

Assessment of **Planktonic** Communities and Water Quality of River Katsina-Ala at Kwantan-Sule, **Benue State, Nigeria**

ABSTRACT

The present study focused on planktonic species and water quality of River Katsina-Ala at Kwantan-Sule, Guma Local Government Area of Benue State, Nigeria. Samples were collected twice in a week for 4 weeks between October and November, 2017 using a 55 µm mesh plankton net. Water quality parameters were determined *in-situ* and *ex-situ* using standard procedures. A total of 144 planktonic specimens were identified during the study period. They were distributed among 6 classes: Cladocera (46%), Diptera (24%), Copepoda (13%), Ephemerophyta (10%), Arachnida (4%) and Protozoa (3%). The plankton diversity indices were: Shannon-Weiner (2.286), Simpson (0.875) and Margalef (2.213). Mean values of physico-chemical parameters were; temperature (27.23 ± 0.23 °C), dissolved oxygen (5.45 ± 0.00 mg/L), biochemical oxygen demand (2.10 ± 0.10 mg/L), pH (7.80 ± 0.01), electrical conductivity (29.75 ± 0.25 µScm⁻¹), transparency (37.06 ± 1.06 cm) and total hardness (0.11 ± 0.00 mg/L). The river contained moderate abundance and varied planktonic organisms. The water quality parameters of the study area were favourable for aquatic life to thrive.

Key words: Zooplankton, Microfauna, Water parameters, Diversity, Kwantan-Sule

INTRODUCTION

Planktonic organisms such as zooplankton and microfauna are important component of aquatic ecosystems (Mishra, 2020). They serve as a crucial link between primary producers such as phytoplankton and higher trophic levels including fish and other freshwater organisms (Karakuş *et al.*, 2022; Declerck and de Senerpont Domis, 2023). The energy transfer within food webs is mediated by these primary consumers (Sánchez *et al.*, 2024), thus playing a significant role in nutrient cycling with much influence on phytoplankton dynamics (Richon and Tagliabue, 2021; Ratnarajah *et al.*, 2023). These processes contribute to the overall ecosystem productivity and biogeochemical processes in aquatic ecosystems (Lomartire *et al.*, 2021; Karakuş *et al.*, 2022). The diversity and abundance of these planktonic organisms are essential indicators of ecosystem health (Muñoz-Colmenares *et al.*, 2021; Tomljanović *et al.*, 2024). High plankton diversity often reflects a stable and healthy environment whereas changes in their populations can indicate environmental stressors such as pollution or habitat degradation (Kumar *et al.*, 2018; Bakhtiyar *et al.*, 2020; Choi *et al.*, 2023). Studies on plankton biodiversity in freshwaters often provide relevant information on species richness, ecological interactions required for proper ecosystem conservation and management (Xiong *et al.*, 2020). More so, zooplankton are vital for fisheries and aquaculture as they serve as a major food source for juvenile fish and their population dynamics can affect fish productivity (Winder and Jassby, 2011; Karakuş *et al.*, 2022). They are important for the effective management of fishery resources (Shao *et al.*, 2019). Zooplankton in particular are sensitive to changes in environmental variables such as nutrient availability, temperature, and dissolved oxygen. This makes them bioindicators for assessing water quality and detecting pollution (Arazu and

Ogbeibu, 2017; Essa *et al.*, 2024). Their swift response to shifting water conditions makes them dependable tools for monitoring ecosystem health (Li *et al.*, 2022; Mohan and Prabha, 2024). A proper understanding of the abundance and diversity of plankton communities is therefore necessary for advancing ecological research which is a gateway to biodiversity protection in order to ensure the sustainable management of aquatic ecosystems.

The water quality parameters in freshwater ecosystems play significant role in maintaining ecological health, supporting fisheries, ensuring safe water for human consumption, and sustaining economic activities (Sun *et al.*, 2021; Omokaro *et al.*, 2024). Freshwater bodies are critical for life and serve as critical habitats for a variety of aquatic organisms including zooplankton species of significant economic and ecological value (Iyiola *et al.*, 2022). Some of these parameters such as temperature, dissolved oxygen (DO), pH, turbidity, and nutrient levels are crucial in establishing the health and productivity of these ecosystems (Opadokun *et al.*, 2015; Uzomah *et al.*, 2021). Water quality has a direct influence on the growth, reproduction, and survival of planktonic organisms (Malik *et al.*, 2020). Changes in physical and chemical parameters such as reduced DO or extreme pH fluctuations can impair physiological processes in these primary consumers (Zhang *et al.*, 2024). This by implication leads to reduced population sizes and diminished fishery yields. Increase in nutrient levels can equally lead to eutrophication with a resultant effect of algal blooms that deplete oxygen thereby disrupting food chains (Glibert, 2017; Devlin and Brodie, 2023; Lan *et al.*, 2024). Thus, the survival of aquatic fauna and other organisms are threatened. Apart from ecological implications, poor water quality affects socio-economic benefits derived from fisheries. Polluted freshwater ecosystem often experience the collapse of fish stocks with a negative implication on the livelihoods of communities that depend on fishing for income and food security (Andrews *et al.*, 2021). Despite numerous researches (Adadu *et al.*, 2019; Barau *et al.*, 2020; Shima *et al.*, 2023) on plankton communities in freshwater ecosystems in the North Central Nigeria, studies focusing Katsina-Ala tributary of River Benue on the abundance and diversity of planktonic organisms however remain scarce which prevents the ability to monitor changes in water quality and assess ecological health effectively. The current study aims to assess the abundance and diversity of planktonic organisms of the River at Kwantan-Sule and equally evaluate its water quality parameters. These findings will contribute to understanding the ecological status of the water body and its potential for fisheries development. Moreover, the study serves as a reference point for future monitoring and research in Nigerian freshwater systems.

MATERIALS AND METHODS

Study Location

The study was conducted in River Katsina-Ala one of the major tributaries of River Benue. It is located between latitude 7° 38' and 7° 52' N and longitude 8° 50' and 9° 05' E. It runs from Katsina – Ala through Buruku and Guma Local Government Areas of Benue State and empties into the Lower River Benue (Dam *et al.*, 2020). The River has extensive alluvial plain stretching for many kilometers, which covers a distance of approximately 187 kilometers. The River experiences tropical climatic condition, with distinct wet and dry seasons (Iwar *et al.*,

2023). It is used for fishing and domestic activities and it also serves as means of transportation for the surrounding populace.

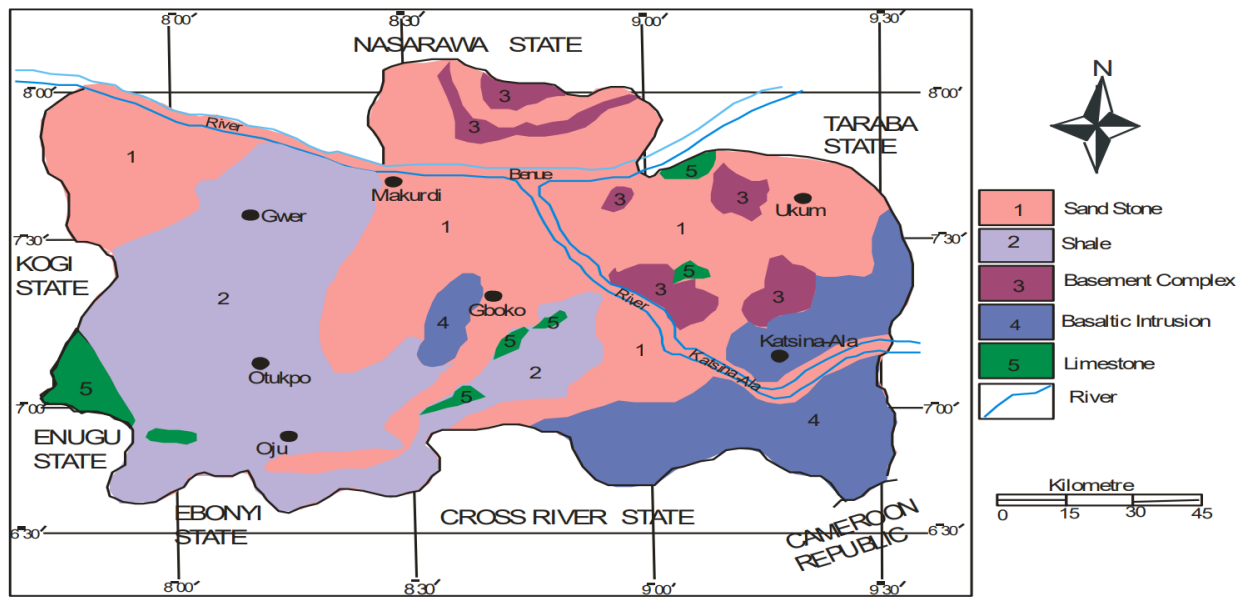


Figure 1: Geology Map of Benue State

Source: Imadojemu and Apelebiri (2024).

Sample Collection

A purposive sampling method was used to collect zooplankton samples for 4 weeks between October and November, 2017 at Kwantan-Sule landing site of River Katsina-Ala. Zooplankton were sampled twice a week giving a total of 8 samplings. Samples were collected in the morning (before 8:00 am) using 55 µm mesh size standard plankton net by dragging the net through water at a distance of 5 m according to Dimowo (2013). The plankton net used was conical in shape with an area of 108 m². By dragging through a distance of 5 m, the volume of water filtered was 540 m³ (540,000 litres). The samples were transferred into 250 ml labeled plastic bottles and preserved with 4% formalin solution for analysis (Kelso *et al.*, 2012). Samples were transported to the Multipurpose Laboratory in the Department of Fisheries and Aquaculture, Federal University of Agriculture, Makurdi. In the laboratory, zooplankton samples were centrifuged using a Gallen Kamp-medico Centrifuge according to Solomon *et al.* (2009). Centrifuged samples were taken using a pipette and 2 drops (cm³) of the zooplankton sample were placed on a glass slide and covered and viewed for identification under a light microscope. Identification of planktonic organisms was guided by the manual of Lynne (2004).

Plankton Abundance and Diversity Analyses

Abundance of zooplankton and other microfauna was calculated as number of organism per m³ using the formula;

$$\text{Density} = \frac{N \times 100}{\text{Initial volume of water filtered}} \quad (\text{Ogbeibu and Obonor, 2002}) \quad (1)$$

Where N = number of organism per sample.

The Shannon-Weiner, Simpson and Margalef indices were used to analyze the diversity and structure of plankton organisms in the river according to Sina and Zulkarnaen (2019). The Shannon-Weiner index was calculated to assess overall species diversity. This index accounts for both the species richness and their relative abundance, which gives higher values in ecosystems with many evenly distributed species. The formula is given as:

$$H' = \sum_{i=1}^S p_i \ln p_i \quad (2)$$

where H' is the species diversity index, S is the number of species, and p_i is the proportion of individual, of each species belonging to the i^{th} species of the total number of individuals.

The Simpson's Index was also utilized to measure species dominance;

$$D = \sum_{i=1}^S p_i^2 \quad (3)$$

S - species richness

p_i - proportion of species

Where values closer to 1 indicate lower dominance, which implies greater evenness within the ecosystem. This index assessed whether certain species were particularly dominant or if there was a more balanced species distribution. The Margalef's Richness index was further used to estimate species richness by normalizing the species count against the total number of individual fish. A higher score of Margalef's index shows a richer community of species. The formula is given as:

$$D_{ma} = \frac{S-1}{\ln N} \quad (4)$$

S – species richness

N – total abundance

Water Quality Parameters

The physico-chemical parameters of River Katsina-Ala was determined both *in-situ* and *ex-situ*. A Multi-parameter water quality monitor (PHT-027) was used to measure hydrogen ion concentration and electrical conductivity ($\mu\text{S}/\text{cm}$) *in-situ* at the sampling station. Temperature ($^{\circ}\text{C}$) was measured using an alcohol in glass thermometer ($0 - 100^{\circ}\text{C}$) while secchi disc was used to determine water transparency (cm). Water samples were collected into pre-washed and sterilized plastic bottles for laboratory analysis. Standard procedures were then used to analyze the samples for a variety of other chemical parameters such as dissolved oxygen (mg/L), biochemical oxygen demand (mg/L) and total hardness according to APHA (1998).

Statistical Analysis

Zooplankton percentage abundance, diversity indices and analysis of variance of water quality parameters were performed using Minitab Application.

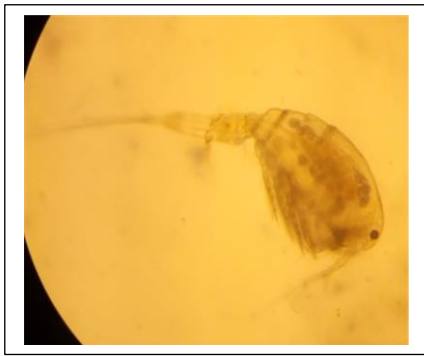
RESULTS

A total of 144 planktonic individuals were identified during the study period comprising of 12 species from 6 classes (Table 1). The planktonic species included 4 species of class cladocera (*Bosmina*, *Ceriodaphnia*, *Daphnia* and *Diaphanosoma*), 2 copepods (*Branchipus* and *Diaptomus*), 2 species from the class ephemerophyta (*Baetis* and *Stenonema*) and 2 dipteran species (*Chironomus* and *Simulium*) were identified. Also identified was 1 species each from the classes Arachnida (*Argyroneta*) and Protozoa (*Paranema*). The class cladocera was dominated by *Daphnia* (53.73 %), followed by *Bosmina* (22.39 %), *Diaphanosoma* (13.43 %) and then *Ceriodaphnia* (10.45 %). Diptera was dominated by *Chironomus* (52.94 %), followed by *Simulium* (47.06 %). The class copepoda was dominated by *Branchipus* (63.16 %), followed by *Diaptomus* (36.84 %) while class ephemerophyta was dominated by the species *Stenonema* (57.14 %), followed by *Baetis* (42.86%). Some of the organisms identified during the study period are presented in figure 2. Results from Figure 3 showed that the class cladocera were most prevalent (46 %), followed by diptera (24 %), copepoda (13 %), ephemerophyta (10 %), arachnida (4 %) and protozoa (3 %).

Table 2 shows a comprehensive data on the richness and distribution of planktonic communities in River Katsina-Ala. The Shannon-Weiner index of 2.286 recorded showed a moderate plankton species diversity which indicates a balanced distribution in the ecosystem. This value indicates the ability of the river to support a considerable number of fish species with each species occupying a specific ecological niche. The Simpson index (1-D) recorded for the study was 0.875 which suggested a low species dominance, where no single species disproportionately influenced the community structure. The Margalef Richness index of 2.213 indicated low species richness. Figure 4 shows weekly variations in diversity indices where the highest diversity was recorded during Week 3 which could be linked to optimal dissolved oxygen (DO) levels and moderate temperatures.

Table 1: Abundance and Composition of Planktonic population

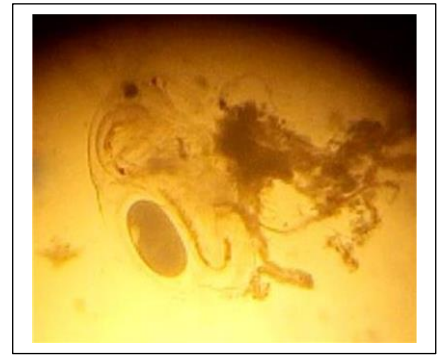
S/N	Class	Species	Weeks				Total Abundance cm ³	% Abundance
			1	2	3	4		
1.	Cladocera		12	23	15	17	67	
		<i>Bosmina</i>	3	4	0	8	15	22.39
		<i>CerioDaphnia</i>	0	4	3	0	7	10.45
		<i>Daphnia</i>	7	15	9	5	36	53.73
		<i>Diaphanosoma</i>	2	0	3	4	9	13.43
		Total percent						100
2.	copepoda		4	3	8	4	19	
		<i>Branchipus</i>	0	0	8	4	12	63.16
		<i>Diaptomus</i>	4	3	0	0	7	36.84
		Total percent						100
3.	Ephemeroptera		3	1	7	3	14	
		<i>Baetis</i>	0	1	5	0	6	42.86
		<i>Stenonema</i>	3	0	2	3	8	57.14
		Total percent						100
4.	Diptera		0	7	13	14	34	
		<i>Chironomus</i>	0	6	4	8	18	52.94
		<i>Simulium</i>	0	1	9	6	16	47.06
		Total percent						100
5.	Arachnida		0	4	2	0	6	
		<i>Argyroneta</i>	0	4	2	0	6	100
		Total percent						100
6.	protozoa		4	0	0	0	4	
		<i>Paranema</i>	4	0	0	0	4	100
		Total percent						100
Total	6	12	23	38	45	38	144	



a



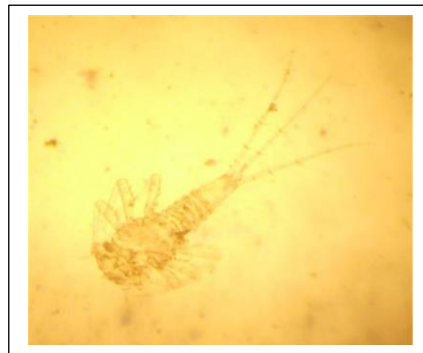
b



c



d



e



f

Figure 2: A Cross section of some identified planktonic organisms

Hint: a-Copepoda: *Branchipus*, b-Diptera: *Simulium*, c-Cladocera: *Daphnia*, d- Ephemeroptera: *Baetis*, e- Ephemeroptera: *Stenonema*, f- Cladocera; *Ceriodaphnia*

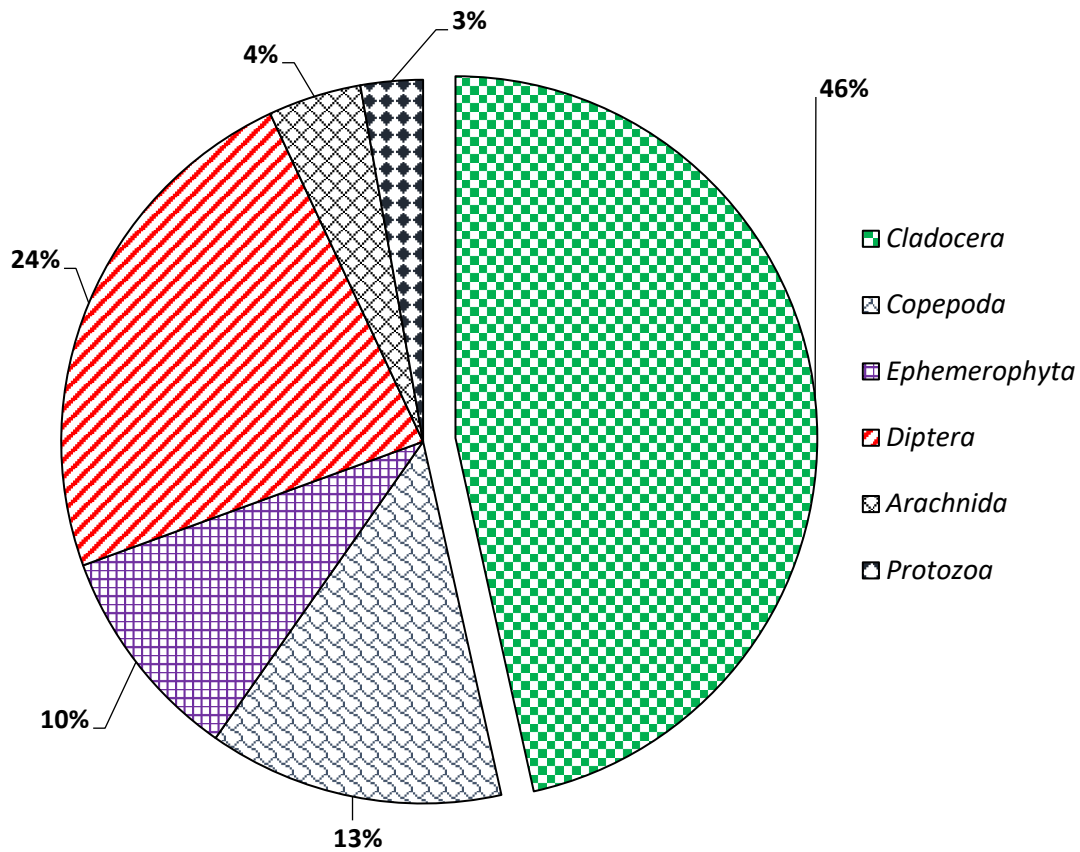


Figure 3: Percentage composition of plankton communities of River Katsina-Ala at Kwantan-Sule

Table 2: Diversity Indices of Plankton Communities of River Katsina-Ala at Kwantan-Sule

Diversity Indices	Sampling Period				Total
	Week 1	Week 2	Week 3	Week 4	
Taxa S	6	8	9	7	12
Individuals	23	38	45	38	144
Dominance D	0.194	0.221	0.144	0.159	0.124
Simpson 1-D	0.805	0.778	0.855	0.840	0.875
Shannon H	1.714	1.761	2.048	1.889	2.286
Evenness	0.925	0.964	0.861	0.944	0.819
Margalef	1.595	1.298	2.102	1.649	2.213
Equitability J	0.956	0.847	0.932	0.970	0.919
Berger Parker	0.304	0.394	0.200	0.210	0.250

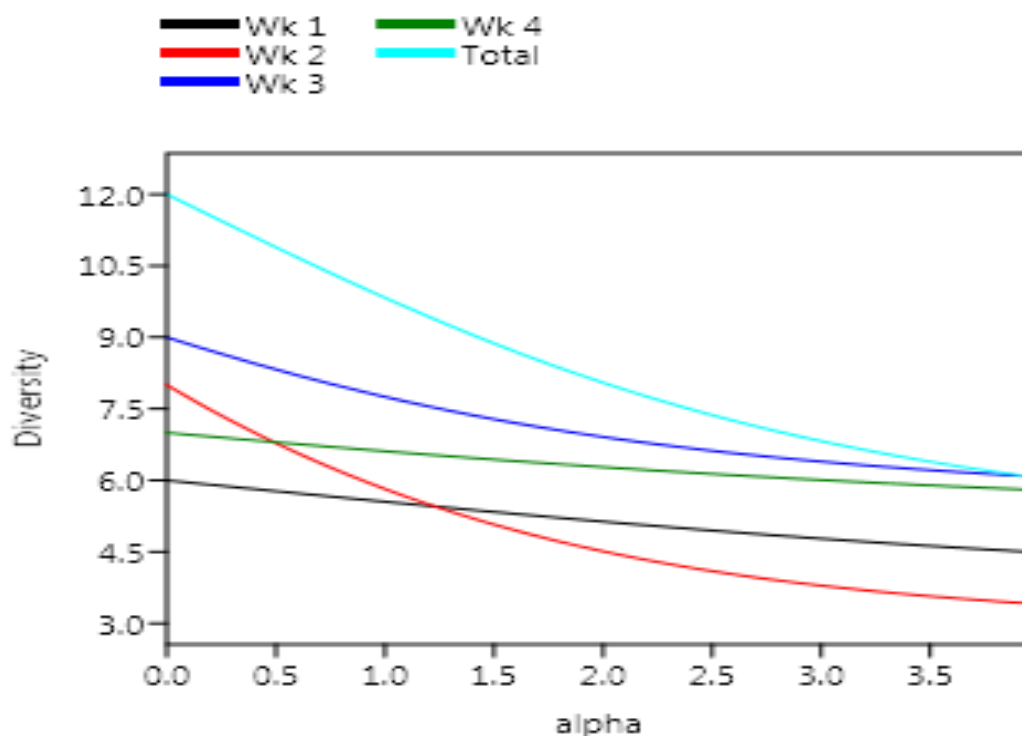


Figure 4: Weekly plankton species diversity

The values of water quality parameters are presented in Table 3. The surface water temperature of the water body ranged between 26.50 ± 0.50 °C and 28.50 ± 0.05 °C for Week 1/Week 4 and Week 2, respectively with no significant variation ($P > 0.05$). The mean surface temperature recorded during the period was 27.23 ± 0.23 °C. Dissolved oxygen levels ranged from 5.05 ± 0.15 mg/L in Week 4 to 5.80 ± 0.10 mg/L in Week 1, with a mean value of 5.45 ± 0.00 mg/L. There was a statistically significant differences across the sampling months ($P = 0.02$). The pH values of the study showed a statistical difference ($p < 0.01$). The highest value was recorded in Week 4 (8.20 ± 0.04) while the lowest value was recorded in Week 1 (7.38 ± 0.03) with a mean value of 7.80 ± 0.01 . Electrical conductivity fluctuated significantly across the months ($p < 0.01$) with the least value recorded in Week 2 (26.50 ± 0.50 μ S/cm) while the highest value was recorded in Week 4 (35.00 ± 1.00 μ S/cm) with a mean of 29.75 ± 0.25 μ S/cm. Water transparency varied significantly ($p < 0.01$) from 31.25 ± 0.75 cm in Week 1 to 47.50 ± 1.50 cm in Week 4 with a mean of 37.06 ± 0.06 cm. A mean value of 2.10 ± 0.10 mg/L was recorded for biochemical oxygen demand (BOD) with the least value recorded in Week 4 (1.70 ± 0.20 mg/L) while the highest value was recorded in Week 3 (2.35 ± 0.05 mg/L). Significant differences were noted across the months ($p = 0.05$) which indicated variations in organic matter decomposition. Similarly, there was statistically significant variation ($p = 0.05$) in the values recorded for total hardness. The lowest value of 0.09 ± 0.00 mg/L recorded in Week 1 while the highest value of 0.13 ± 0.01 mg/L Week 2, with a mean of 0.11 ± 0.00 mg/L.

Table 3: Water Quality Parameters of River Katsina-Ala at Kwantan-Sule

Water Quality Parameters	Mean	Sampling Period				P-Value
		Week 1	Week 2	Week 3	Week 4	
Temperature (°C)	27.23±0.23	26.50±0.50	28.50±0.50	27.45±0.45	26.50±0.50	0.11 ^{ns}
Dissolved Oxygen (mg/L)	5.45±0.00	5.80±0.10 ^a	5.70±0.10 ^{ab}	5.27±0.07 ^{bc}	5.05±0.15 ^c	0.02
Biochemical Oxygen Demand (mg/L)	2.10±0.10	2.25±0.05 ^a	2.10±0.10 ^{ab}	2.35±0.05 ^a	1.70±0.20 ^b	0.05
pH	9.80±0.01	9.38±0.03 ^c	9.75±0.05 ^b	9.89±0.04 ^b	10.20±0.04 ^a	<0.01
Electrical Conductivity (µS/cm)	29.75±0.25	28.00±1.00 ^b	26.50±0.50 ^b	29.50±0.50 ^b	35.00±1.00 ^a	<0.01
Transparency (cm)	37.06±0.06	31.25±0.75 ^c	32.25±1.25 ^c	37.25±0.75 ^b	47.50±1.50 ^a	<0.01
Total Hardness (mg/L)	0.11±0.00	0.09±0.00 ^b	0.13±0.01 ^a	0.12±0.01 ^{ab}	0.12±0.00 ^{ab}	0.05

Means on the same row (sampling period) with different superscript are statistically significant ($p < 0.05$)

DISCUSSION

The plankton community of River Katsina-Ala at Kwantan-Sule is moderately diverse. The class Cladocera was most dominant with *Daphnia* occurring most. This means that this group of zooplankton were well adapted to the environmental variables of the river. The filter-feeding behaviour of *Daphnia* and the ability of the species to thrive in habitats with adequate phytoplankton availability could be the reason for its predominance (Beisner and Thackeray, 2024). The result of the current study corroborates the findings of Barau *et al.* (2020) in the upper Benue River at Mayo-Ranewo, Taraba State where copepods were dominant because of the presence of macrophytes and favourable water conditions. Similarly, the plankton assemblage in River Katsina-Ala at Kwantan-Sule also agrees with findings in other Nigerian rivers such as River Niger (Arazu & Ogbeibu, 2017) and River Ogun (Dimowo, 2013) where the class Cladocera and Copepoda were dominant. The absence of Rotifera in this study is however dissimilar with findings from Dimowo (2013) in River Ogun and Adudu *et al.* (2019) in River Okpokwu in Benue State where Rotifers, particularly the genus *Brachionus*, were dominant. The explanation to this discrepancy may be as a result of the differences in nutrient input as Rotifers have been reported to thrive in nutrient-rich waters, whereas River Katsina-Ala appeared to have limited nutrient availability, thus reducing their presence. The presence of Diptera specifically *Chironomus* could be due to the presence of substantial organic matter levels in the river. Chironomid larvae are often associated with detrital environments which suggests some amount of organic enrichment (Martins *et al.*, 2021). This finding agrees with Barau *et al.* (2020), who reported a significant presence of pollution-tolerant genera in the Benue River system. Nevertheless, the non-existence of significant pollution indicators like Rotifers in this study could be due to relatively low organic pollution compared to the River Okpokwu, where nutrient levels supported higher zooplankton abundance during the dry season (Adudu *et al.*, 2019).

Diversity indices provide in-depth comprehension into the health of the freshwater ecosystem and plankton community structure. The value recorded for Shannon-Weiner index showed moderate diversity with an even distribution of species which is a representation of a stable ecosystem capable of supporting numerous trophic interactions. Comparatively, Shima *et al.* (2023) recorded slightly higher diversity indices in the Lower River Benue which could be due to wider variations in environmental variables and habitat complexity. Furthermore, the Simpson index recorded in this study indicated low species dominance which is a shows balanced ecosystem. The moderate Margalef richness index recorded however showed that species richness in the ecosystem is limited. It could be that environmental or anthropogenic factors may be acting against planktonic species recruitment in the river. The weekly variations in diversity were highest in Week 3 which could be influenced by increased dissolved oxygen levels and moderate temperatures. Weinstock *et al.* (2022) stated that plankton diversity is better enhanced under favorable conditions. In a reversed trend, the lower diversity recorded in Week 1 may be associated with reduced dissolved oxygen. This means that the zooplankton and microfauna in the river were sensitive to fluctuations in environmental variables.

Water quality parameters have been reported to have influence on plankton abundance and diversity. The temperature range during the study period was within the optimal limit for reproduction and survival of planktonic organisms. This finding corroborates findings by Opadokun *et al.* (2015), who asserted that similar temperature ranges in Lekki Lagoon were responsible for improved plankton productivity. The dissolved oxygen levels were also adequate for aquatic life to thrive even though the varied levels had influence on zooplankton diversity. Shima *et al.* (2023) reported a positive correlation between dissolved oxygen and plankton abundance in the Lower River Benue, affirming its critical role in maintaining aquatic ecosystems. The pH levels recorded were also optimal for the plankton to survive. Barau *et al.* (2020) and Adudu *et al.* (2019) however, reported lower ranges of pH which supported higher plankton diversity. Electrical conductivity range in the river showed the ionic concentrations were moderate and suitable for plankton communities. Also, the water transparency recorded during the study period signifies moderate productivity and light penetration. These factors are essential for phytoplankton growth which serve as food for zooplankton and other micro fauna (Opadokun *et al.*, 2015).

Conclusion

The findings of the study provided information on the abundance and diversity of zooplankton and water quality of River Katsina-Ala. The river has moderate zooplankton species diversity and a balanced species distribution. The favourable dissolved oxygen and temperature levels shows that the ecosystem is stable and is capable of supporting aquatic life. This is reflected in the dominance of Cladocera and Diptera. The peculiar absence of Rotifers in the river and the moderate richness index could mean that there is low availability of nutrients.

Recommendation

There is need to conduct an elaborate temporal and spatial assessment of the zooplankton community for comprehensive documentation of the ecological status of River Katsina-Ala. Continuous monitoring of the ecosystem is also necessary to detect early signs of ecological changes which could stem from anthropogenic activities such as nutrient runoff and organic pollution.

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Disclaimer (Artificial intelligence)

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.

REFERENCES

- Adadu, M. O., Omeji, S. & Garba, A. A. (2019). Seasonal diversity and abundance of zooplankton community index in river Okpokwu, Benue state, Nigeria. *International Journal of Fisheries and Aquatic Studies* 2019; 7(5): 217-223.
- Andrews, N., Bennett, N. J., Le Billon, P., Green, S. J., Cisneros-Montemayor, A. M., Amongin, S. & Sumaila, U. R. (2021). Oil, fisheries and coastal communities: A review of impacts on the environment, livelihoods, space and governance. *Energy Research & Social Science*, 75, 102009.
- APHA (1998). *Standard Methods for the Examination of Water and Wastewater*. 20th Edition, American Public Health Association, Washington DC.
- Bakhtiyar, Y., Arafat, M. Y., Andrabi, S., & Tak, H. I. (2020). Zooplankton: the significant ecosystem service provider in aquatic environment. *Bioremediation and Biotechnology*, (30: 227-244.
- Barau, B. W., Bature, A. A., Bingari, S. M., David, D. L., Danba, E. P., Hammanjoda, S. A., Azuchukwuene, C. G. & Fauziya, K. M. (2020). Plankton diversity in the upper Benue river of Taraba state, Nigeria. *International Journal of Fisheries and Aquatic Studies*, 8(2): 120-125.
- Beisner, B. E. & Thackeray, S. J. (2024). Ecology and Functioning of Zooplankton Communities. In *Wetzel's Limnology* (pp. 587-620). Academic Press.
- Choi, Y., Oh, H. J., Lee, D. H., Jang, M. H., Lee, K. L., Chang, K. H. & Kim, H. W. (2023). Current Utilization and Further Application of Zooplankton Indices for Ecosystem Health Assessment of Lake Ecosystems. *Sustainability*, 15(14), 10950.
- Dam, D. P., Iorliam, S., Kwaghsende, F., Anule, P. T., Mngutyo, I., Atser, J. & Gyuse, T. (2020). Emerging Urban Systems in the Benue Basin of Nigeria. *American Journal of Rural Development*, 8(1): 17-27.
- Declerck, S. A. & de Senerpont Domis, L. N. (2023). Contribution of freshwater metazooplankton to aquatic ecosystem services: an overview. *Hydrobiologia*, 850(12), 2795-2810.
- Devlin, M. & Brodie, J. (2023). Nutrients and eutrophication. In *Marine pollution—monitoring, management and mitigation* Cham: Springer Nature Switzerland. pp. 75-100.
- Essa, D. I., Elshobary, M. E., Attiah, A. M., Salem, Z. E., Keshta, A. E., & Edokpayi, J. N. (2024). Assessing phytoplankton populations and their relation to water parameters as early alerts and biological indicators of the aquatic pollution. *Ecological Indicators*, 159, 111721.
- Glibert, P. M. (2017). Eutrophication, harmful algae and biodiversity—Challenging paradigms in a world of complex nutrient changes. *Marine Pollution Bulletin*, 124(2): 591-606.

- Imadojemu, P. E. & Apelebiri, S. (2024). Profile Study of Soils along the Toposequence of Katsina-Ala River in Benue State, Nigeria. *FUW Trends in Science & Technology Journal*, 9(1): 104 -110.
- Iwar, M., Kaa, A. & Olufeagba, S. O. (2023). Some soil parameters concerning macrophyte abundance along the Manatee habitat along River Benue, Nigeria. *Scientific Reports in Life Sciences (SRLS)*, 4(4): 60 – 71.
- Iyiola, A. O., Asiedu, B., Oyewole, E. O. & Akinrinade, A. J. (2022). Impacts of Climate Change on Aquatic Biodiversity in Africa. In *Biodiversity in Africa: Potentials, Threats and Conservation*. Singapore: Springer Nature Singapore, pp. 369-394.
- Karakuş, O., Völker, C., Iversen, M., Hagen, W. & Hauck, J. (2022). The role of zooplankton grazing and nutrient recycling for global ocean biogeochemistry and phytoplankton phenology. *Journal of Geophysical Research: Biogeosciences*, 127(10), e2022JG006798.
- Kelso, W. E., Kaller, M. D. & Rutherford, D. A. (2012). Collecting, processing, and identification of fish eggs and larvae and zooplankton. *Fisheries techniques*, 363-452.
- Kumar, S., Trakroo, M. D., Goswami, K. & Tewari, H. (2018). Observations on Zooplankton Community of Nanak Sagar Reservoir, Uttarakhand, India. *International Journal of Current Microbiology and Applied Sciences*, 7(10):339-349. doi: 10.20546/IJCMAS.2018.710.036
- Lan, J., Liu, P., Hu, X., & Zhu, S. (2024). Harmful Algal blooms in Eutrophic Marine environments: causes, monitoring, and treatment. *Water*, 16(17), 2525.
- Li, Z., Ma, C., Sun, Y., Lu, X. & Fan, Y. (2022). Ecological health evaluation of rivers based on phytoplankton biological integrity index and water quality index on the impact of anthropogenic pollution: A case of Ashi River Basin. *Frontiers in Microbiology*, 13, 942205.
- Lomartire, S., Marques, J. C. & Gonçalves, A. M. (2021). The key role of zooplankton in ecosystem services: A perspective of interaction between zooplankton and fish recruitment. *Ecological Indicators*, 129, 107867.
- Malik, D. S., Sharma, A. K., Sharma, A. K., Thakur, R. & Sharma, M. (2020). A review on impact of water pollution on freshwater fish species and their aquatic environment. *Advances in environmental pollution management: wastewater impacts and treatment technologies*, (1): 10-28.
- Martins, I., Castro, D. M., Macedo, D. R., Hughes, R. M. & Callisto, M. (2021). Anthropogenic impacts influence the functional traits of Chironomidae (Diptera) assemblages in a neotropical savanna river basin. *Aquatic Ecology*, 55(3): 1081-1095.
- Mishra, Y. (2020). Study of zooplankton community structure for aquaculture planning in Lony dam reservoir. *GSC Biological and Pharmaceutical Sciences*, 11(1), 116-165.
- Mohan, B., & Prabha, D. (2024). Evaluation of trophic state conditions in the three urban perennial lakes of the Coimbatore district, Tamil Nadu: Based on water quality parameters and rotifer composition. *HydroResearch*, 7, 360-371.

- Muñoz-Colmenares, M. E., Soria, J. M. & Vicente, E. (2021). Can zooplankton species be used as indicators of trophic status and ecological potential of reservoirs? *Aquatic Ecology*, 55(4), 1143-1156.
- Omokaro, G. O., Idama, V., Airueghian, E. O. & Michael, I. (2024). Water Resources, Pollution, Integrated Management and Practices in Nigeria—An Overview. *American Journal of Environmental Economics*, 3(1): 5-18.
- Ratnarajah, L., Abu-Alhaija, R., Atkinson, A., Batten, S., Bax, N. J., Bernard, K. S. & Yebra, L. (2023). Monitoring and modelling marine zooplankton in a changing climate. *Nature Communications*, 14(1), 564.
- Richon, C. & Tagliabue, A. (2021). Biogeochemical feedbacks associated with the response of micronutrient recycling by zooplankton to climate change. *Global Change Biology*, 27(19): 4758-4770.
- Sánchez, N., Goldenberg, S. U., Brüggemann, D., Jaspers, C., Taucher, J. & Riebesell, U. (2024). Plankton food web structure and productivity under ocean alkalinity enhancement. *Science Advances*, 10(49), eado0264.
- Shao, N. F., Yang, S. T., Sun, Y., Gai, Y., Zhao, C. S., Wang, F. & Dong, B. (2019). Assessing aquatic ecosystem health through the analysis of plankton biodiversity. *Marine and Freshwater Research*, 70(5): 647-655.
- Shima, N. J., Odo, J. I., Ode, O. S. & Lois, I. A. (2023) Physicochemical parameters and plankton diversity from Lower River Benue, Makurdi. *Journal of Bioscience and Biotechnology Discovery*, 8(5): 141-150.
- Sina, I. & Zulkarnaen, I. (2019). Margalef Index, Simpson Index and Shannon-Weaver Index calculation for diversity and abundance of beetle in tropical forest. *Statmat: Jurnal Statistika dan Matematika*, 1(2).
- Solomon, S. G., Ataguba, G. A. & Baiyewunmi, A. S. (2009). Study of dry season zooplankton of Lower River Benue at Makurdi, Nigeria. *Journal of Animal and Plant Science*, 1: 42-50.
- Sun, F., Mu, Y., Leung, K. M., Su, H., Wu, F. & Chang, H. (2021). China is establishing its water quality standards for enhancing protection of aquatic life in freshwater ecosystems. *Environmental Science & Policy*, 124: 413-422.
- Tomljanović, T., Tasevska, O., Špoljar, M., Kostoski, G., Radanović, I., Sarafiloska, E. V. & Dražina, T. (2024). Zooplankton as Indicator of Ecological Status in the Streževo Reservoir (North Macedonia). *Sustainability*, 17(1), 171.
- Uzomah, A., Lundebye, A. K., Kjellekvold, M., Chuku, F. A. & Stephen, O. A. (2021). A review of chemical contaminants in marine and fresh water fish in Nigeria. *Foods*, 10(9), 2013.
- Weinstock, J. B., Vargas, L. & Collin, R. (2022). Zooplankton abundance reflects oxygen concentration and dissolved organic matter in a seasonally hypoxic estuary. *Journal of Marine Science and Engineering*, 10(3), 427.
- Winder, M., & Jassby, A. D. (2011). Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. *Estuaries and Coasts*, 34, 675-690

Xiong, W., Huang, X., Chen, Y., Fu, R., Du, X., Chen, X. & Zhan, A. (2020). Zooplankton biodiversity monitoring in polluted freshwater ecosystems: A technical review. *Environmental Science and Ecotechnology*, 1, 100008.

Zhang, K., Ye, Z., Qi, M., Cai, W., Saraiva, J. L., Wen, Y. & Zhao, J. (2024). Water Quality Impact on Fish Behavior: A Review from an Aquaculture Perspective. *Reviews in Aquaculture*.

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