Seasonal Variation of Physicochemical Properties in the Lower River Benue, Nigeria

Abstract

The study investigates the impact of seasonal changes on water quality in the River Benue, Nigeria. Conducted over eighteen months from January 2020 to June 2021, the research focuses on three locations: Ibi, Lau, and Mayo-Ranewo. Key physicochemical parameters such as temperature, pH, turbidity, conductivity, biochemical oxygen demand (BOD), hardness, dissolved oxygen (DO), fluoride, and nitrate were measured to assess water quality.The findings reveal significant seasonal variations in these parameters, influenced by rainfall patterns, land use, and anthropogenic activities. Temperature ranged from 25.56°C to 30.70°C, remaining within acceptable limits for tropical waters, supporting stable biological processes. However, turbidity levels exceeded recommended values, indicating the presence of suspended solids that could impair water quality and harm aquatic life. Total dissolved solids (TDS) and conductivity showed potential contamination risks, likely due to agricultural runoff and urban discharges.Dissolved oxygen (DO) levels were generally adequate, especially during the wet season, enhancing oxygen content through increased photosynthetic activity and water inflows. However, BOD spiked with rainfall, signalling organic pollution and potential eutrophication risks. Seasonal shifts in pH and water hardness reflected changes in runoff and photosynthesis, with values largely within acceptable ranges for aquatic life. Fluoride and nitrate concentrations increased in the wet season, primarily due to agricultural runoff, highlighting the influence of land-based activities on water quality.

Key words: Physicochemical Properties, Water Quality, Global Environmental Change,Anthropogenic Activities

1 Introduction

Water is an essential component of life, making up 50-90% of living organisms and covering nearly three-fourths of the Earth's surface, upon which all life depends for survival(Chakraborty, 2021). However, increased rates of urbanization, industrialization, and other forms of modernization have continued to threaten the quality of natural water available to organisms(Chakraborty, 2021). In particular, the sustained usage of fertilizer, pesticides, and other agrochemicals, has, to a large extent, contaminated natural water sources, often rendering highly polluted with various harmful substances(Odewale et al., 2023).

Anthropogenic activities are the primary drivers of global environmental change, either directly or indirectly caused by human actions(Volta & Jeppesen, 2021). Numerous studies have identified anthropogenic activities as major sources of water pollution in Nigeria and globally (Song et al., 2022; Wei et al., 2023). Natural water bodies are frequently used as disposal sites for untreated or inadequately treated wastewater from industrial, agricultural, commercial, and domestic sources (Wei et al., 2023). As a result, increased anthropogenic inputs through erosion, leaching, and weathering have rapidly degraded surface water, rendering many water bodies unsuitable for fishing and domestic use (Volta & Jeppesen, 2021).

Understanding the physicochemical properties of water is essential for assessing its quality and identifying potential risks to human health and ecosystem integrity(Chakraborty, 2021). Physicochemical parameters such as pH, temperature, dissolved oxygen, turbidity, conductivity, and nutrient concentrations provide valuable insights into the overall health and ecological status of aquatic environments (Rahman et al., 2021). Changes in these parameters can indicate natural processes such as seasonal variations or anthropogenic influences such as pollution events (Mammeri et al., 2023). Several studies have highlighted the importance of monitoring and assessing water quality in rivers to mitigate pollution and safeguard environmental and public health (Kassegne& Leta, 2020; Mammeri et al., 2023; Rahman et al., 2021).This study aims to assess various water quality variables at three different locations (Ibi, Lau and Mayo-Ranewo) to identify the most relevant parametersfor water properties and determine whether these properties remain consistent across different seasons.

2Materials and Methods

2.1 Study Area

The River Benue, Nigeria's second-largest river, originates in the Adamawa mountains in Cameroon, near the Nigerian border. It flows westward across Nigeria, eventually joining the River Niger at Lokoja in Kogi State (Okayi et al., 2001). This study was conducted in Taraba

State, located in northeastern Nigeria, and named after the Taraba River, which traverses the state's southern region. The state capital, Jalingo, lies at coordinates 8º 00' N, 10º 30' E. Taraba State spans an area of 54,473 km² and had a population of 2,294,800 as of the 2006 census. The landscape is largely undulating, with notable features such as the scenic Mambilla Plateau. Major rivers in Taraba include the Benue, Donga, Taraba, and Ibi rivers.

Ibi is a town and administrative district situated on the southern bank of the River Benue, near the confluence of the Taraba and Donga rivers converge with the Benue. Ibi's coordinates are 8º 19' N, 9º 51' E.Lau, another Local Government Area in Taraba, is bordered by Ardo Kola, Jalingo, Yorro, and Zing LGAs. It has a predominantly Hausa-Fulani population, with headquarters in the town of Lau at 9º12' 29.77" N, 11º16' 31.48" E.Mayo-Ranewo, known for its renowned fish market, is located along the banks of the River Benue, approximately 8 kilometers off the Jalingo-Wukari road (Figure 1).

2.2 Experimental Design

The study was conducted over an eighteen-month period, from January 2020 to June 2021, with monthly sampling from the River Benue covering both the wet and dry seasons. During this period, water quality parameters such as temperature, pH, turbidity, conductivity, biochemical oxygen demand (BOD), hardness, Dissolved oxygen (DO), fluoride, and nitrate, were assessed.Sampling was carried out at three designated stations along the river: Station A at Lau, Station B at Mayo-Ranewo, and Station Cat Ibi. These stations were chosen based on the level of fishing activity in each area. (Figure.1)

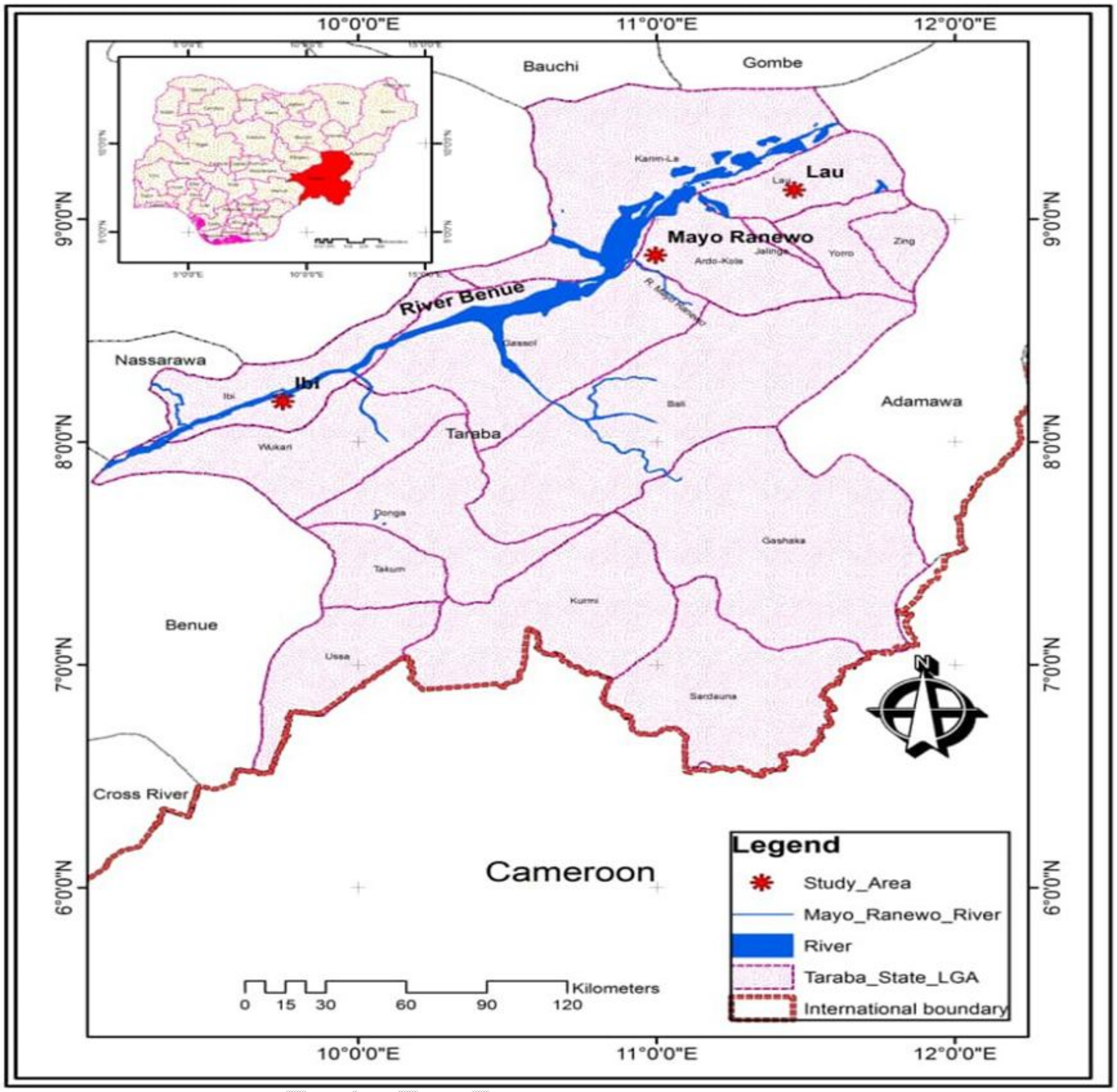

Figure 1. Map of Taraba State showing River Benue and the three-sampling locations

2.3 Calibration of the Horiba U-50

To obtain accurate measurement values, the sensors were calibrated using a standard solution before measurement. The pH, conductivity, and turbidity sensors were auto-calibrated simultaneously in a pH 4 standard solution, while the DO and DEP sensors were calibrated in air.Atother times, manual calibration of individual measurement parameters was performed, especially when only a single parameter reading was needed

2.4 Sample Collection and Analysis

Water samples (approximately 1 000 mL each) were collected duringtwo distinct seasons from Lau, Mayo-ranewo, and Ibi.Some physicochemical parameters of the water, such as temperature, pH, turbidity DO, electrical conductivity, and total dissolved solids (TDS) were measured instantly in the field using water testing equipment (Horiba, model U-50, Kyoto, Japan).Other parameters, such as nitrates, hardness, and biochemical oxygen demand (BOD), which could not be determined in the field, were analyzed at the water treatment section of the Jalingo Water Supply Agency. Water samples were collected at the selected points using plastic bottled water containers. The bottles were thoroughly rinsed with sample water following the standard guidelines for the Plainest Photometer 7100 model. After sampling, an alkaline potassium iodide solution was added to protect the water samples from any fungal or other pathogenic contamination (Rahman et al., 2021). Since the sample could not analysed in situ, they were a cooler with ice for transport to theTaraba State Water Supply Agency laboratory for analysis. The bottles were kept airtight, properly labelled, and stored in the refrigerator until subsequent analysis. The analysis of nitrates, hardness, and BOD was conducted using a WagtechPalintest Photometer (Model 7100, United Kingdom).

3 Statistical Analysis

The data collected on physicochemical parameters were analysed using descriptive statistics to determine the mean, variance, and standard deviation, and were visualized with bar charts. Additionally, one-way analysis of variance (ANOVA) was conducted to assess the significance($P>0.05$) differences among the parameters.

4Results

4.1 Temperature (°C)

In the dry season, the highest temperature of 30.7℃ was recorded at Site C in March 2021, while the lowest, 25.56℃, was observed at Site B in the same month. The mean temperature during this period ranged from 27.65℃ to 29.60℃, with no significant difference in the overall mean temperature ($P > 0.05$; Fig. 2).In the wet season, the highest temperature of 30.06℃ was recorded at Site B in April 2020, and the lowest, 25.45℃, at Site C in April 2021. The mean temperature for the wet season ranged from 26.02℃ to 29.14℃, with no significant difference in the overall mean temperature ($P > 0.05$; Fig. 3)

4.2 Turbidity (mg/L)

During the dry season, turbidity was highest at Site A in February 2021, with a value of 112.33 NTU, while the lowest value of 35 NTU was recorded at Site C in January 2020. The mean turbidity ranged from 51.77 to 89.11 NTU, with a significantin the overall mean for the dry months ($P < 0.05$; Fig. 4).In the wet season, the highest turbidity of 116.33 NTU was observed at Site A in June 2021, and the lowest, 41 NTU, was recordedat Site B in the same month. Mean turbidity for the wet season ranged from 63.66 to 102.88 NTU, also showing a significant in theoverall mean ($P < 0.05$; Fig. 5).

4.3 Total dissolved solids (TDS)

The Total Dissolved Solids (TDS) during the dry season showed that the highest value, 474.36 mg/L, was recorded at Site A in January 2020, while the lowest value, 297.7 mg/L, was recorded at Site C in February 2020. The mean TDS ranged from 352.21 mg/L to 423.97 mg/L, with a significant overall mean for the dry months ($P < 0.05$; Fig. 6). During the wet season, the highest TDS of 715.83 mg/L was recorded in Site A in the month of August, 2020, and the lowest of 224.33 mg/L was recorded in Site A in April, 2021. The mean TDS for the wet season ranged from 280.74 mg/L to 606.27 mg/L, with no significant difference in the overall mean ($P > 0.05$; Fig. 7).

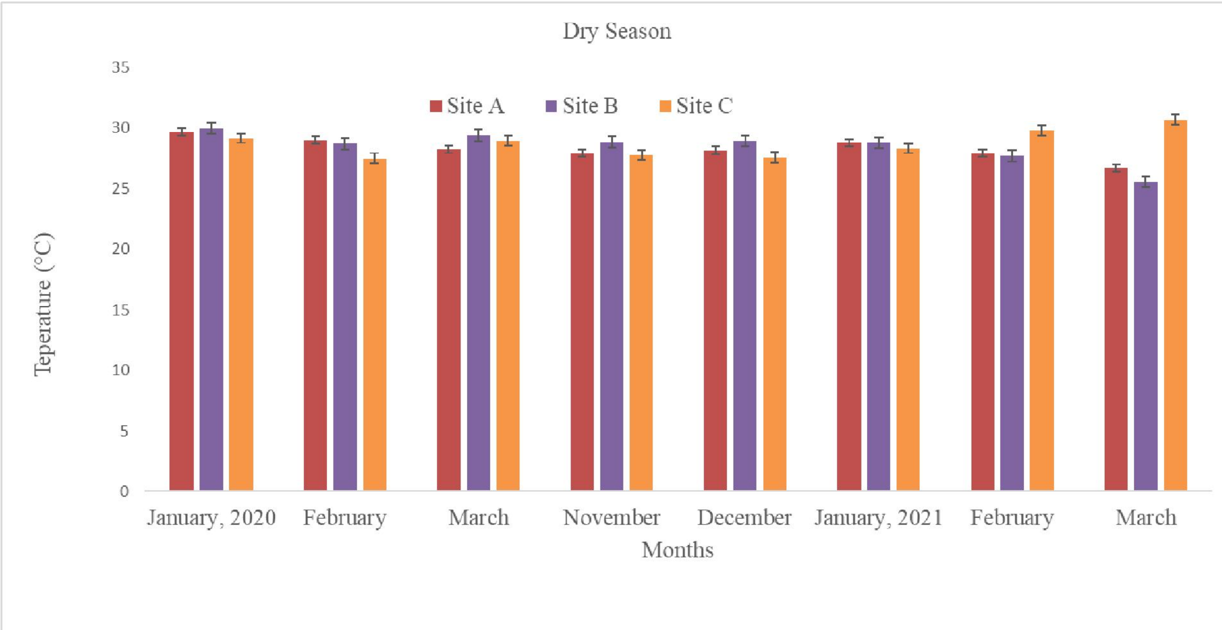

Figure 2: Dry season mean Temperature (°C) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

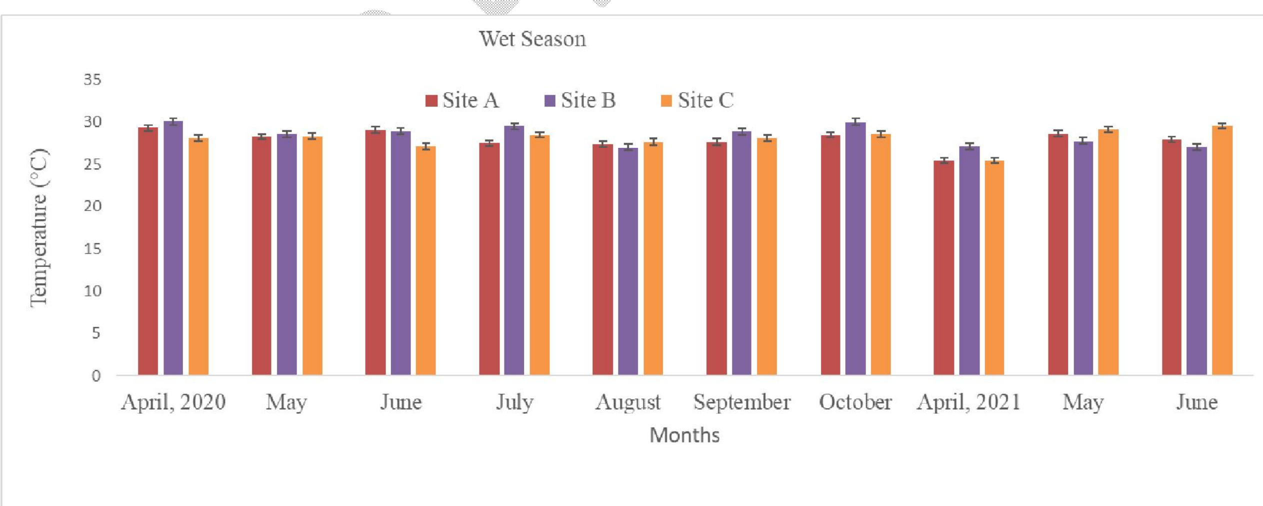

Figure 3: Wet season mean Temperature (°C) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

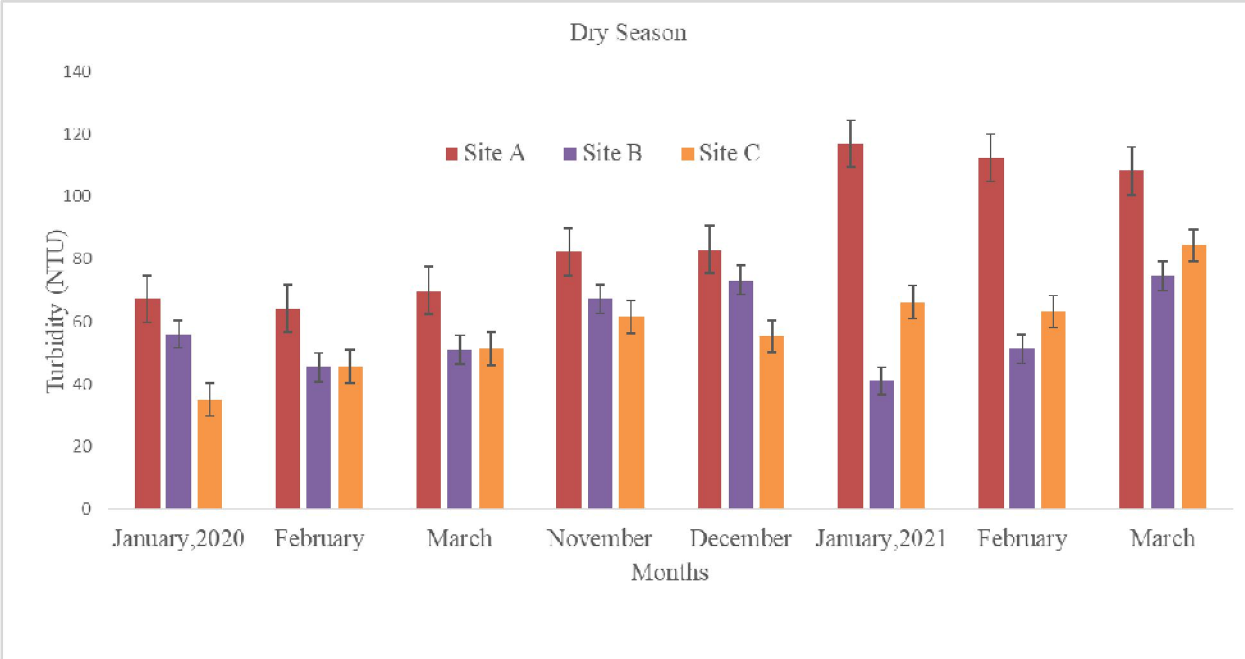

Figure 4: Dry season mean Turbidity (NTU) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

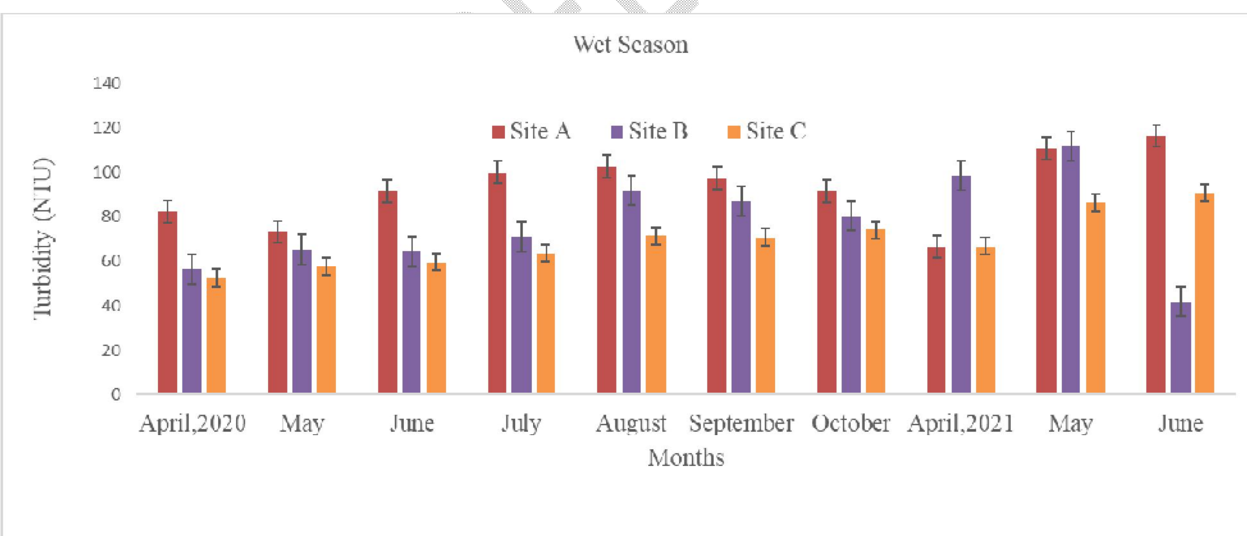

Figure 5: Wet season mean Turbidity (NTU) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

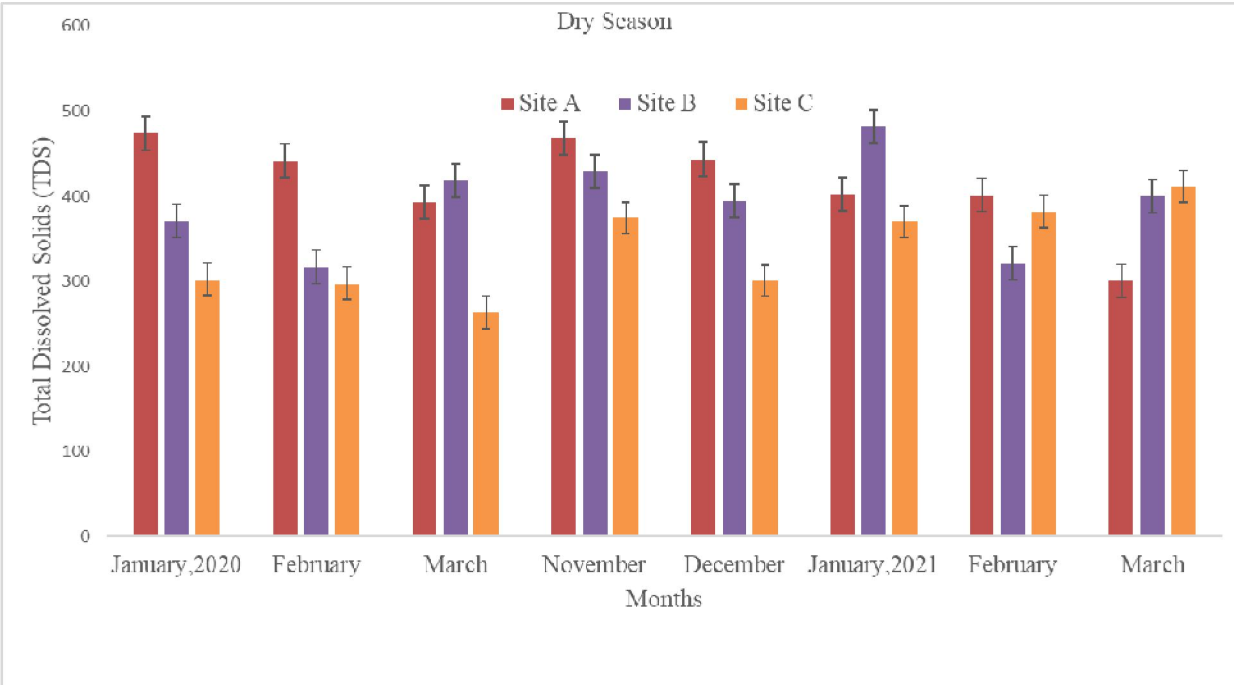

Figure 6: Dry season mean Total Dissolved Solids (TDS) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021).Site A Lau, Site B Mayo-ranewo, and Site C Ibi

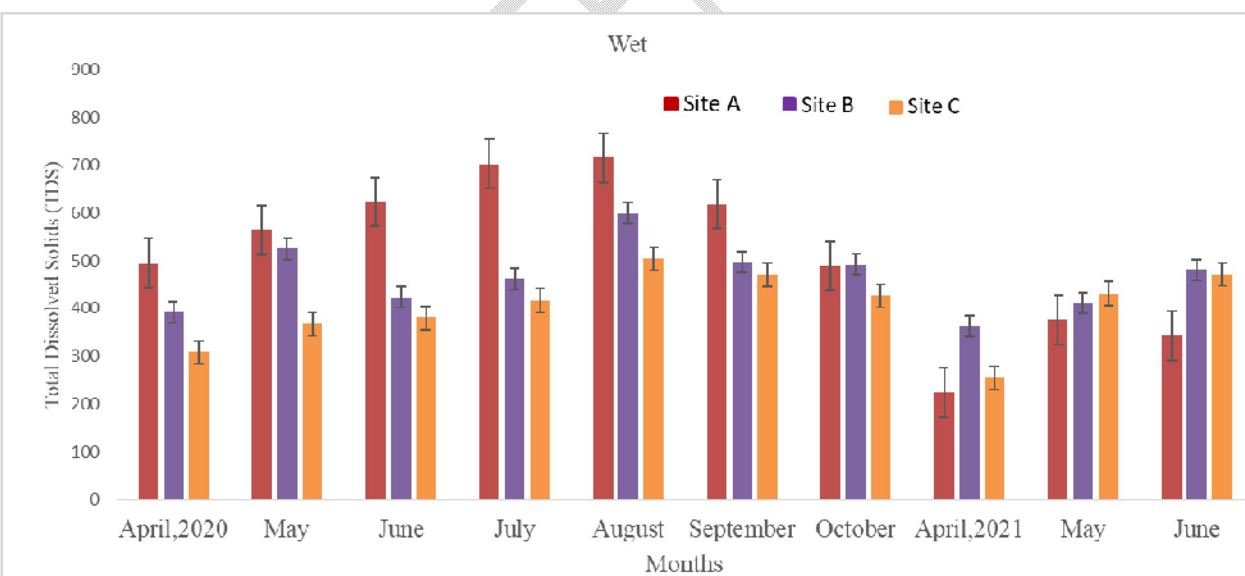

Figure 7: Wet season mean Total Dissolved Solids (TDS) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021).Site A Lau, Site B Mayo-ranewo, and Site C Ibi

4.4Conductivity (µS/cm)

The Conductivity during the dry season showed at Site A in January, 2021 had the highest value with 671 (µS/cm)and the least value of 306.33 (µS/cm)was recorded in Site B in February, 2021.The mean conductivity ranged from 402.77 µS/cm to 611.4 µS/cm, with no significant difference in the overall mean for the dry months (P > 0.05; Fig. 8).

During the wet season, the highest conductivity of 896.8 (µS/cm)was recorded in Sites A in August, 2020, and the lowest conductivity of 103.33 (µS/cm)was recorded in Site A in May, 2021.The mean conductivity for the wet season ranged from 354.33 µS/cm to 781.06 µS/cm, with no significant difference in the overall mean (P > 0.05; Fig. 9)

4.5 Dissolved oxygen DO (mg/L)

The dissolve oxygen (DO) level during the dry season showed that Site Bhad thehighest value inJanuary, 2021 with 8.22 mg/L, while the least value of 6.1 mg/L was recorded at Site A in November, 2020.The mean DO ranges from 6.64 mg/L to 7.41 mg/L. The overall mean DO for the dry months was not significant (P>0.05; Fig. 10).

During the wet season, the highest DO level of 8.56 mg/L was recorded in Sites A in June, 2021, while the lowest DO of 6.06 mg/L was recorded at Site A in May, 2020. The mean DO ranges from 6.25 mg/L to 7.62 mg/L. The overall mean conductivity for the wet monthswas significant (P<0.05; Fig. 11).

4.6Biochemical Oxygen Demand (BOD) (mg/L)

The Biochemical Oxygen Demand (BOD level during the dry season showed that Site A had the highest value of 4.77 mg/L in January 2020, while the lowest value of 3.10 mg/L was recorded at Site A in November 2021.The mean BOD ranges from 3.81 mg/L to 4.41 mg/L. The overall mean BOD for the dry months were not significant (P>0.05; Fig. 12).

During the wet season, the highest BOD level of 5.1 mg/L was recorded atboth Sites A and B in July and August 2020, while the lowest BOD of 2.82 mg/L was recorded at Site B in May 2020.The mean BOD ranges from 3.31 mg/L to 4.73 mg/L. The overall mean BOD for the wet months was not significant (P>0.05; Fig. 13).

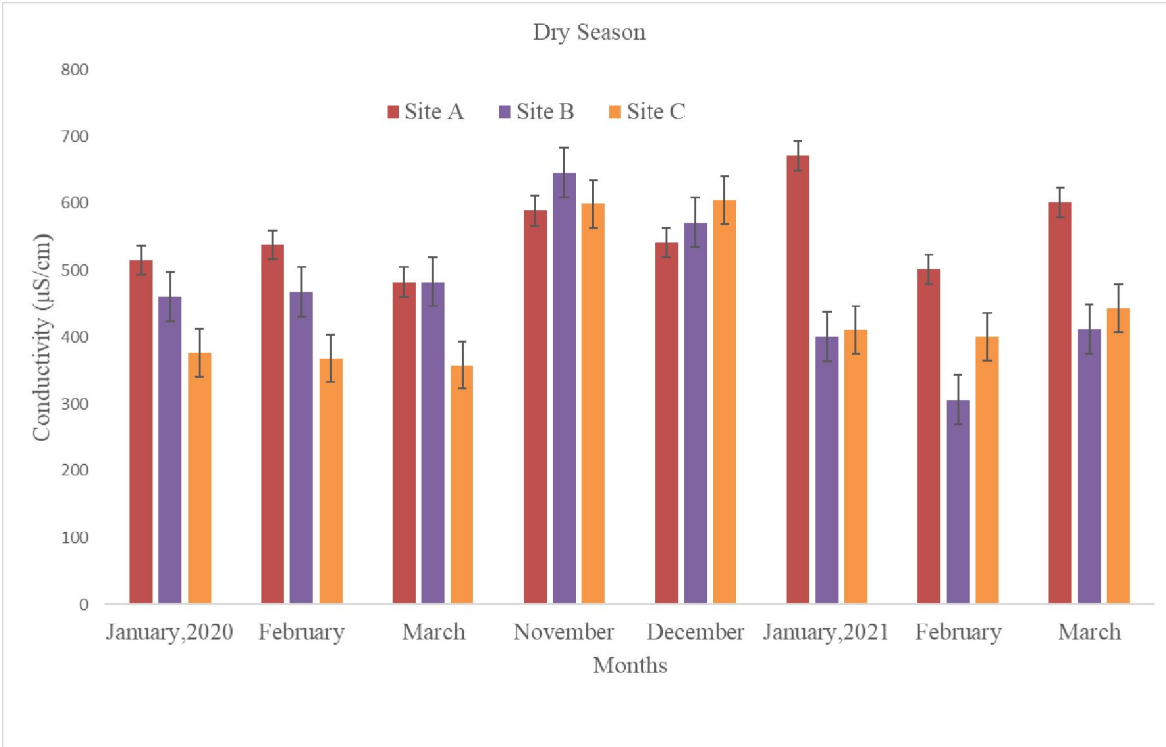

Figure 8: Dry season mean Conductivity (µS/cm) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

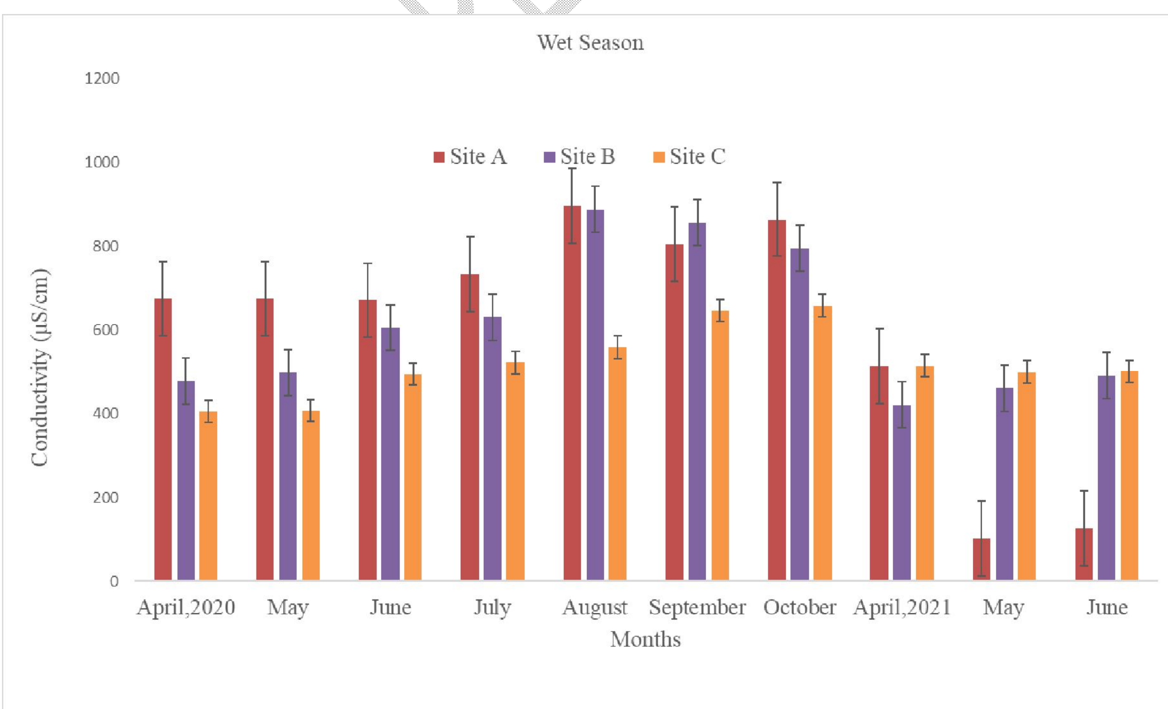

Figure 9: Wet season mean Conductivity (µS/cm) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

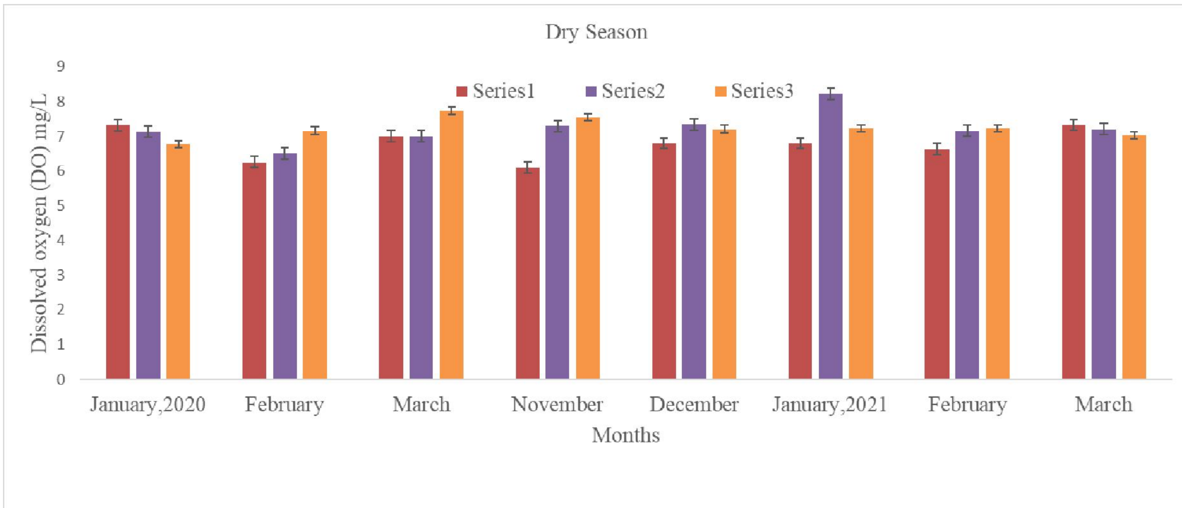

Figure10: Dry season mean Dissolved oxygen (DO) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

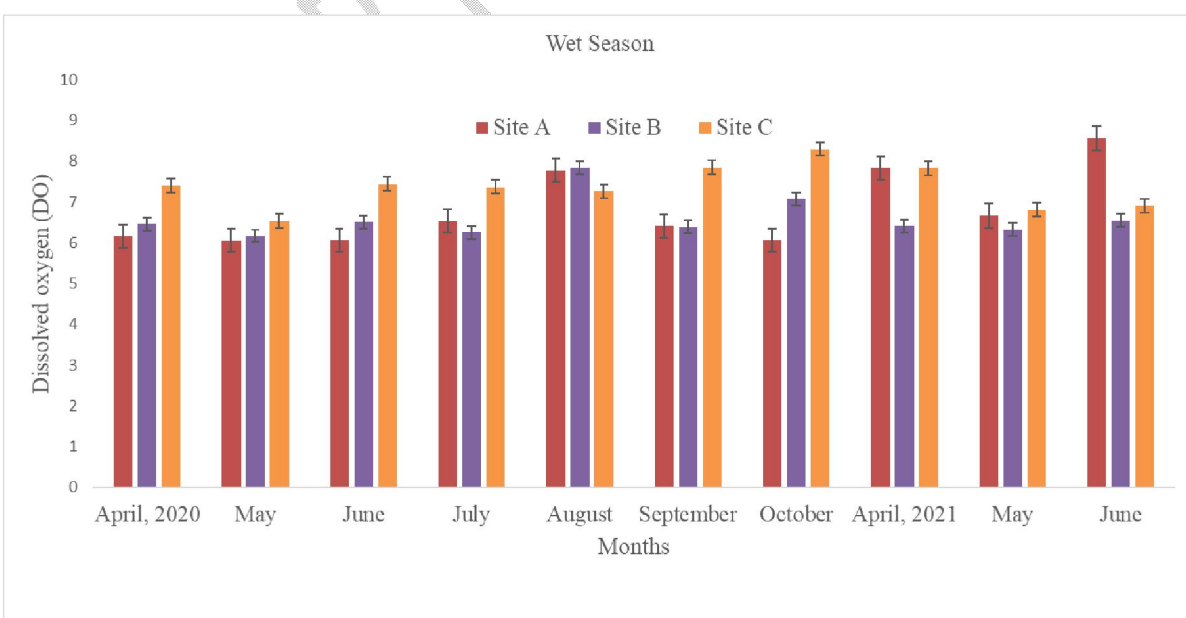

Figure11: Wet season mean Dissolved oxygen (DO) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021).Site A Lau, Site B Mayo-ranewo, and Site C Ibi

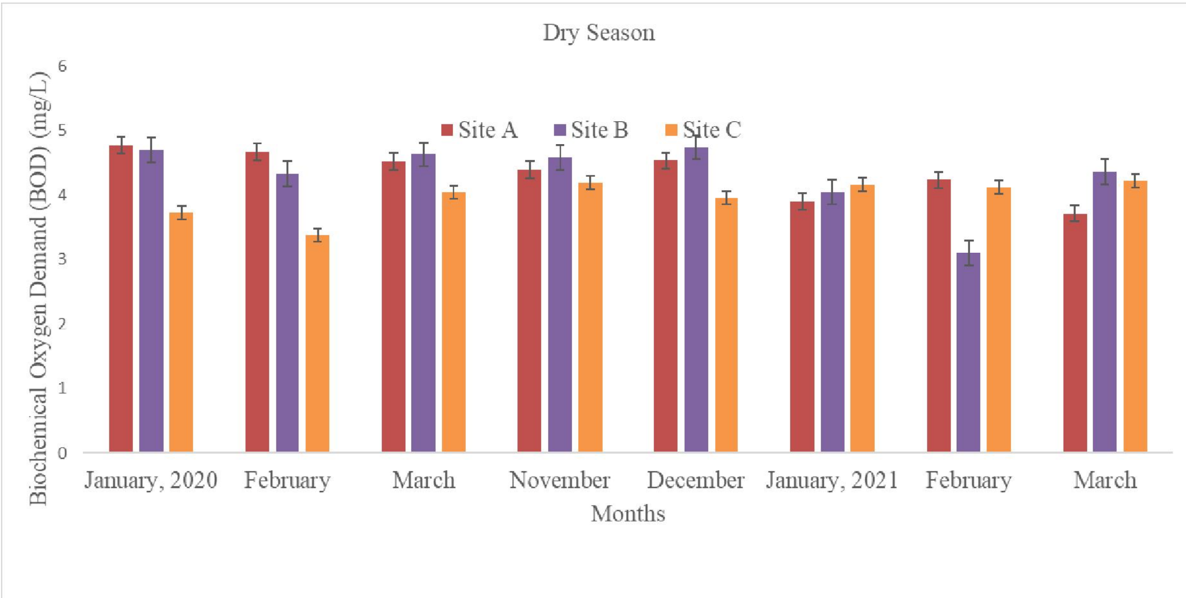

Figure 12: Dry season mean Biochemical Oxygen Demand (BOD) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

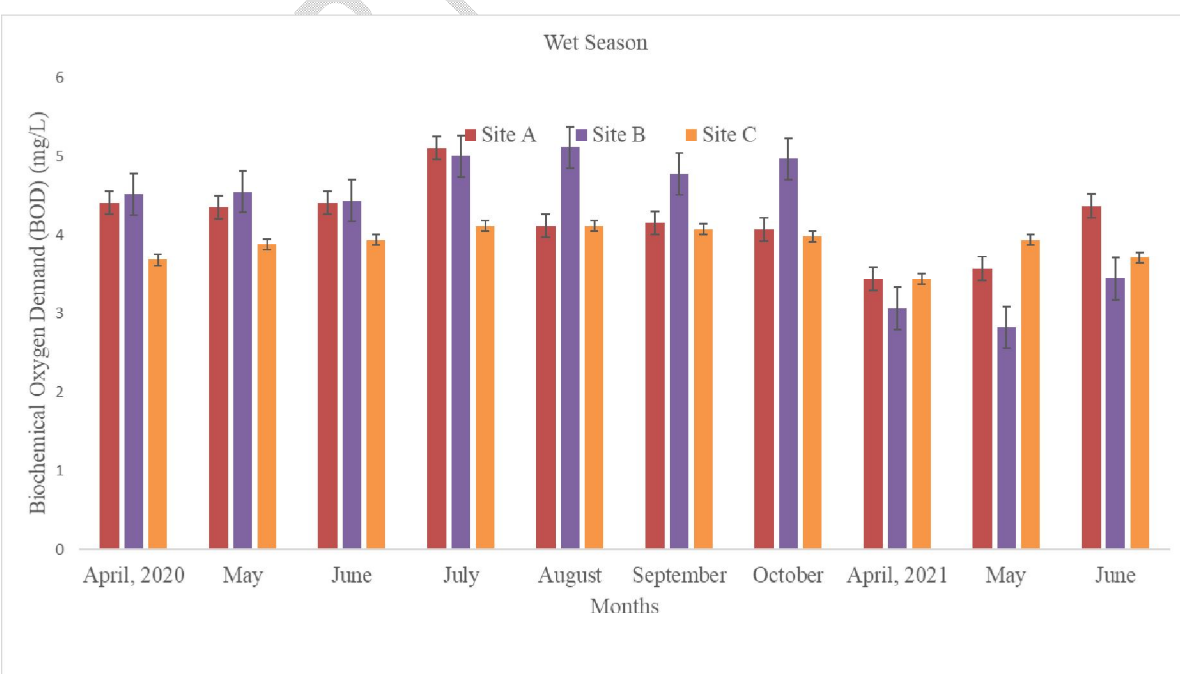

Figure 13: Wet season mean Biochemical Oxygen Demand (BOD) mg/L variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

4.7pH

The pH level during the dry season showed that Site C had the highest value of 8.01 in January 2021, while the lowest value of 6.67 was recorded at Site B in February 2021. The mean pH ranged from 6.98 to 7.54. The overall mean pH for the dry months was not significant ($P > 0.05$; Fig. 14).

During the wet season, the highest pH level of 8.07 was recorded at Site A in May 2020, while the lowest pH of 6.16 was recorded at Site C in May 2021. The mean pH ranged from 6.16 to 7.71. The overall mean pH for the wet months was not significant ($P > 0.05$; Fig. 15).

4.8Water Hardness (mg/L)

The hardness level during the dry season showed that Site A had the highest value of 170.33 mg/L in March 2021, while the lowest value of 48.1 mg/L was recorded at Site C in February 2020. The mean hardness ranged from 63.25 mg/L to 133.77 mg/L. The overall mean hardness for the dry months was not significant ($P > 0.05$; Fig. 16)

During the wet season, the highest hardness level of 165.63 mg/L was recorded at Site B in May 2020, while the lowest hardness of 36.66 mg/L was recorded at Site A in June 2021. The mean hardness ranged from 70.03 mg/L to 135.26 mg/L. The overall mean hardness for the wet months (Fig. 17) was not significant ($P > 0.05$; Fig. 17).

4.9Fluoride (mg/L)

The fluoride level during the dry season showed that Site A had the highest value of 0.86 mg/L in January 2021, while the lowest value of 0.01 mg/L was recorded at both Site A and Site C in December 2020. The mean fluoride ranged from 0.02 mg/L to 0.86 mg/L. The overall mean fluoride for the dry months was not significant ($P > 0.05$; Fig. 18).

The highest fluoride level of 1.12 mg/L was recorded at Site A in June 2021, while the lowest fluoride of 0.01 mg/L was recorded at Site C in July 2020 during the wet season. The mean fluoride ranged from 0.00 mg/L to 0.53 mg/L. The overall mean fluoride for the wet months was not significant ($P > 0.05$; Fig. 19).

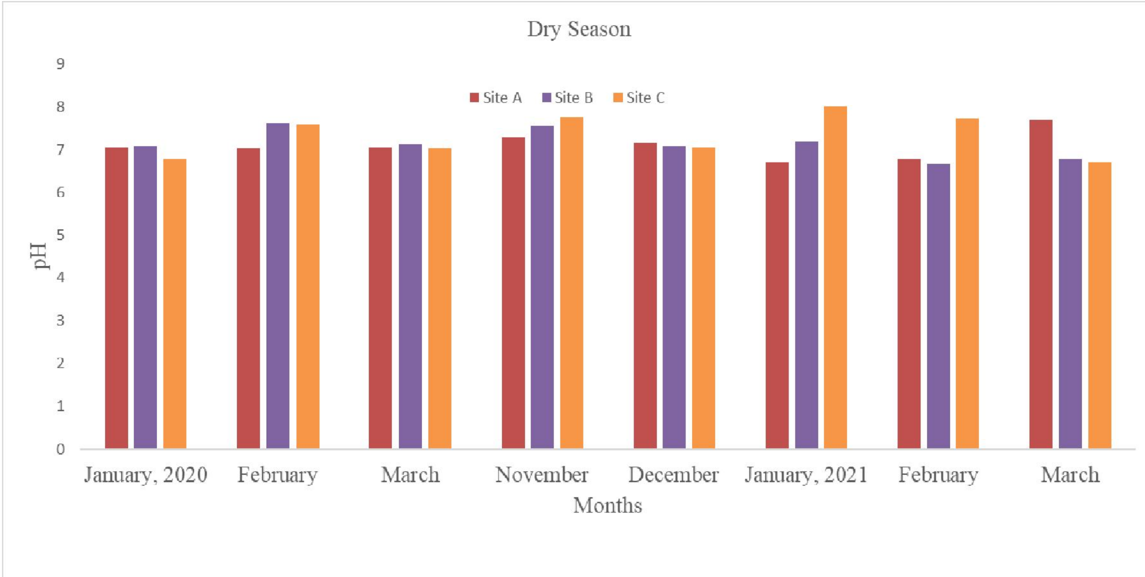

Figure 14: Dry season mean pH variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

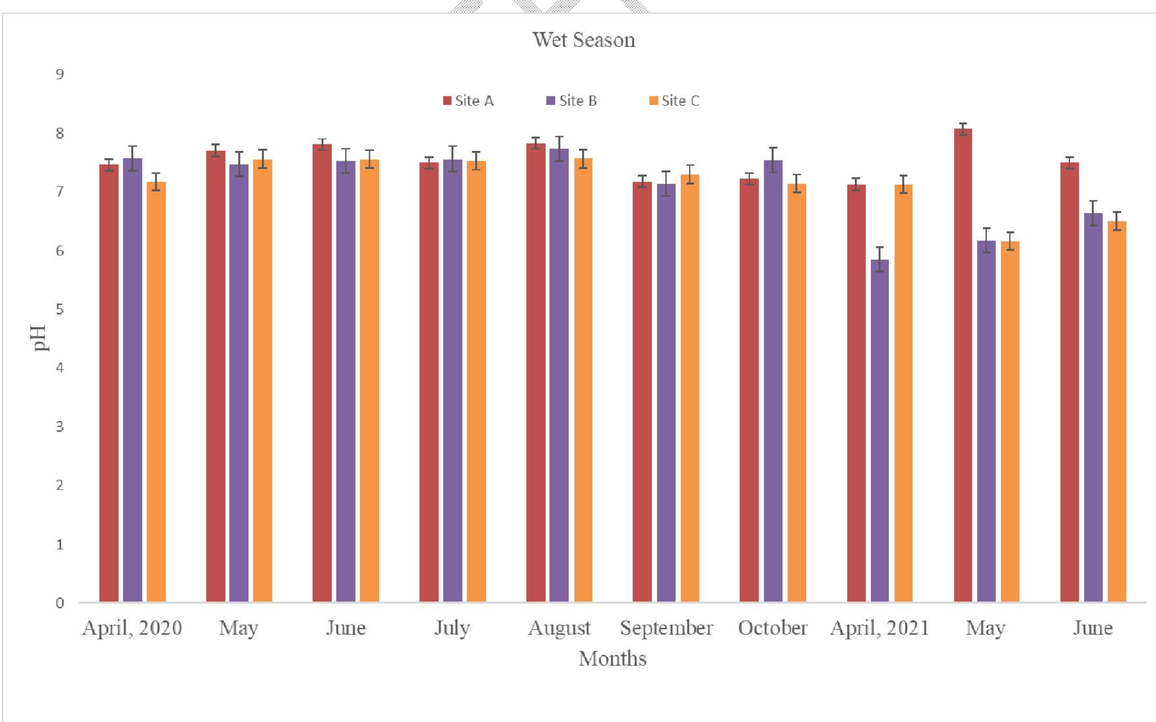

Figure 15: Wet season mean pH variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

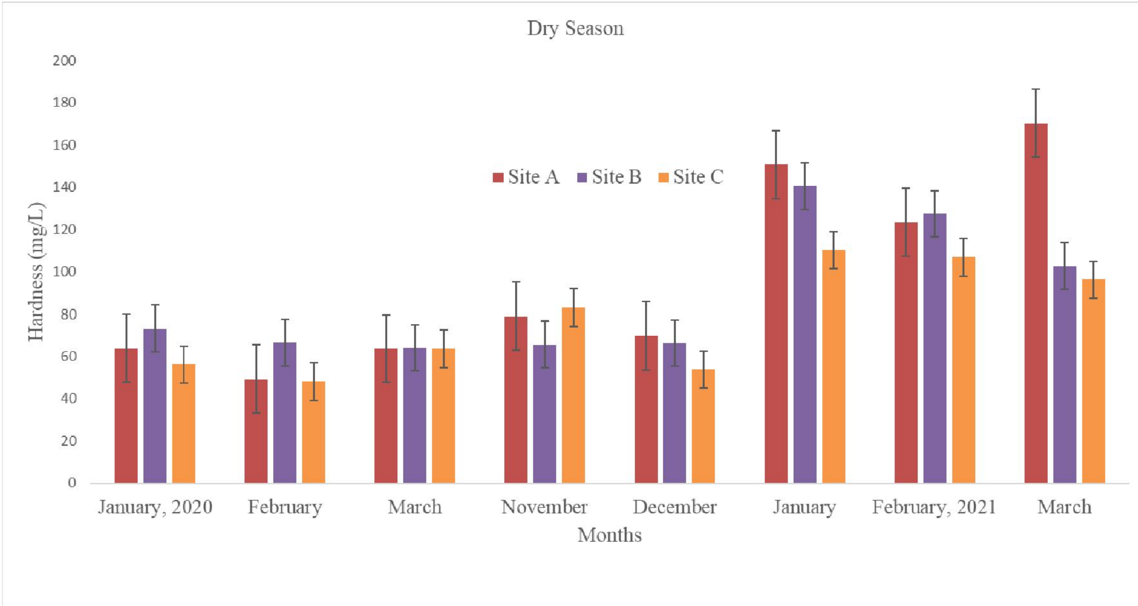

Figure 16: Dry season mean Hardness (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

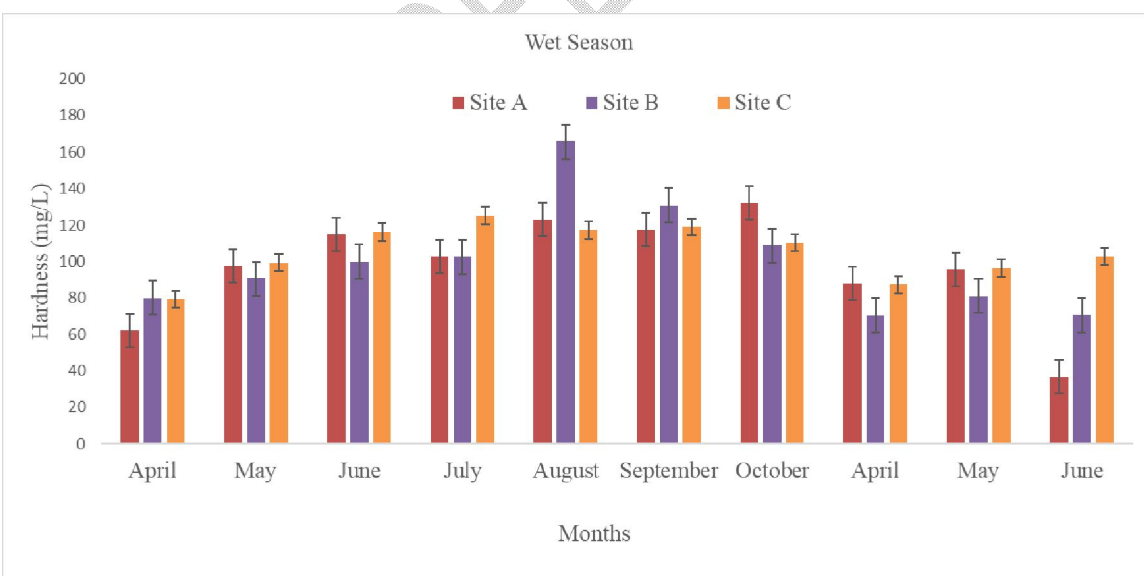

Figure 17: Wet season mean Hardness (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

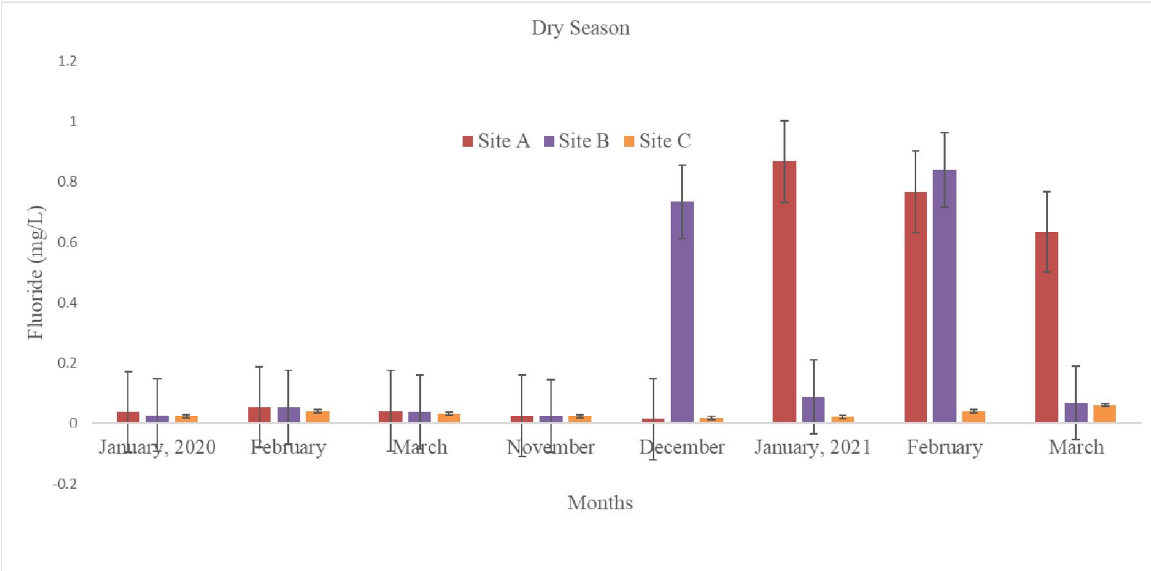

Figure 18: Dry season mean Fluoride (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

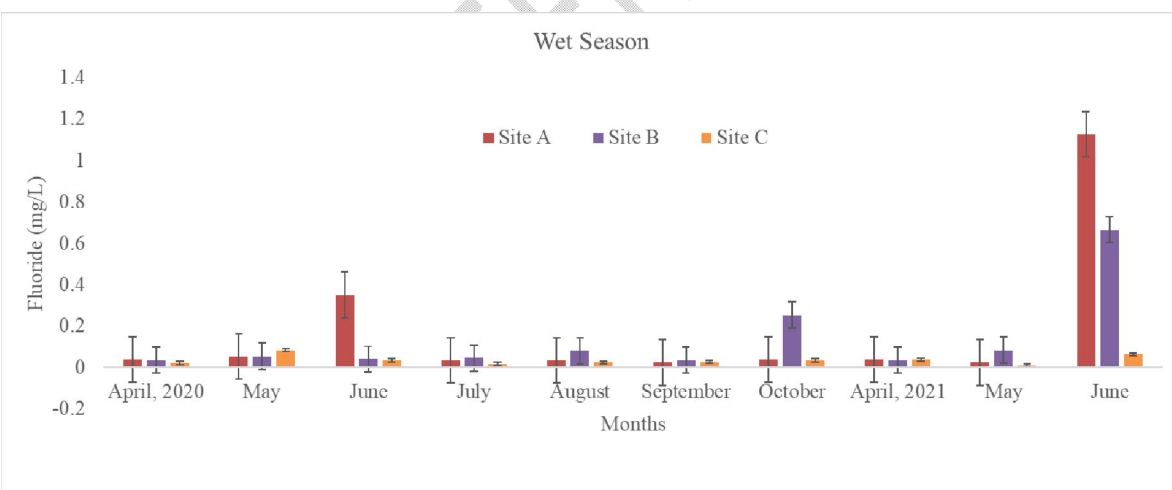

Figure 19: Wet season mean Fluoride (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

3.10Nitrate (mg/L)

During the dry season, nitrate levels peaked at 23.33 mg/L at Site A in March 2021, while the lowest level was 5.7 mg/L at Site B in January 2021. Mean nitrate levels ranged from 8.98 to 21.17 mg/L, with no significant differences (P>0.05; Fig. 20). In the wet season, the highest nitrate level was 56 mg/L at Site A in April 2021, and the lowest was 5.4 mg/L at Site C in August 2020, with mean levels between 8.23 and 29.18 mg/L, also showing no significant differences (P>0.05; Fig. 21).

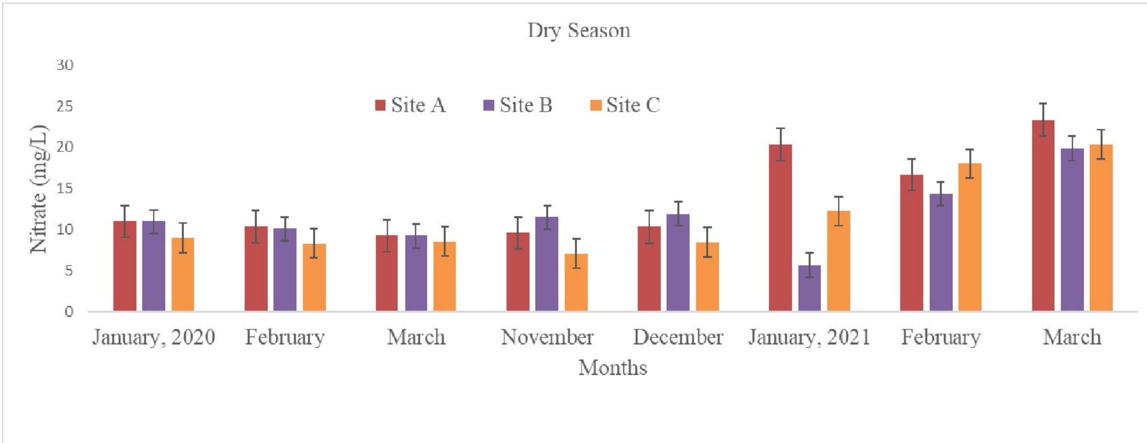

Figure 20: Dry season mean Nitrate (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

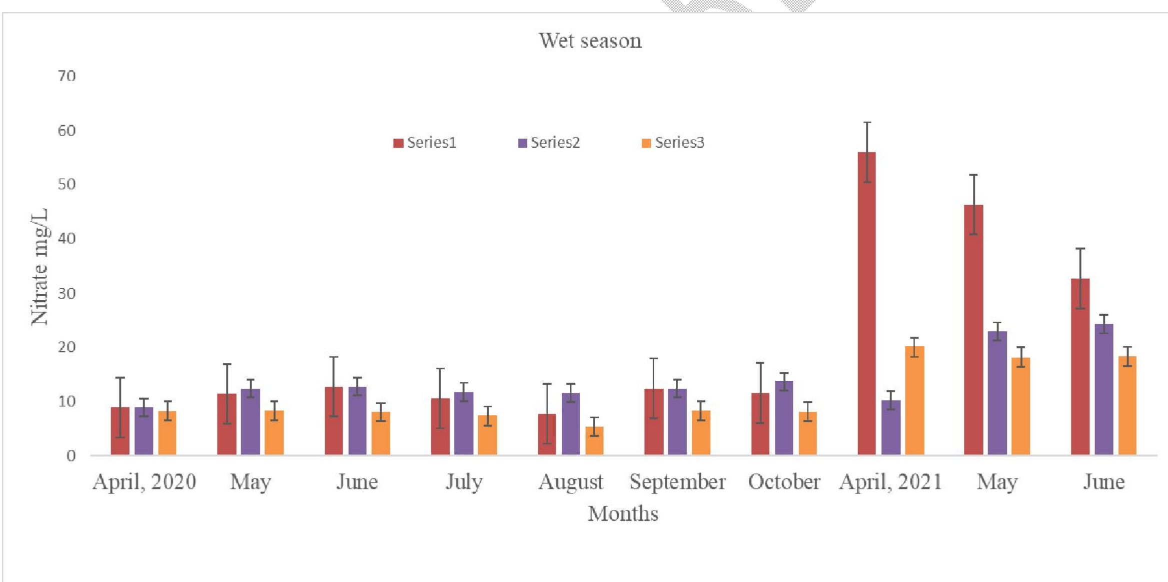

Figure 21: Wet season mean Nitrate (mg/L) variation of River Benue at Lau, Mayo-ranewo, and Ibi (2020-2021). Site A Lau, Site B Mayo-ranewo, and Site C Ibi

4 Discussion

Temperature is a crucial factor in aquatic environments, influencing the physical and chemical properties of water, as well as the biological activities of aquatic organisms and vegetation. In this study, the physico-chemical parameters of River Benue exhibited variations that could be linked to patterns of wateruse and rainfall, as previously noted by Ayoade *et al.* (2006) and Anago *et al.* (2013). The water temperature fluctuated between 25.56°C and 30.70°C, which falls within the acceptable range for tropical water bodies. This range is consistent with findings from Abubakar *et al.* (2015), who reported similar temperature profiles in their assessments. Additionally, Fafioye (2021) observed temperatures ranging from 27°C to 35°C in preliminary studies on the water characteristics and microbial populations in Kojalo fish pond, further supporting the consistency of temperature patterns across various aquatic systems.Temperature variations are significant because they can influence the solubility of gases, such as oxygen, and affect the metabolic rates of aquatic organisms(Kazmi et al., 2022). Armstrong et al. 2021) emphasizes that warm water fish thrive best at temperatures between 25°C and 32°C, highlighting the importance of maintaining optimal temperature ranges for the growth and health of aquatic species.

Turbidity in river water refers to the cloudiness or haziness caused by suspended particles such as silt, clay, organic matter, algae, and microorganisms. In the present study, turbidity levels ranged from 51.77 NTU to 89.11 NTU during the dry season, exceeds the United States Environmental Protection Agency (USEPA, 2020) recommendation that turbidity in surface waters should generally not exceed 10 NTU to protect aquatic life. Elevated turbidity levels during the wet season indicate a higher presence of suspended solids, which can adversely affect aquatic organisms and overall water quality (Matos et al., 2024). Similar patterns have been observed in other rivers, where turbidity tends to spike during high rainfall months. For instance, Dodds *et al.* (2002) documented comparable increases in turbidity levels during wet conditions. Nwankwoala and Ememu (2017) reported turbidity values ranging from 60 NTU to 100 NTU in their assessment of surface water quality in the Niger Delta, Nigeria, focusing on turbidity and other physicochemical parameters. Additionally, Utang and Apkan (2012) found turbidity levels ranging from 126.2 NTU to 130.9 NTU, indicating very turbid conditions at their sampling stations during the study.

The mean total dissolved solids (TDS) value in this study is consistent with findings from Akinyemi et al. (2019), who reported TDS levels ranging from 270 mg/L to 480 mg/L in water at the confluence of the Niger and Benue Rivers in Lokoja, Kogi State, Nigeria.Similarly, Adedeji et al. (2019) recorded a mean TDS of 352.83 ± 1.81 mg/L in Lake Ribadu. Elevated TDS levels have also been observed in other water bodies, such as Ero Reservoir (Oso &Fagbuaro, 2008), Awba Reservoir (Anago et al., 2013), and Dadin-Kowa (Abubakar et al., 2015).

Elevated TDS levels can affect water taste and quality, often indicating the presence of various pollutants and dissolved substances. The U.S. Environmental Protection Agency (USEPA, 2020) notes that high TDS concentrations may impact water palatability and suggest contamination sources such as agricultural runoff, industrial discharges, or urban wastewater. This is critical for assessing the suitability of water for drinking and aquatic life. Additionally, Kadir et al. (2019) found that elevated TDS can alter the ionic composition of water, impacting the physiological processes of aquatic organisms.

The mean conductivity in this study was slightly higher than that reported by Adedeji et al. (2019), who found a mean conductivity of 432 ± 8.64 µmhos/cm. Adeleke (1982) classifies conductivity as low (below 50 µmhos/cm), medium (50–600 µmhos/cm), and high (above 600 µmhos/cm). Conductivity levels observed here suggest a medium to high classification, with implications for water quality and aquatic life. This increase in conductivity may result from higher ion concentrations due to anthropogenic influences, such as agricultural runoff, industrial discharges, and urbanization (WHO, 2017).Similarly, Kadir et al. (2019) observed that higher conductivity often correlates with increased dissolved salts and nutrients, impacting aquatic ecosystem health. Additionally,Olajire and Imeokparia (2007) found that seasonal changes and land use practices can lead to variations in conductivity.

DO levels in the current study ranged from 6.06 mg/L to 8.56 mg/L in River Benue, with significantly higher concentrations during the wet season compared to the dry season.These values are consistent with the findings of Kefas (2016), who reported DO levels ranging from 3.51 mg/L to 13.2 mg/L in Lake Geriyo, highlighting the variability of DO across different aquatic environments. The mean DO levels observed in this study fall within the permissible value of 5 mg/L recommended by the World Health Organization (WHO). This is further supported by the United States Environmental Protection Agency (USEPA), which also sets a minimum DO concentration of 5.0 mg/L for freshwater to sustain aquatic life. Research by Olajire and Imeokparia (2007), Akan *et al*. (2010), Akinbile and Sangodoyin (2011), and Adeyemi and Gobo (2012) corroborates these findings, reporting consistently elevated DO levels above 5 mg/L in various water bodies, indicating good water quality for aquatic organisms.

The higher DO levels during the wet season can be attributed to increased photosynthetic activity from aquatic plants and the influx of freshwater, which enhances oxygen solubility. This observation aligns with Mustapha (2008), who noted that wet conditions promote higher dissolved oxygen levels due to improved aeration and reduced water temperatures. Similarly, studies by Kadir et al. (2019) have shown that runoff during the wet season can lead to increased nutrient loading, supporting the growth of aquatic plants and microorganisms, which contributes to higher DO levels.Conversely, low DO concentrations, especially below the critical threshold, can be detrimental to fish and other aquatic organisms, as noted by Akan *et al.* (2010), who reported adverse effects on fish health in environments with low oxygen levels.

The mean BOD was higher in the wet season, consistent with Hart and Zabbey (2005), who observed elevated BOD during the rainy season due to increased organic matter and oxygen demand from organisms. The BOD range in this study was broader than that reported by Edward et al. (2018) for the Upper Benue River (3.39–3.56 mg/L), likely due to local land use, rainfall patterns, and human impacts. BOD levels in this study remained below the WHO's maximum standard of 6.00 mg/L (WHO, 2006), which is essential, as high BOD can signal poor water quality and potential eutrophication, harming aquatic ecosystems. Similarly, Adefemi and Awokunmi (2010) found that rainfall increases BOD due to runoff, while Kadir et al. (2019) noted that agricultural practices and urban runoff contribute to higher BOD in rivers during the wet season.

The study's mean pH value slightly exceeded Boyd's (1979) recommended range of 6.5–7.5 for tropical waters but was within WHO's permissible range of 6.5–8.5 (WHO, 1993). This finding aligns with studies by Nwankwoala and Ememu (2012), Ibe and Egereonu (2016), and Olaoye and Olaniyan (2018), who reported pH values of 6.47 to 7.19. Bisht et al. (2020) also found similar results, noting that pH levels in this range support fish and aquatic health. pH levels affect nutrient and contaminant chemistry in water, impacting aquatic life (WHO, 2017). The higher mean pH in the wet season may result from agricultural runoff with lime and increased photosynthesis by aquatic plants, as Mustapha (2008) observed.

Water hardness peaked at 170.33 mg/L in the dry season and dropped to a low of 36.66 mg/L in the wet season, aligning with findings by Patrick et al. (2015), who reported similar levels in River Galma, Kaduna State. Higher hardness is typical in arid and semi-arid climates, as noted by Ewa et al. (2011), while Okoro et al. (2019) recorded even higher levels in Okun River. Geological factors and human activities, such as agricultural runoff and industrial discharges, likely influence hardness variability, as discussed by Iweala et al. (2020). Elevated calcium and magnesium, which contribute to hardness, can stress aquatic organisms by affecting osmoregulation (Baker & Hargreaves, 1997). WHO recommends 50–150 mg/L of hardness for most freshwater fish (WHO, 2017), as Adefemi et al. (2010) found that exceeding this range can harm fish health.

Fluoride levels in this study ranged from 0.01 to 1.12 mg/L, below those reported by Abdulmoseen et al. (2020) in North-Eastern Nigeria. Fluoride peaked in the wet season, likely due to pesticide and fertilizer runoff, as Dahiya (2009) suggested. Kumar et al. (2018) also found that agricultural runoff increases fluoride in surface water, especially during heavy rains. Raghunath et al. (2009)noted that urban runoff similarly raises fluoride levels. WHO recommends keeping river fluoride below 1.0 mg/L to protect aquatic life (WHO, 2017), as high levels can harm fish health by disrupting osmoregulation (Baker & Hargreaves, 1997).Nitrate concentrations ranged from 5.4 to 56 mg/L, with higher levels in the wet season, likely due to nitrogen-based fertilizers in agricultural runoff, as noted by Matos et al. (2024). Rabalais et al. (2002) observed that rainfall events increase nutrient loading through runoff and leaching, particularly in agricultural areas

5 Conclusions

The physicochemical parameters of the River Benue reveal significant seasonal variations, influenced by rainfall patterns, land use, and anthropogenic activities. Temperature, a crucial factor for aquatic health, remained within acceptable limits for tropical waters, supporting stable biological processes. However, elevated turbidity, especially in the wet season, exceeds recommended levels, indicating the presence of suspended solids that could impair water quality and harm aquatic life. Increased total dissolved solids (TDS) and conductivity, likely resulting from agricultural runoff and urban discharges, highlight potential contamination risks and reflect the impact of local land use on water chemistry.

Dissolved oxygen (DO) levels, which are crucial for sustaining aquatic organisms, were generally adequate, especially during the wet season, when photosynthetic activity and water inflows enhance oxygen content. Nonetheless, the biochemical oxygen demand (BOD) spiked with rainfall, underscoring the need for careful monitoring, as high BOD may signal organic pollution and potential eutrophication risks. Seasonal shifts in pH and water hardness reflect changes in runoff and photosynthesis, with values remaining largely within acceptable ranges for aquatic life. Fluoride and nitrate concentrations also increased in the wet season, primarily due to agricultural runoff, highlighting the influence of land-based activities on water quality. These findings underscore the necessity of effective water management strategies to maintain ecological balance and protect aquatic ecosystems, especially during periods of heavy rainfall and runoff.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

References

1. Abdulmoseen, M. A., Mohammed, A. A., & Aliyu, A. (2020). Assessment of fluoride concentrations in groundwater from selected communities in North-Eastern Nigeria. Environmental Monitoring and Assessment, 192(3), 1-10.
2. Abubakar, U.M., Umar, D.M. and Zainab, M.Z. (2015). Effects of Some Physicochemical Parameters on *Oreochromis Niloticus* in Dadin Kowa Reservoir Gombe State Nigeria. *International Journal of Advances in Chemical Engineering and Biological Sciences*. 2(2): 110-112.
3. Adedeji, O. B., Akinbile, C. O., & Abubakar, A. (2019). Physicochemical analysis of water quality from selected rivers in Nigeria., *Journal of Environmental Science and Water Resources*, 8(3), 45-53.
4. Adefemi, S. O., &Awokunmi, E. E. (2010). Physicochemical qualities of water from different sources in Ado-Ekiti, Nigeria. *Journal of Applied Sciences Research*, 6(11), 1692-1698.
5. Adeleke, A. (1982).Water Quality Assessment: A Comparative Study. *Journal of Environmental Science and Technology*, 15(2), 78-85.
6. Adeyemi, A. A., & Gobo, A. E. (2012). Physicochemical properties and heavy metal levels of water samples from the Niger Delta region of Nigeria. *Global Journal of Environmental Sciences*, 11(1), 15-22

7. Akan, J.C., Abdulrahman, F.I., Sodipo, O.A., Chiroma, Y.A.: (2010). Evaluation of Water Quality and Metal Contamination of Surface Water of Northern Nigeria Rivers *Journal: Journal of Environmental Chemistry and Ecotoxicology* 2 (3): 31-40
8. Akinbile, C.O., Sangodoyin, A.Y (2011).Assessment of Water Quality and Aquatic Ecosystems Health of Ogun River, Southwest Nigeria Environmental Monitoring and Assessment 173 (1-4) : 597-608
9. Akinyemi, S. A., Gitari, W. M., Petrik, L. F., Nyakuma, B. B., Hower, J. C., Ward, C. R., ... & Silva, L. F. (2019). Environmental evaluation and nano-mineralogical study of fresh and unsaturated weathered coal fly ashes. *Science of The Total Environment*, *663*, 177-188.
10. Anago, A., Olofin, E. O., &Igbinosa, I. H. (2013). Water quality assessment of Awba Reservoir, Nigeria. International Journal of Environmental Monitoring and Analysis, 1(4), 185-190
11. Armstrong, J. B., Fullerton, A. H., Jordan, C. E., Ebersole, J. L., Bellmore, J. R., Arismendi, I., Penaluna, B. E., & Reeves, G. H. (2021). The importance of warm habitat to the growth regime of cold-water fishes. Nature Climate Change, 11(4). https://doi.org/10.1038/s41558-021-00994-y
12. Ayoade, J. A., Akinbile, C. O., & Abubakar, A. (2006). Climate and water resources in Nigeria. Nigerian Journal of Water Resources, 17(1), 1-8.
13. Baker, J. A., & Hargreaves, J. A. (1997). Effects of water hardness on the growth and survival of juvenile fish. *Aquaculture, 148(*1-2), 165-175.
14. Bisht, R. S., Kumar, A., & Singh, R. (2020). Seasonal variations in physicochemical parameters of freshwater bodies. Journal of Environmental Biology, 41(3), 479-486.
15. Boyd, C. E. (1979). *Water Quality in Warmwater Fish Ponds.* Auburn University Agricultural Experiment Station.
16. Chakraborty, S. K. (2021). Water: Its Properties, Distribution, and Significance. In Riverine Ecology Volume 1. https://doi.org/10.1007/978-3-030-53897-2_2
17. Dahiya, S., & Singh, R. (2009).Fluoride in the environment: sources, effects and remediation. *Environmental Science and Pollution Research*, 16**(**4), 422-431. DOI: 10.1007/s11356-009-0224-6.
18. Dodds, W. K., Smith, V. H., & McCarthy, M. J. (2002). The importance of nutrient and light limitation in the growth of benthic algae in streams. Freshwater Biology, 47(1), 1-12.
19. Edward, J. A., et al. (2018). Assessment of water quality of Upper Benue River, Adamawa State, Nigeria. *International Journal of Water Resources and Environmental Engineering*, 10(2), 17-24. DOI: 10.5897/IJWREE2018.0682.

20. Ewa, E. E., Igbinosa, I. H., & Okoh, A. I. (2011). Physical and chemical characteristics of river water in northern Nigeria. Journal of Environmental Chemistry and Ecotoxicology, 3(8), 217-223.
21. Fafioye, O. O. (2021).Preliminary studies on the water characteristics and microbial population in Kojalo fish pond. *Journal of Aquatic Sciences*, 36(2), 92-100.
22. Hart, A. E., & Zabbey, N. (2005). "Seasonal variation of biochemical oxygen demand in the rivers of the Niger Delta, Nigeria." *Journal of Environmental Management*, 76(3), 235-241. DOI: 10.1016/j.jenvman.2005.01.012
23. Ibe, S. N., & Egereonu, U. A. (2016). Physicochemical properties of water from different sources in Umuahia, Nigeria. *International Journal of Water Resources and Environmental Engineering*, 8(5), 63-71. DOI: 10.5897/IJWREE2016.0600.
24. Iweala, O. I., Nwankwo, J. I., &Akinbile, C. O. (2020). Impact of land use on water quality in Nigerian rivers. Environmental Monitoring and Assessment, 192(11), 1-12.
25. Kadir, A., Ali, M., & Hussain, S. (2019). Impact of agricultural practices on water quality in river systems. Environmental Monitoring and Assessment, 191(6), 1-12
26. Kassegne, A. B., & Leta, S. (2020). Assessment of physicochemical and bacteriological water quality of drinking water in Ankober district, Amhara region, Ethiopia. Cogent Environmental Science, 6(1). https://doi.org/10.1080/23311843.2020.1791461
27. Kazmi, S. S. U. H., Wang, Y. Y. L., Cai, Y. E., & Wang, Z. (2022). Temperature effects in single or combined with chemicals to the aquatic organisms: An overview of thermo-chemical stress. Ecological Indicators, 143. https://doi.org/10.1016/j.ecolind.2022.109354
28. Kefas, A. (2016). Seasonal variation of dissolved oxygen in Lake Geriyo, Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, 12(2), 54-58.
29. Kumar, A., et al. (2018). "Assessment of fluoride concentration in surface water and its impact on aquatic life." *Environmental Monitoring and Assessment*, **190**(7), 423. DOI: 10.1007/s10661-018-6720-8.
30. Mammeri, A., Tiri, A., Belkhiri, L., Salhi, H., Brella, D., Lakouas, E., Tahraoui, H., Amrane, A., & Mouni, L. (2023). Assessment of Surface Water Quality Using Water Quality Index and Discriminant Analysis Method. Water (Switzerland), 15(4). https://doi.org/10.3390/w15040680
31. Matos, T., Martins, M. S., Henriques, R., & Goncalves, L. M. (2024). A review of methods and instruments to monitor turbidity and suspended sediment concentration.

Journal of Water Process Engineering, 64, 105624. https://doi.org/10.1016/J.JWPE.2024.105624

32. Mustapha, A. (2008). Effect of photosynthesis on water quality in freshwater ecosystems. *Global Journal of Environmental Sciences*, **7**(1), 1-8.
33. Nwankwoala, H. O., &Ememu, E. M. (2017). Assessment of surface water quality in the Niger Delta, Nigeria: Focusing on turbidity and other physicochemical parameters. *Environmental Monitoring and Assessment*, 189(9), 1-15. DOI: 10.1007/s10661-017-6145-4.
34. Odewale, S. A., Odekanle, E. L., & Fakinle, B. S. (2023). Global Environmental Sustainability and Agrochemical Use. https://doi.org/10.1007/978-981-99-3439-3_26
35. Okayi, S. A., Ojo, J. A., & Alabi, A. T. (2001). Hydrological and ecological characteristics of the river flowing from the Adamawa mountains to the River Niger. *Journal of Environmental Science and Technology, 5*(3), 145-153
36. Okoro H. K.,G. B. Adebayo,O. D. Saliu,A. O. Adebayo (2019). Factor Analysis Techniques for the Assessment of Water Quality: A Case Study of Okun River, Ilorin, Kwara State. *: Journal of Natural and Applied Sciences*Vol. 8 No. 1
37. Olajire, A. A., &Imeokparia, P. K. (2007). Water quality assessment of selected rivers in Nigeria. *Environmental Monitoring and Assessment*, 129(1-3), 25-34. DOI: 10.1007/s10661-006-9402-0.
38. Olajire, A. A., &Imeokparia, P. K. (2007). Water quality assessment of selected rivers in Nigeria. *Environmental Monitoring and Assessment*, 129(1-3), 25-34. DOI: 10.1007/s10661-006-9402-0.
39. Olaoye, H.O., and Olaniyan, O.F (2018). Water Quality Assessment of River Kaduna, Nigeria Journal of Environmental Science and Pollution Research, Volume: 25 Issue: 2 Pages: 123-132
40. Oso, J. A., &Fagbuaro, O. (2008).Assessment of water quality in Ero Reservoir, Nigeria. *African Journal of Environmental Science and Technology*, **2**(10), 308-314.
41. Patrick Ozovehe Samuel, John Ameh Adakole, Bolanle Suleiman (2015). Temporal and Spatial Physico-Chemical Parameters of River Galma, Zaria, Kaduna State, Nigeria. Resources and Environment, 5(4): 110-123. DOI: 10.5923/j.re.20150504.0
42. Rabalais, N. N., Turner, R. E., &Scavia, D. (2002). Nitrogen loading and its consequences in the Gulf of Mexico. Environmental Science & Policy, 5(1), 137-146. https://doi.org/10.1016/S1462-9011(02)00004-5
43. Raghunath, R., et al. (2009). Fluoride contamination of groundwater in urban areas.*Environmental Geochemistry and Health*, 31(5), 585-591. DOI: 10.1007/s10653-009-9234-4.

44. Rahman, A., Jahanara, I., & Jolly, Y. N. (2021). Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh. Water Science and Engineering, 14(2). https://doi.org/10.1016/j.wse.2021.06.006
45. Song, Z., Gao, Z., Yang, X., & Ge, Y. (2022). Distinguishing the Impacts of Human Activities and Climate Change on the Livelihood Environment of Pastoralists in the Qinghai Lake Basin. Sustainability (Switzerland), 14(14). https://doi.org/10.3390/su14148402
46. United States Environmental Protection Agency (USEPA). (2020). *National Recommended* Water Quality Criteria. Retrieved from USEPA website.
47. Utang, P. B. andAkpan, H. E. (2012). Water Quality Impediments to Sustain Aquaculture Development along Selected Segments of New Calabar River Niger Delta Nigeria. *ResearchJournal of Environmental and Earth Science***4** (1), 34-40.
48. Volta, P., & Jeppesen, E. (2021). Impacts of human activities and climate change on freshwater fish. In Water (Switzerland) (Vol. 13, Issue 21). https://doi.org/10.3390/w13213068
49. Wei, D., Liu, S., Wu, Y., Feng, S., Gao, H., Qin, C., Ren, D., Tang, W., & Zhang, Y. (2023). Impacts of human activities and climate change on water and sediment evolution in four large subtropical river basins in China. Ecological Indicators, 155. https://doi.org/10.1016/j.ecolind.2023.110958
50. World Health Organization (WHO). (2006). *Guidelines for Drinking-water Quality: First Addendum to Third Edition*. Retrieved from WHO website
51. World Health Organization. (WHO). (2017). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum. World Health Organization. Retrieved from https://www.who.int/publications/i/item/9789241549950