Appraisal of Water Quality Trends in Kitiri Reservoir, Jigawa State, Nigeria

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ABSTRACT

Water bodies in Nigeria's semi-arid zone, such as Kitiri Reservoir in Jigawa State, play a critical role in irrigation, fisheries, and local livelihoods, yet their physicochemical profiles remain poorly documented. This study aimed to assess the spatial and seasonal variations in key water quality parameters of Kitiri Reservoir over a 24-month period (January 2022–December 2023) to establish baseline data for sustainable management. Monthly samples from three stations—Kitiri, Dakori Malam Buba, and Rafa—were analyzed in situ for temperature, transparency, pH, dissolved oxygen (DO), alkalinity, ammonia, and hardness using standard APHA protocols. Results showed significant ($P < 0.05$) station-based differences in temperature (25.01–25.45°C), DO (6.02–6.13 mg/l), and hardness (80.91–82.30 ppm), while transparency, pH, alkalinity, and ammonia showed no spatial variation. Seasonally, temperature, transparency, DO, and hardness differed significantly ($P < 0.05$), with higher temperature (26.43°C), transparency (0.30 m), and DO (6.18 mg/l) in the rainy season, and higher hardness (85.03 ppm) in the dry season. Extremes recorded included 17.20°C (January 2022, Rafa), 29.35°C (April 2022, Kitiri), 0.21 m transparency (January 2022, Rafa), 0.38 m (August 2023, Rafa), pH 6.05 (March 2022, Rafa) to 7.44 (March 2023, Dakori Malam Buba), DO 5.12 mg/l (December 2023, Rafa) to 6.51 mg/l (October 2023, Rafa), alkalinity 23.43–26.39 ppm, ammonia 1.05–2.23 ppm, and hardness 61.07–97.39 ppm. The study demonstrates pronounced seasonal influences on Kitiri Reservoir's water quality, underscoring the need for continuous monitoring to guide its ecological management and sustain its socio-economic benefits

Key words: Kitiri Reservoir; Physicochemical parameters; Water quality; Seasonal variation; Sustainable management

INTRODUCTION

Nigeria's semi-arid regions, particularly within the northern belt, heavily depend on man-made water bodies such as reservoirs for agricultural irrigation, fisheries, domestic water supply, and the sustenance of rural livelihoods. These reservoirs are lifelines in areas characterized by low and erratic rainfall, making their proper management essential for socio-economic well-being (Muhammad *et al.,* 2025).

Despite their importance, many reservoirs in Nigeria's drylands remain poorly studied in terms of water quality. In the Gubi Reservoir, Bauchi State, seasonal and spatial variations in key parameters such as temperature, pH, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), and hardness were documented, with recommendations for continuous monitoring to safeguard water quality (Muhammad *et al.,* 2025). Similarly, research on Owalla Reservoir in Osun State revealed seasonal fluctuations in temperature, pH, DO, alkalinity, hardness, and turbidity over two years, indicating ongoing ecological changes that must be managed (Mustapha & Olaleye, 2021).

The case of Tiga Reservoir in Kano State further illustrates these patterns. Seasonal differences in TDS, turbidity, alkalinity, and DO were linked to both natural processes and possible anthropogenic inputs, emphasizing the need for regular surveillance and preventive management measures (Elaigwu *et al.,* 2023).

Against this backdrop, Kitiri Reservoir in Jigawa State stands as a vital yet understudied water body in Nigeria's semi-arid zone, with little to no documented information on its physicochemical characteristics. This research gap highlights the lack of baseline data necessary for sustainable ecological management and socio-economic development. To address this, the present study was conducted over a 24-month period (January 2022–December 2023) across three stations—Kitiri, Dakori Malam Buba, and Rafa—assessing spatial and seasonal variations in temperature, transparency, pH, DO, alkalinity, ammonia, and hardness, using standard APHA methodologies. The findings are expected to provide baseline data necessary for sustainable ecological management and the enhancement of local socio-economic benefits.

MATERIALS AND METHODS

Description of the study Area

Kitiri reservoir

Kitiri Reservoir is located in the eastern region of Jigawa State, Nigeria, straddling the boundaries of Birnin Kudu and Buji Local Government Areas. As a key water resource, the reservoir plays a vital role in supporting local agricultural activities, particularly by supplying irrigation water to nearby farmlands during the dry season. Given Jigawa State's position within Nigeria's semi-arid zone—characterized by limited and irregular rainfall—water bodies like Kitiri Reservoir are essential for sustaining livelihoods and ensuring food security. Despite its importance, there is a notable lack of documented data on the reservoir's characteristics and condition, highlighting the need for comprehensive scientific assessment.

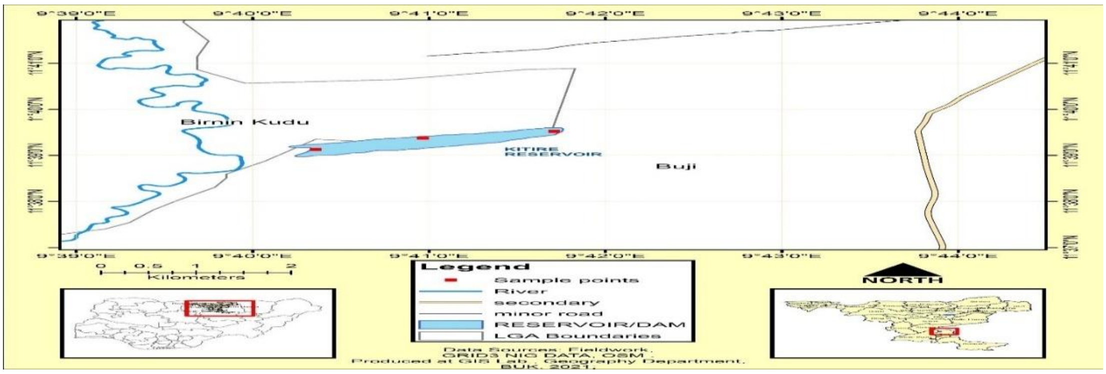

Figure 1. Map of Jigawa showing Kitiri Reservoir and the sample points

Samling Design and Duration

Over a continuous 24-month period, from January 2022 to December 2023, water samples were systematically collected on a monthly basis from three strategically selected stations within the Kitiri Reservoir—Kitiri, Dakori Malam Buba, and Rafa. Each sampling session involved in-situ measurement of essential physicochemical parameters, including temperature, transparency, pH, dissolved oxygen, alkalinity, ammonia, and hardness. The sampling and analytical procedures strictly adhered to the standardized methods established by the American Public Health Association (APHA., 2012] and were conducted in alignment with the field protocols described by (Dauda and Akinwole, 2014), ensuring consistency and reliability in data collection.

Data Analysis

The collected water quality data were first subjected to descriptive statistical analysis to provide a general overview of the observed values. To identify spatial and temporal variations across the three sampling stations and over the 24-month period, Analysis of Variance (ANOVA) was employed. Seasonal differences in the

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physicochemical parameters were further examined using the student's t-test. Additionally, regression analysis was conducted to illustrate trends and relationships among variables, with results visually represented through graphical plots.

RESULTS

The variations in the physicochemical parameters of Kitiri Reservoir are presented in Table 1 and Figures 2–8.

Temperature varied significantly across stations, months, and seasons ($P < 0.05$), with higher values observed during the rainy season compared to the dry season (Table 2, Fig. 2).

Transparency showed no significant differences among stations ($P > 0.05$) but differed significantly between months ($P < 0.05$). Seasonal comparison indicated slightly higher transparency in the rainy season (Table 2, Fig. 3).

The pH remained slightly acidic across the study period, with no significant variation between stations or seasons ($P > 0.05$), although monthly differences were significant ($P < 0.05$) (Table 1, Fig. 4).

Dissolved oxygen (DO) varied significantly between stations, months, and seasons ($P < 0.05$), with higher concentrations generally recorded during the rainy season (Table 2, Fig. 5).

Alkalinity showed no significant variation across stations and seasons ($P > 0.05$) but differed significantly between months ($P < 0.05$) (Table 1, Fig. 6).

Ammonia did not differ significantly across stations and seasons ($P > 0.05$) but showed significant monthly variations ($P < 0.05$) (Table 1, Fig. 7).

Hardness differed significantly between stations, months, and seasons ($P < 0.05$), with mean values higher in the dry season than in the rainy season (Table 2, Fig. 8).

Table 1**.** Physicochemical parameters of Kitiri Reservoir (Jan 2022–Dec 2023)

Parameter	Kitiri	Dakori Malam Buba	Rafa	P-value ANOVA
				Station
Temperature (°C)	25.45 ± 2.55^a	25.23 ± 2.54^b	25.01 ± 2.75^b	0.001*
Transparency (m)	0.28 ± 0.02^a	0.28 ± 0.03^a	0.29 ± 0.05^a	0.150
pH	6.66 ± 0.47^a	6.65 ± 0.50^a	6.65 ± 0.50^a	0.921
Dissolved oxygen (mg/l)	6.04 ± 0.33^b	6.02 ± 0.36^b	6.13 ± 0.30^a	0.001*
Alkalinity (ppm)	24.67 ± 0.82^a	24.65 ± 0.76^a	24.67 ± 0.77^a	0.948
Ammonia (ppm)	1.53 ± 0.40^a	1.53 ± 0.40^a	1.53 ± 0.38^a	0.923
Hardness (ppm)	82.30 ± 11.69^a	81.23 ± 11.15^b	80.91 ± 10.67^b	0.013*

Different superscript letters in a row shows significant difference ($p<0.005$). *Indicate significantly calculated p-value.

Table 2. Seasonal variations in physicochemical parameters (Jan 2022–Dec 2023)

Parameter	Season		T-test value	P-value
	Dry	Rainy		
Temperature (°C)	24.03 ± 3.10	26.43 ± 1.05	-6.213	0.001*

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Transparency (m)	0.27 ± 0.03	0.30 ± 0.03	-4.674	0.001*
pH	6.61 ± 0.53	6.70 ± 0.44	-1.094	0.276
Dissolved oxygen (mg/l)	5.95 ± 0.39	6.18 ± 0.20	-4.367	0.001*
Alkalinity (ppm)	24.79 ± 0.90	24.54 ± 0.61	1.955	0.053
Ammonia (ppm)	1.48 ± 0.48	1.58 ± 0.26	-1.556	0.122
Hardness (ppm)	85.03 ± 12.12	77.94 ± 8.74	4.027	0.001*

Note * indicate Significantly calculated P- Value

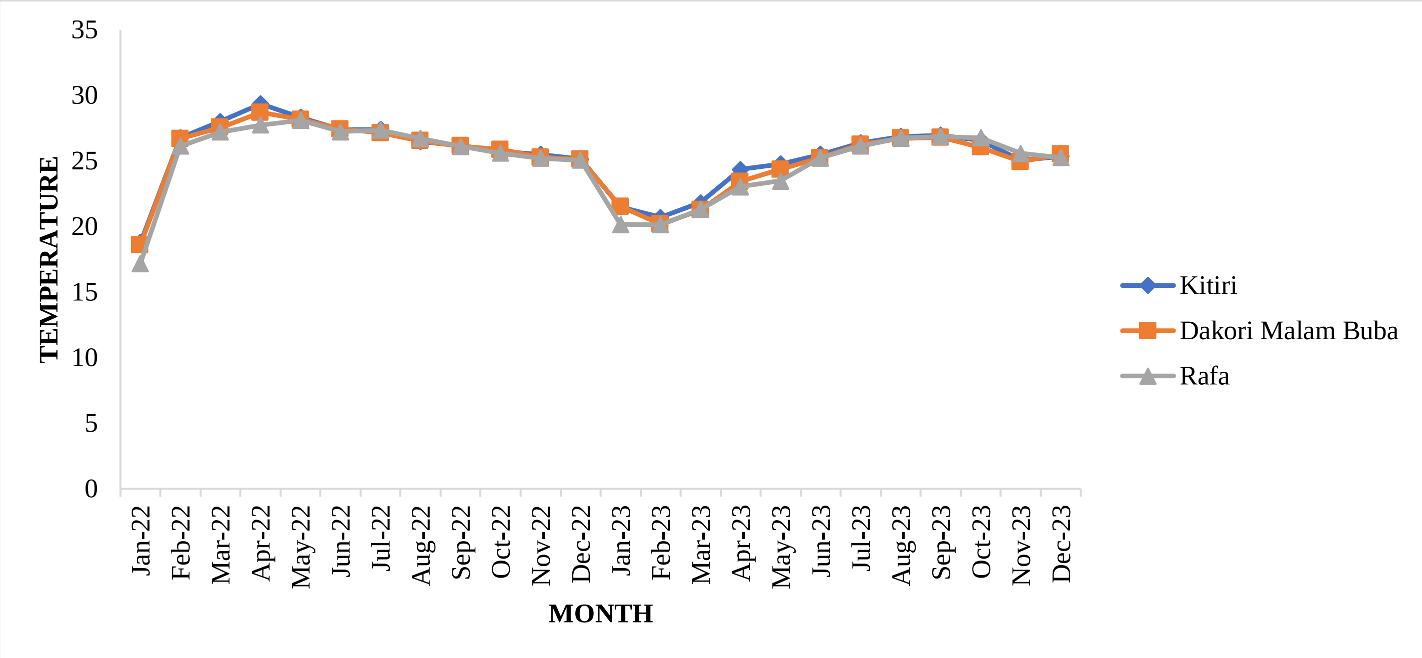

Figure 2. Monthly variation in Temperature (2022–2023)

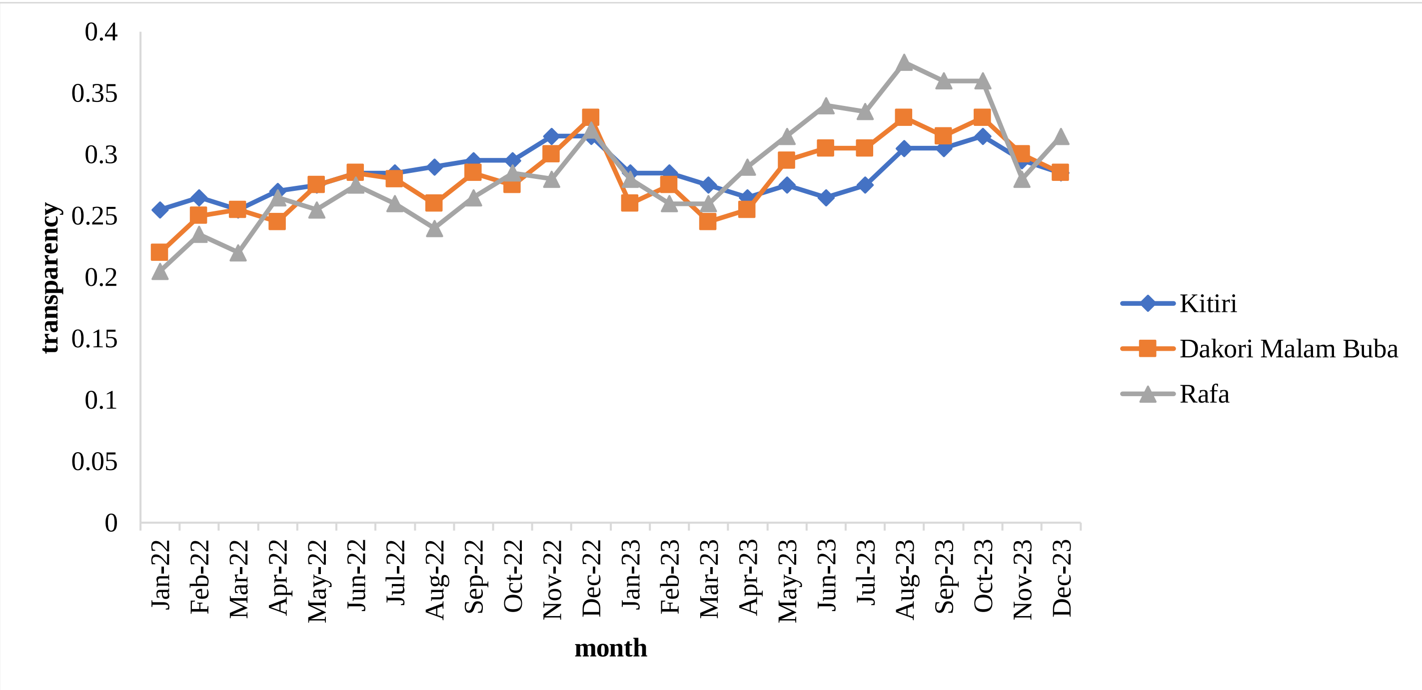

Figure 3. Monthly variation in Transparency (2022–2023)

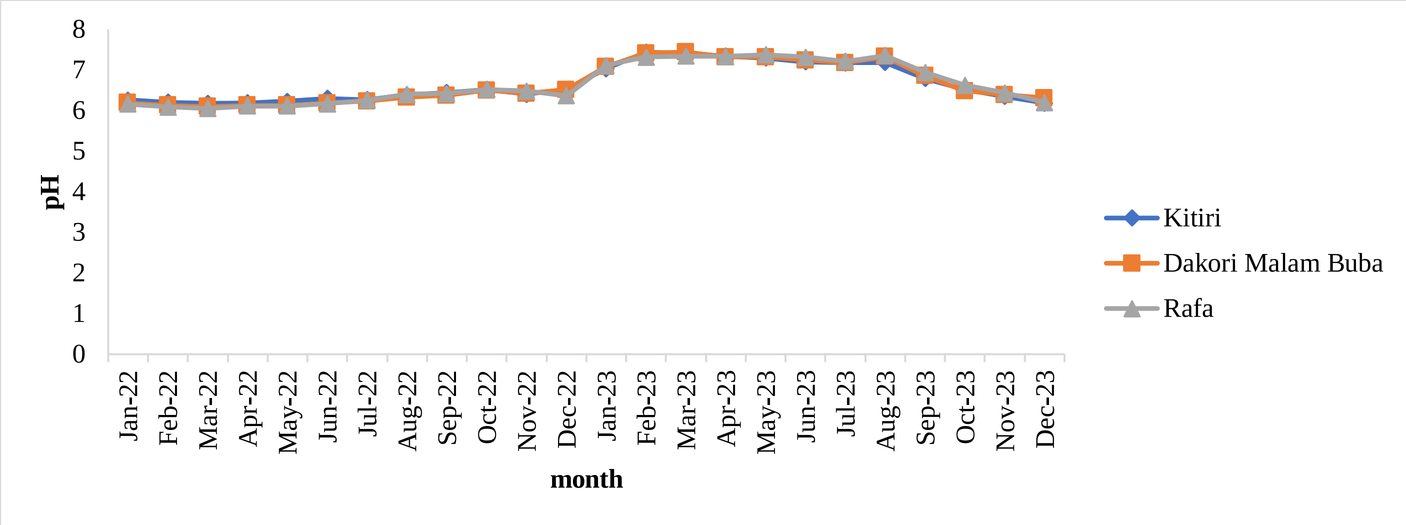

Figure 4. Monthly variation in PH. (2022–2023)

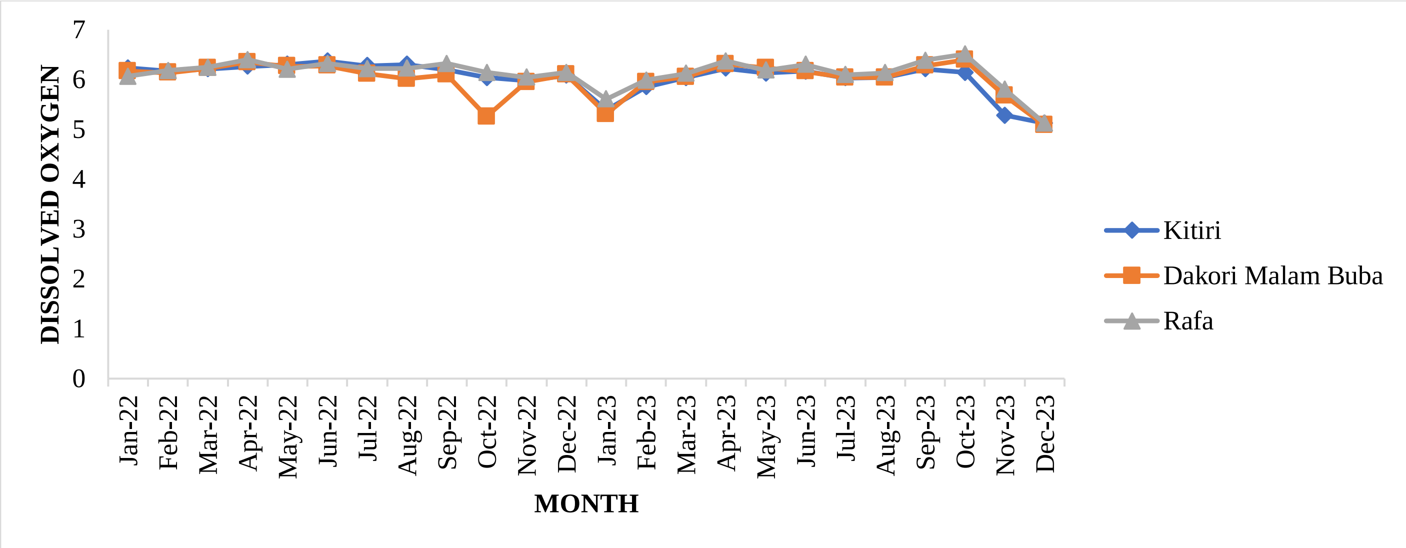

Figure 5. Monthly variation in Dissolve oxygen (2022–2023)

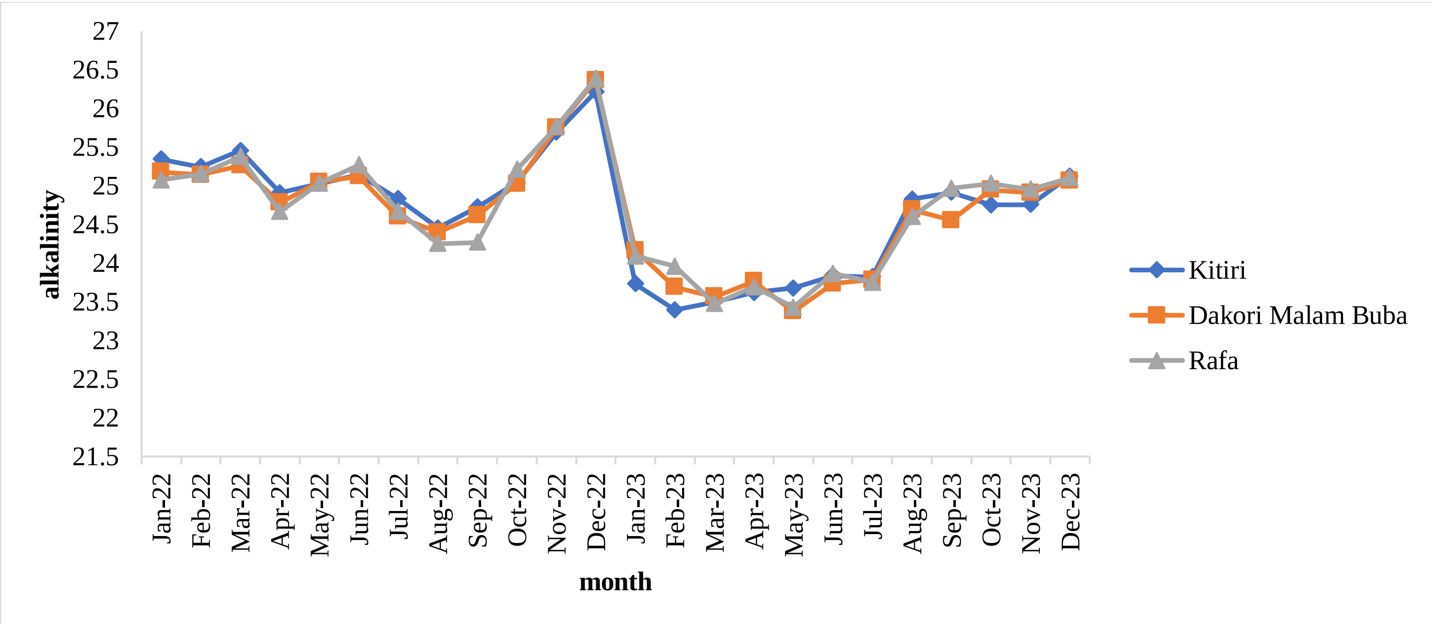

Figure 6. Monthly variation in Alkalinity (2022–2023)

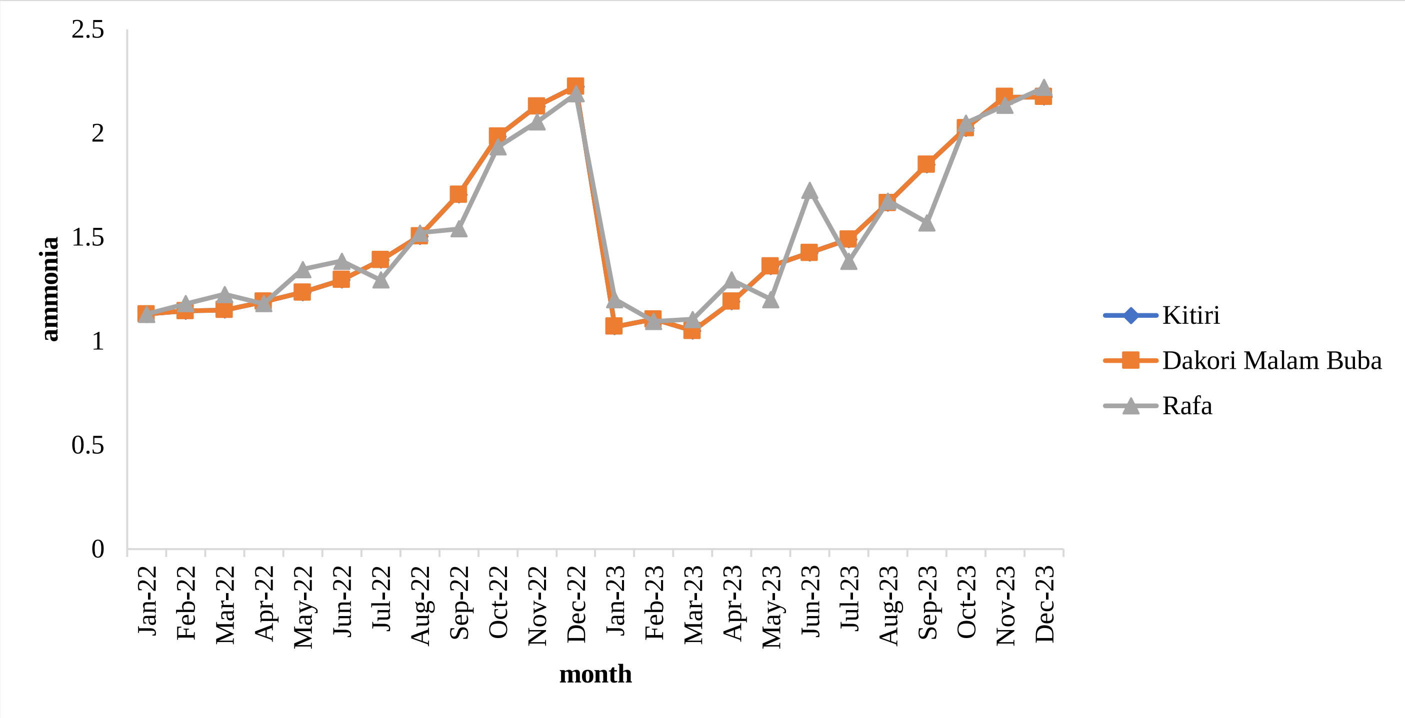

Figure 7. Monthly variation in Ammonia (2022–2023)

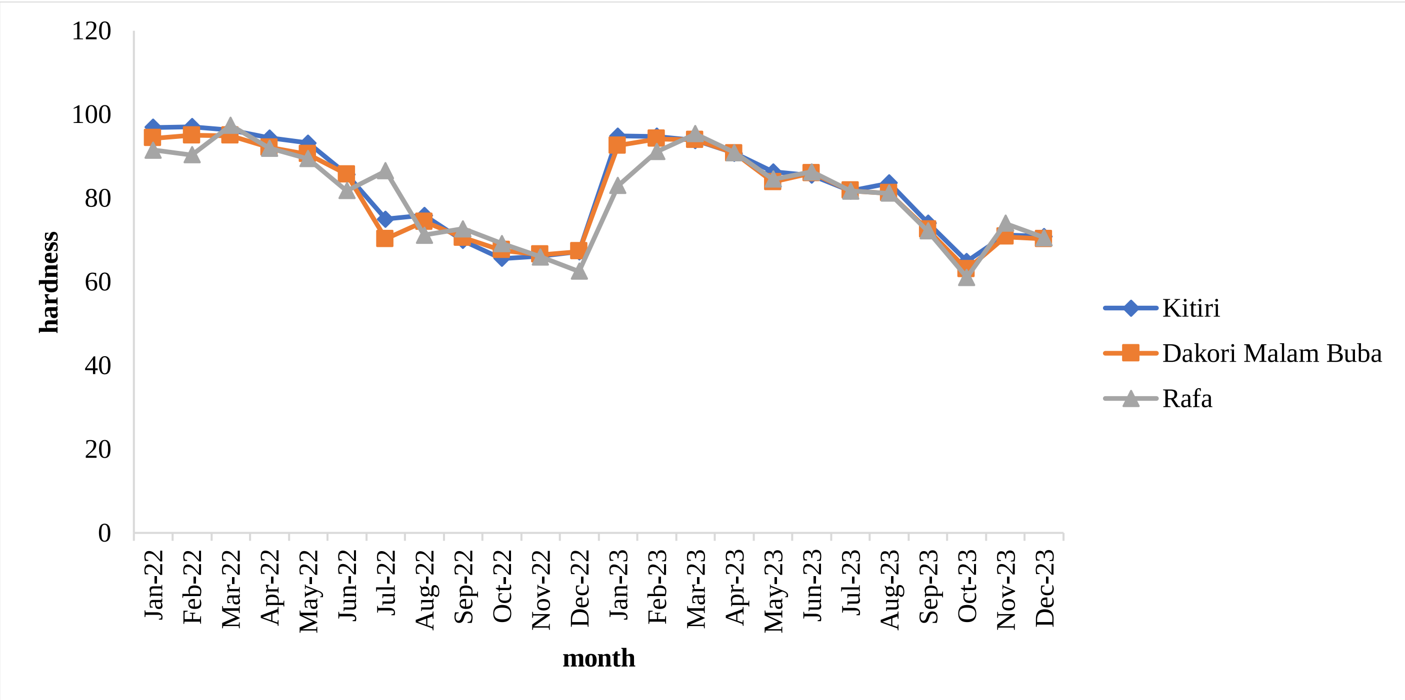

Figure 8. Monthly variation in hardness (2022–2023).

DISCUSSION

The physicochemical parameters of Kitiri Reservoir exhibited significant spatial and temporal variations during the 24-month monitoring period, influenced strongly by seasonal changes.

Temperature:

Water temperature is one of the most critical environmental parameters influencing the physiology and overall welfare of aquatic organisms. It regulates metabolic processes, feeding behavior, growth rates, reproductive cycles, distribution, and migratory patterns in fish (Suski *et al.,* 2006). In the present study, temperature ranged from 17.20°C in the dry season to a peak of 29.35°C during the rainy season, with a statistically significant seasonal difference—mean values of 24.03°C in the dry season and 26.43°C in the rainy season. This pattern aligns with typical tropical freshwater ecosystems, where temperature fluctuations are driven largely by seasonal climatic changes. These findings are consistent with the temperature range reported by Lawal and Ahmed (2014), who noted that fish in tropical waters are generally adapted to temperatures ranging from 8°C to 30°C, which represent the critical thermal minimum and maximum for tropical species. Additionally, temperature has a direct effect on the solubility of dissolved gases such as oxygen and influences biochemical and physiological processes in aquatic organisms (Wetzel, 2001). The statistically significant variations observed across sampling stations and months may be attributed to localized climatic differences, differences in depth and shading, and varying degrees of solar radiation exposure (APHA, 2012). Understanding temperature dynamics is therefore essential in monitoring ecosystem health, particularly in the face of climate variability and its impact on aquatic biodiversity.

Comparable studies across African reservoirs reinforce these observations. In Omi water body, southwest Nigeria, temperatures of 26.5–31.5°C were reported, highlighting seasonal shifts similar to the present study (Fafioye *et al.,* 2005). Likewise, diel and seasonal temperature variations in Kangimi Reservoir influenced plankton and ecosystem dynamics (Kemdirim, 2000), while (Adeosun *et al.* 2019) observed temperature-driven growth patterns in *Brycinus macrolepidotus* from Akomoje Reservoir. Regionally, (Dalu *et al.* 2013) documented seasonal thermal stratification in Malilangwe Reservoir, Zimbabwe, stressing the role of temperature in dissolved oxygen distribution and water quality management. Together, these findings underscore that the seasonal thermal regime of Kitiri Reservoir is consistent with other tropical reservoirs and has important implications for fisheries productivity, water policy, and reservoir management.

Transparency

Turbidity, often measured inversely through transparency, reflects the clarity of water and is influenced by the presence of suspended particles such as sediments, organic matter, and pollutants. These suspended materials scatter light, thereby reducing water clarity and limiting light penetration, which in turn affects thermal properties and biological productivity of aquatic ecosystems (Omondi *et al.,* 2011). In this study, transparency values ranged from 0.21 m to 0.38 m, with no significant difference across the sampling stations, but with a notable seasonal trend—higher transparency during the rainy season compared to the dry season. This trend may be attributed to dilution effects and flushing during increased rainfall, which reduces particle concentration in the water column. Similar findings were reported by (Tegu *et al.* 2023), who observed significantly higher turbidity values during the rainy season (28.50 NTU) compared to the dry season (11.64 NTU), attributing the variation to increased particulate matter and sloughing of biofilm. However, while rainfall can increase sediment load through surface runoff, short-term dilution effects or sediment settling can occasionally lead to improved clarity, especially in lentic water bodies like reservoirs (Boyd, 2015). High turbidity levels are known to interfere with sunlight penetration, negatively impacting photosynthetic activity and primary productivity (Smith and Davies, 2001). Therefore, variations in transparency directly influence the structure and function of aquatic food webs, particularly through their effect on primary producers.

Regional studies further support these observations. In Kangimi Reservoir, Nigeria, seasonal transparency fluctuations were linked to rainfall and runoff patterns, which significantly influenced plankton dynamics and fish availability (Kemdirim, 2000). Similarly, Akomoje Reservoir showed transparency values directly tied to particulate matter input and water flow regimes, with implications for fish growth and recruitment (Adeosun et al., 2019). Beyond Nigeria, (Dalu *et al.* 2013) demonstrated that water clarity in Malilangwe Reservoir, Zimbabwe, strongly influenced nutrient cycling and invertebrate communities. On a broader scale, global studies emphasize that transparency is a critical determinant of primary productivity and fisheries yield, making it an essential indicator for reservoir management and water policy. Poor water clarity can reduce the efficiency of fisheries, affect fish feeding strategies, and complicate water treatment for human use. Consequently, sustained monitoring of transparency is vital for ensuring ecological balance, supporting sustainable fisheries, and guiding evidence-based water policy

pH

The pH values recorded during the study period ranged from 6.05 to 7.44, indicating a slightly acidic to neutral environment. These values are typical of tropical freshwater reservoirs and reflect a stable aquatic ecosystem conducive to aquatic life (Wetzel, 2001). While spatial variations across stations were not statistically significant, temporal variations suggest that pH was influenced by biological activities such as photosynthesis and respiration, as well as by organic matter decomposition and seasonal rainfall inputs (Mitsch and Gosselink, 2015). The observed pH values fall within the acceptable range recommended by the Federal Environmental Protection Agency (FEPA), which specifies 6.0–9.0 for the protection of aquatic life and 6.5–8.5 for drinking water quality. This suggests that the water in Kitiri Reservoir remains within safe limits for both ecological and potential domestic use. These findings also corroborate the earlier work of (Auta, 1993), who reported that freshwater bodies with pH values between 6.5 and 9.0 tend to be productive and are considered suitable for fish culture. Similarly, (Teame and Abergelle, 2016) reported seasonal pH fluctuations, with significantly lower values in the dry season (7.80 ± 0.58) compared to the wet season (8.30 ± 0.34), indicating a general trend in tropical environments where rainfall and runoff can dilute or buffer the water chemistry. Comparable studies in Nigerian reservoirs further support these observations. For instance, (Ibrahim and Abdulkarim 2017) reported near-neutral pH (6.8 ± 0.1) in Ajiwa Reservoir, Katsina State, while (Fafioye *et al*. 2005) recorded values of 6.7–7.2 in Omi water body, South-West Nigeria. Similarly,(Kolo and Oladimeji 2004) found Shiroro Lake to maintain pH within 6.5–7.5, underscoring the fact that most tropical reservoirs fall within the FEPA and WHO protective ranges. These patterns indicate that Kitiri Reservoir is consistent with regional trends, and highlight the importance of managing runoff and organic inputs, maintaining riparian buffers, and incorporating pH monitoring into reservoir management strategies to ensure fisheries productivity and water safety.

Dissolve Oxygen (DO)

Dissolved oxygen (DO) is one of the most critical parameters for assessing the biological quality of aquatic systems. It supports aerobic respiration in aquatic organisms, facilitates the decomposition of organic detritus, and enables the completion of essential biochemical processes (Indabawa, 2009). In the present study, DO levels ranged from 5.12 to 6.51 mg/L and showed significant spatial and temporal variation, with higher concentrations generally recorded during the rainy season. This seasonal trend is likely due to enhanced photosynthetic activity from increased phytoplankton productivity and lower water temperatures, both of which contribute to greater oxygen solubility in water (Wetzel, 2001).

The observed fluctuations align with findings by (Chindah and Braide 2003), who reported that DO concentrations in natural waters are dynamic and influenced by temperature, depth, and biological activity. Similar patterns have been reported in Nigerian and African reservoirs. For instance, Ibrahim and Abdulkarim (2017) recorded higher DO concentrations during the rainy season in Ajiwa Reservoir, attributing this to phytoplankton photosynthesis and dilution effects, while (Kolo and Oladimeji 2004) observed comparable seasonal variations in Shiroro Lake. Likewise, (Fafioye et al. 2005) reported that DO levels in Sagbami River fluctuated in response to rainfall and organic load, highlighting the link between seasonal hydrology and oxygen availability.

Lower DO levels during the dry season may be attributed to elevated temperatures and reduced water volumes, which increase microbial respiration and organic matter decomposition, thereby consuming more oxygen (APHA, 2012). These conditions can create localized hypoxia, especially in stagnant or nutrient-enriched waters, and may stress aquatic life if oxygen levels fall below optimal thresholds. From a management perspective, maintaining adequate DO is vital for sustaining reservoir fisheries and ensuring ecosystem stability. Seasonal monitoring is therefore essential for guiding fisheries management, water quality policy, and climate adaptation strategies in tropical reservoirs.

Alkalinity:

Alkalinity in aquatic systems serves as a key indicator of the water's buffering capacity, enabling it to resist abrupt pH fluctuations and thus maintain ecological stability (Mitsch and Gosselink, 2015). In this study, alkalinity values ranged from 23.43 ppm to 26.39 ppm, showing no significant variation across sampling stations but exhibiting monthly fluctuations. The absence of a marked seasonal pattern suggests a relatively stable influence of the reservoir's geological and hydrological conditions throughout the year.

The recorded values fall well within the recommended range of 5–500 mg/L for surface waters, as outlined by (Lawson, 1995), indicating suitability for aquatic life and water quality stability. These results also align with the guidelines provided by the United States Environmental Protection Agency (USEPA, 1976), which emphasize the ecological importance of alkalinity in buffering natural pH variations arising from biological processes such as photosynthesis. Furthermore, the findings are in agreement with (Lawson, 2011), who stated that alkalinity values between 30 and 50 mg/L as $CaCO_3$ are generally considered optimal for fish and shrimp culture. Although the alkalinity values in this study are slightly below this optimal aquaculture range, they still exceed the minimum threshold of 20 ppm suggested by (USEPA, 1976) for supporting freshwater aquatic life under natural conditions.

Comparable values have been reported in Nigerian inland waters. (Fafioye *et al.* 2005) recorded alkalinity concentrations in Sagbami River, southwestern Nigeria, which supported diverse aquatic organisms and provided buffering against pH fluctuations. Similarly, (Ibrahim and Abdulkarim 2017) observed moderate alkalinity levels in Ajiwa Reservoir, Katsina State, which were within ecologically stable limits and suitable for fisheries production. These regional findings corroborate the present study and emphasize the importance of alkalinity as a determinant of water quality, aquatic biodiversity, and fisheries sustainability in tropical reservoirs.

Overall, the observed alkalinity levels in Kitiri Reservoir suggest a stable chemical environment conducive to sustaining aquatic ecosystems and potentially supporting aquaculture development.

Ammonia:

Ammonia is a key nitrogenous compound in aquatic ecosystems, primarily originating from the decomposition of organic matter, excretion by aquatic organisms, and anthropogenic inputs such as agricultural runoff and sewage discharge. In this study, ammonia concentrations displayed clear temporal variation, with the highest levels observed in December 2023. Although values remained relatively low overall, seasonal trends suggest an increase during the rainy season, likely due to enhanced surface runoff introducing nitrogen-rich materials into the reservoir. While elevated ammonia levels are known to be potentially toxic to aquatic life, particularly in their un-ionized (NH_3) form, the recorded concentrations in this study remained well below critical toxicity thresholds. Toxic effects in freshwater organisms have been reported at concentrations ranging from 0.53 to 22.8 mg/L, depending on species sensitivity, pH, and temperature (Camargo and Alonso, 2006). It is important to note that ammonia toxicity increases with rising pH and temperature, due to higher proportions of un-ionized ammonia in such conditions (Kim *et al.,* 2008; Hira *et al.,* 2018).

The observed ammonia levels in Kitiri Reservoir are consistent with findings from other tropical freshwater systems. For instance, (Bala and Bolorunduro, 2011) reported ammonia-nitrogen concentrations ranging from 0.3 to 1.17 mg/L in Sabke Reservoir, while (Andem *et al.* 2012) documented concentrations between 0.11 and 0.15 mg/L in the Ona River. Similar patterns of seasonal variation have also been recorded in Nigerian waters. In Awba Reservoir, for example, ammonia levels were elevated at effluent-receiving stations due to runoff and organic matter inputs (Akin-Oriola, 2003). Likewise, investigations on River Osun showed wet-season increases in ammonia concentrations linked to surface runoff and catchment activities (Olomukoro and Ezemonye, 2007) These findings demonstrate that the seasonal dynamics observed in Kitiri Reservoir reflect broader patterns in tropical freshwater systems. Overall, the ammonia concentrations in Kitiri Reservoir do not pose immediate ecological risks but warrant continued monitoring, particularly during the rainy season, to detect potential increases due to land-use changes or pollution events

Hardness:

Water hardness in Kitiri Reservoir ranged from 61.07 ppm to 97.39 ppm, exhibiting significant spatial and temporal variations, with notably higher values recorded during the dry season. Hardness primarily results from the presence of divalent metal ions, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}), which play essential roles in aquatic organism physiology and overall water chemistry (APHA, 2012). These ions contribute to enzyme function, osmoregulation, and structural development in aquatic fauna, including fish and invertebrates. The seasonal differences observed in this study can be attributed to evaporation during dry periods, which concentrates dissolved minerals and increases hardness levels. This observation aligns with the findings of (Kolo and Oladimeji, 2004), who also reported higher water hardness during the dry season in Nigerian reservoirs, attributing the increase to reduced water levels and ionic concentration. Conversely, the lower values during the rainy season may result from dilution by increased water volume and runoff. The recorded hardness values fall well within acceptable ecological limits, as water with hardness levels below 500 ppm is generally considered productive and supportive of aquatic life (Wetzel, 2001). Furthermore, (Mustapha, 2009) emphasized the biological importance of hardness, noting that water with total hardness below 5 ppm (as $CaCO_3$) could induce stress and inhibit fish growth, which contrasts with the healthy range observed in this study. Overall, the hardness values in Kitiri Reservoir suggest a moderately hard water system that supports aquatic life effectively, particularly during the dry season when ion concentration increases. However, continuous monitoring is essential to detect any significant shifts that could impact water quality or ecosystem stability.

CONCLUSION

Over the 24-month study period from January 2022 to December 2023, the physicochemical parameters of Kitiri Reservoir exhibited notable spatial and temporal variations. Temperature, dissolved oxygen, transparency, and hardness showed significant differences across sampling stations and months, with seasonal influences clearly evident—higher temperatures, dissolved oxygen, and transparency values were generally observed during the rainy season, while hardness was higher in the dry season. Parameters such as pH, alkalinity, and ammonia showed no significant spatial differences but varied significantly over time. The study confirms that seasonal changes play a crucial role in shaping the water quality dynamics of the reservoir. These findings provide valuable baseline data essential for the effective management and sustainable utilization of the Kitiri Reservoir ecosystem.

RECOMMENDATIONS

Based on the findings of this study, the following measures are recommended for the sustainable management of Kitiri Reservoir:

1. **Routine Monitoring:** Establish a continuous monthly monitoring program for key physicochemical parameters, with emphasis on seasonal variations.

2. **Seasonal Focus:** Intensify monitoring during the rainy season when runoff increases nutrient inputs, and in the dry season when hardness peaks.

3. **Nutrient Control:** Identify and regulate sources of nutrient inflow, promote vegetative buffer zones, and strengthen community awareness on waste management and sustainable farming practices.

4. **Watershed Protection:** Implement catchment management strategies such as afforestation, erosion control, and enforcement of land-use regulations to reduce sediment and pollutant loadings.

5. **Data Integration:** Develop a centralized database for water quality records to guide policy, establish early warning thresholds, and inform adaptive management.

6. **Fisheries Sustainability:** Link water quality assessments to fisheries management by encouraging eco-friendly aquaculture practices and periodic biodiversity evaluations.

7. **Capacity Building:** Strengthen local capacity through training, community participation, and partnerships with academic and governmental institutions to ensure long-term monitoring and effective resource management

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