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Physicochemical Properties and Heavy Metal Contamination of Surface Water from Upper River Benue at Jimeta, Yola North, Nigeria

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Abstract- ***Surface water pollution by heavy metals is a major environmental concern due to its adverse effects on aquatic ecosystems and human health. This study assessed the physicochemical properties and heavy metal concentrations of surface water from the Upper River Benue at the Jimeta axis, Yola North, Adamawa State, Nigeria. Water samples were collected monthly between August 2024 and January 2025 from three sampling sites: Near Custom Office, Middle of the River, and Damare side. Physicochemical parameters including temperature, pH, electrical conductivity, turbidity, and dissolved oxygen were determined using standard analytical methods, while concentrations of lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn) were analyzed using Flame Atomic Absorption Spectrophotometry (FAAS). Results revealed slightly alkaline pH values (8.57–9.13), moderate electrical conductivity, and dissolved oxygen levels adequate for aquatic life. Heavy metal concentrations across all sites and months were below World Health Organization permissible limits. Statistical analysis showed no significant spatial or temporal variation in heavy metal concentrations (P > 0.05). The findings indicate that surface water from River Benue at Jimeta is currently suitable for domestic and ecological use; however, continuous monitoring is recommended to prevent future contamination.***

Keywords- ***Surface water; Heavy metals; Physicochemical parameters; River Benue; FAAS***

I. INTRODUCTION

Surface water resources play a vital role in domestic supply, agriculture, fisheries, and industrial activities, particularly in developing countries. However, rapid urbanization, population growth, and increased anthropogenic activities have contributed to the deterioration of surface water quality through the introduction of pollutants, including heavy metals [1], [4]. Heavy metals are of particular concern because they are non-biodegradable, persistent in the environment, and capable of accumulating in aquatic systems, posing serious risks to human health and aquatic organisms [6], [10].

Physicochemical parameters such as temperature, pH, dissolved oxygen, electrical conductivity, and turbidity are important indicators of water quality, as they influence the mobility, bioavailability, and toxicity of heavy metals in aquatic environments [3], [17]. Variations in these parameters can alter chemical equilibria in water bodies, thereby enhancing or reducing metal solubility and transport [9], [11]. Consequently, integrated assessment of physicochemical characteristics alongside heavy metal concentrations is essential for understanding surface water quality status [2], [27].

In many parts of Nigeria, rivers receive untreated domestic waste, agricultural runoff, and urban effluents, resulting in increased levels of potentially toxic metals such as lead, cadmium, chromium, copper, and zinc [7], [8], [10]. Studies conducted on Nigerian river systems have reported seasonal variations in heavy metal concentrations, often linked to hydrological conditions, sediment resuspension, and reduced dilution during dry seasons [9], [16], [18]. Although some metals such as copper and zinc are essential micronutrients, elevated concentrations can be toxic to aquatic organisms and humans [29], [30].

River Benue is one of the major river systems in Nigeria and serves as an important source of water for domestic use, fishing, irrigation, and transportation in Yola North, Adamawa State. Despite its socio-economic importance, increasing urban activities around the Jimeta axis raise concerns about potential degradation of its water quality. Continuous monitoring of physicochemical parameters and heavy metal concentrations is therefore necessary to ensure compliance with international water quality standards and to safeguard public health [1], [31].

This study assessed the physicochemical properties and heavy metal contamination of surface water from the Upper River Benue at Jimeta, Yola North, Nigeria, with a view to determining its suitability for domestic and ecological use.

II. METHODOLOGY

Study Area

The study was conducted along the Upper River Benue at the Jimeta axis, Yola North Local Government Area, Adamawa State, Nigeria. The river serves as a major source of water for domestic activities, fishing, irrigation, and transportation within the study area. Three sampling sites were selected based on differences in anthropogenic activities and accessibility: Site A (Near Custom Office), Site B (Middle of the River), and Site C (Damare side).

Sample Collection

Surface water samples were collected monthly from August 2024 to January 2025 at the three designated sampling sites. Samples were collected using clean, acid-washed polyethylene bottles following standard water sampling procedures [3]. Prior to collection, bottles were rinsed with river water to avoid contamination. Samples intended for heavy metal analysis were preserved with nitric acid to pH < 2 and transported to the laboratory for analysis.

Physicochemical Analysis

Physicochemical parameters including temperature, pH, electrical conductivity, turbidity, and dissolved oxygen were measured using standard analytical methods as described by the American Public Health Association [3]. Temperature and pH were measured in situ using a calibrated digital thermometer and pH meter, respectively. Electrical conductivity was determined using a conductivity meter, turbidity was measured using a turbidity tube, and dissolved oxygen was analyzed using a portable dissolved oxygen meter. These parameters were selected due to their influence on water quality and metal mobility [17].

Heavy Metal Analysis

Concentrations of lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn) in water samples were determined using Flame Atomic Absorption Spectrophotometry (FAAS) following standard digestion and analytical procedures [3], [8]. Calibration was carried out using standard metal solutions, and quality control measures including reagent blanks and replicate analyses were employed to ensure analytical accuracy. The choice of metals was based on their toxicity, persistence, and prevalence in aquatic environments [6], [29].

Statistical Analysis

Data obtained from physicochemical and heavy metal analyses were subjected to descriptive statistics to determine mean values and standard deviations. One-way Analysis of Variance (ANOVA) was used to assess spatial and temporal variations in physicochemical parameters and heavy metal concentrations among sampling sites and months at a significance level of $P < 0.05$. Statistical analyses were performed to evaluate compliance with international water quality guidelines [1], [2].

III. RESULTS AND DISCUSSION

Physicochemical Properties of Surface Water

The physicochemical characteristics of surface water from River Benue across the three sampling sites are presented in Table 1. Water temperature showed minimal spatial variation, ranging from 27.17 to 27.50 °C, which is typical of tropical freshwater systems and unlikely to exert thermal stress on aquatic organisms. Similar temperature stability has been reported in Nigerian river systems [9], [17].

Turbidity values ranged from 25.88 to 27.98 cm, indicating the presence of suspended particles in the water. Higher turbidity reduces light penetration and can facilitate the transport of particle-bound heavy metals, particularly during periods of sediment resuspension [11], [27]. Dissolved oxygen concentrations ranged from 5.95 to 6.08 mg/L, suggesting adequate oxygen availability to sustain aerobic aquatic life. These values are comparable to those reported for other freshwater bodies in Nigeria [16], [18].

Electrical conductivity values ranged from 2.83 to 2.93 mhos/m, reflecting moderate ionic content of the

river water. Conductivity provides an indirect measure of dissolved ions and potential contamination inputs from runoff and domestic activities [3], [17]. The pH values recorded (8.67–9.03) indicate slightly alkaline conditions, which may influence the chemical behavior and solubility of heavy metals. Alkaline conditions have been reported to reduce the bioavailability of some metals through precipitation processes [6], [10]. Statistical analysis showed no significant spatial variation in physicochemical parameters among the three sites ($F(2,12) = 0.001$; $P = 0.997$; $P > 0.05$), indicating relatively uniform water quality along the studied stretch of the river.

Monthly Variations in Physicochemical Parameters

Monthly variations in physicochemical parameters are presented in Table 2. The pH values ranged from 8.57 in August to 9.13 in December, showing a gradual increase toward the dry season. Such seasonal alkalinity may be attributed to reduced dilution, increased evaporation, and biological activity [9], [17]. Electrical conductivity ranged from 2.63 to 3.13 mhos/m, with higher values recorded in August and January. These fluctuations may be linked to surface runoff during the rainy season and concentration of dissolved ions during the dry season [11]. Turbidity values varied widely from 12.20 to 41.00 cm, with higher values observed in December and January, possibly due to sediment resuspension and reduced river flow [27].

Dissolved oxygen concentrations ranged from 3.80 to 8.13 mg/L. The lower DO observed in August may be associated with increased organic matter input and microbial decomposition during peak rainfall, while higher DO levels during the dry season reflect improved aeration and photosynthetic activity [16], [18]. Temperature remained relatively stable throughout the study period (27.00–27.67 °C), indicating limited seasonal thermal influence.

Heavy Metal Concentration in Surface Water

Mean concentrations of heavy metals in surface water from River Benue are presented in Table 3. Lead (Pb) concentrations ranged from 0.004 to 0.009 mg/L, remaining below the World Health Organization permissible limit of 0.01 mg/L [1]. A gradual increase in Pb concentration from August to January suggests seasonal accumulation, possibly due to reduced dilution and sediment resuspension during the dry season [6], [9].

Cadmium (Cd) was undetectable in August but increased slightly to 0.02 mg/L in December and January across all sites. Although these values are low, the seasonal appearance of Cd may indicate inputs from agricultural runoff or domestic wastewater [7], [29]. Cadmium is highly toxic even at low concentrations, and its presence warrants continuous monitoring [31]. Chromium (Cr) concentrations ranged from 0.05 to 0.12 mg/L, with higher values consistently recorded at Site A (Near Custom Office). This pattern suggests possible influence of urban activities and localized anthropogenic inputs around the Jimeta axis. Similar spatial trends have been reported in other Nigerian river systems [9], [16]. Copper (Cu) and Zinc (Zn) showed gradual increases from August to January but remained far below WHO guideline limits of 2.0 mg/L and 3.0 mg/L, respectively [1]. Copper ranged from 0.01 to 0.07 mg/L, while zinc ranged from 0.00 to 0.06 mg/L. These metals are essential micronutrients, and their concentrations at the observed levels are not considered harmful to aquatic organisms or humans [29], [30].

Spatial comparison revealed that Site A generally recorded the highest concentrations of Pb and Cr, Site B showed moderate values, and Site C consistently recorded the lowest concentrations, indicating a downstream dilution effect. Statistical analysis showed no significant spatial variation ($F(2,626) = 0.01$; $P = 0.994$; $P > 0.05$) and no significant monthly variation ($F(5,624) = 0.05$; $P = 0.998$; $P > 0.05$) in heavy metal concentrations. However, significant differences were observed among the metals analyzed ($F(4,625) = 123.38$; $P < 0.05$), reflecting inherent differences in metal abundance and behavior in the aquatic environment. Thus, the heavy metal concentrations recorded indicate that surface water from River Benue at Jimeta is currently within acceptable limits for domestic use and aquatic life. Nonetheless, observed seasonal increases, particularly during the dry season, highlight the need for continuous water quality monitoring to prevent potential future contamination [1], [4].

IV. CONCLUSION

This study evaluated the physicochemical properties and heavy metal concentrations of surface water from the Upper River Benue at the Jimeta axis, Yola North, Nigeria. The results showed that water temperature, pH, dissolved oxygen, electrical conductivity, and turbidity were within acceptable ranges for freshwater systems. The slightly alkaline pH conditions observed may reduce the bioavailability of certain heavy metals, while dissolved oxygen levels were adequate to support aquatic life.

Concentrations of lead, cadmium, chromium, copper, and zinc in surface water across all sampling sites and months remained below the World Health Organization permissible limits for drinking water [1]. Statistical analysis revealed no significant spatial or temporal variations in heavy metal concentrations ($P > 0.05$), indicating relatively uniform water quality conditions along the studied stretch of the river. Although seasonal increases in some metals were observed during the dry season, these levels do not presently pose significant risks to human health or the aquatic ecosystem. Thus, the findings indicate that surface water from River Benue at Jimeta is currently suitable for domestic and ecological use. However, considering increasing urban activities around the study area, continuous monitoring and effective environmental management are recommended to prevent potential future contamination and to ensure sustained water quality in line with international guidelines [1], [4].

Table 1: Physicochemical Parameters of Surface Water from River Benue Based on Sampling Sites

Parameter	Site A (Near Custom Office)	Site B (Middle of River)	Site C (Damare Side)
Temperature (°C)	27.50	27.17	27.18
Turbidity (cm)	27.98	26.48	25.88
Dissolved Oxygen (mg/L)	6.03	6.08	5.95
Electrical Conductivity (mhos/m)	2.93	2.83	2.87
pH	9.03	8.87	8.67

ANOVA (Site): $F(2,12) = 0.001$; $P = 0.997$; $P > 0.05$

Table 2: Monthly Variations in Physicochemical Parameters of Surface Water from River Benue

Month	Parameter	Mean	SD
August	Temperature (°C)	27.33	0.58
	Turbidity (cm)	17.07	1.40
	Dissolved Oxygen (mg/L)	3.80	0.17
	Electrical Conductivity (mhos/m)	3.13	0.25
	pH	8.57	0.15
September	Temperature (°C)	27.00	0.00

	Turbidity (cm)	12.20	1.04
	Dissolved Oxygen (mg/L)	5.33	0.32
	Electrical Conductivity (mhos/m)	2.83	0.21
	pH	8.67	0.12
October	Temperature (°C)	27.00	0.00
	Turbidity (cm)	17.87	0.40
	Dissolved Oxygen (mg/L)	6.00	0.10
	Electrical Conductivity (mhos/m)	2.63	0.15
	pH	8.77	0.21
November	Temperature (°C)	27.67	0.58
	Turbidity (cm)	32.73	2.02
	Dissolved Oxygen (mg/L)	7.90	0.10
	Electrical Conductivity (mhos/m)	2.70	0.35
	pH	8.93	0.15
December	Temperature (°C)	27.67	0.58
	Turbidity (cm)	39.83	0.38
	Dissolved Oxygen (mg/L)	8.13	0.15
	Electrical Conductivity (mhos/m)	2.93	0.15
	pH	9.13	0.21
January	Temperature (°C)	27.00	0.00
	Turbidity (cm)	41.00	4.58
	Dissolved Oxygen (mg/L)	4.97	0.45
	Electrical Conductivity (mhos/m)	3.03	0.06
	pH	9.07	0.41

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Table 3: Mean Heavy Metal Concentration in Surface Water from River Benue (mg/L)

Site	Month	Pb	Cd	Cr	Cu	Zn
A	August	0.006	0.00	0.07	0.01	0.00
	September	0.007	0.01	0.08	0.02	0.01
	October	0.007	0.01	0.09	0.03	0.02
	November	0.008	0.01	0.09	0.03	0.02
	December	0.008	0.02	0.11	0.04	0.03
	January	0.009	0.02	0.12	0.05	0.04
B	August	0.005	0.00	0.06	0.02	0.01
	September	0.006	0.01	0.07	0.03	0.02
	October	0.006	0.01	0.08	0.04	0.03
	November	0.007	0.02	0.09	0.05	0.04
	December	0.008	0.02	0.10	0.06	0.05
	January	0.009	0.02	0.11	0.07	0.06
C	August	0.004	0.00	0.05	0.01	0.00
	September	0.005	0.01	0.06	0.02	0.01
	October	0.006	0.01	0.07	0.03	0.02
	November	0.006	0.02	0.08	0.04	0.03
	December	0.007	0.02	0.09	0.05	0.04
	January	0.008	0.02	0.10	0.06	0.05

ANOVA:

- Site: $F(2,626) = 0.01$; $P = 0.994$
- Month: $F(5,624) = 0.05$; $P = 0.998$
- Heavy metals: $F(4,625) = 123.38$; $P < 0.05$

Note:
Site A = Near Custom Office; Site B = Middle of River; Site C = Damare Side

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