower temperatures during the wet season. Similar seasonal patterns have been documented for tropical rivers across northeastern Nigeria [1, 6]. Temperature is a key regulator of aquatic biochemical processes because it influences dissolved oxygen solubility, microbial metabolism, and nutrient cycling. The significant interaction between sampling site and season further indicates that local environmental conditions amplify seasonal temperature responses, thereby affecting overall river water quality.

B. Turbidity

Turbidity exhibited significant spatial and seasonal variation, with the highest values recorded at the downstream station and during the rainy season as shown in both table 2 and table 3 respectively. Although the measured values exceeded the WHO guideline value of 5 NTU for drinking water [15], they remained substantially lower than the extreme turbidity levels previously reported by [3] for River Benue. The pronounced increase during the rainy season is associated with enhanced surface runoff, bank erosion, and sediment transport from cultivated lands and urban surfaces. The downstream increase reflects cumulative inputs from municipal drainage, construction activities, and agricultural runoff within the Geriyo irrigation corridor. Elevated turbidity reduces light penetration, limits primary productivity, and promotes the transport of nutrients, pathogens, and heavy metals adsorbed onto suspended particles. These findings agree with those of [3] and [8], confirming that rainfall-driven runoff remains a dominant factor controlling suspended sediment dynamics in the study area.

C. Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD)

Dissolved oxygen and biochemical oxygen demand displayed contrasting spatial and seasonal patterns (Table 3). Dissolved oxygen remained highest at the upstream station and during the dry season, whereas BOD increased significantly downstream and during the rainy season. The observed reduction in DO downstream reflects increased microbial respiration resulting from the decomposition of organic matter introduced through municipal wastewater, agricultural runoff, and other anthropogenic discharges. Conversely, elevated BOD indicates increased concentrations of biodegradable organic matter requiring oxygen for microbial degradation. The inverse relationship between DO and BOD represents a well-established indicator of organic pollution in freshwater ecosystems and is consistent with previous studies conducted on River Benue [8, 14]. Importantly, mean DO concentrations remained above the minimum threshold of 5 mg/L recommended for sustaining healthy aquatic life, whereas BOD values approached levels indicative of moderate organic pollution. These findings suggest that although the river maintains sufficient oxygen to support aquatic organisms, continued increases in organic loading could reduce its ecological resilience and accelerate water quality deterioration, particularly in downstream reaches.

D. Nutrients (Nitrate and Phosphate)

Nitrate and phosphate concentrations increased significantly toward the downstream station and during the rainy season, with nitrate exhibiting a significant site and season interaction (Tables 2 and 3). This interaction indicates that nutrient enrichment was greatest at the downstream Geriyo axis during periods of intense rainfall, when agricultural runoff, irrigation return flows, and urban stormwater

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contributed substantial nutrient loads to the river. These findings are consistent with those of [3] and [14] Hong et al. (2014) and Luka et al. (2013), who identified fertilizer application, municipal runoff, and irrigation activities as the principal sources of nutrient enrichment within this section of River Benue. Although nitrate concentrations remained well below the WHO guideline value of 50 mg/L for drinking water [15] and phosphate concentrations did not exceed values commonly associated with severe contamination, the progressive downstream accumulation of both nutrients indicates increasing anthropogenic influence. Persistent nutrient enrichment promotes algal proliferation, accelerates eutrophication, and alters aquatic ecosystem functioning by increasing oxygen demand during organic matter decomposition. Consequently, effective management of agricultural practices, wastewater discharge, and stormwater runoff is essential to prevent further nutrient accumulation and preserve the ecological integrity of River Benue.

IV. CONCLUSION

The spatio-temporal assessment of River Benue at the Jimeta-Yola axis showed that surface water quality is significantly influenced by seasonal variation and increasing anthropogenic activities along the downstream reach. The downstream station near the Damare-Geriyo axis exhibited the greatest water quality deterioration, characterized by elevated turbidity, biochemical oxygen demand, and nutrient concentrations resulting from cumulative urban wastewater and agricultural runoff. These impacts intensified during the rainy season because surface runoff increased the transport of sediments, organic matter, and nutrients into the river. Although most physicochemical parameters remained within the guideline limits of the World Health Organization and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015), the significant site and season interactions indicate increasing vulnerability to localized eutrophication and ecological degradation. These findings emphasize the need for integrated watershed management, stricter control of wastewater discharges, improved agricultural practices, and continuous water quality monitoring to protect the ecological integrity of River Benue and sustain its domestic and agricultural uses.

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