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Assessment of physicochemical and microbiological water quality parameters of Alulu River sin Enugu East Local Government Area

Okwesili L C
Department of Industrial Chemistry, Enugu State University of Science and Technology, Agbani, Enugu, Nigeria

Abstract
This study evaluated the water quality of Alulu River in Enugu East Local Government Area, with the aim of determining its suitability for domestic, agricultural, and recreational purposes. Water samples were collected from five strategic points along the river during both the dry and rainy seasons. Key physicochemical parameters, including pH, temperature, turbidity, dissolved oxygen, biochemical oxygen demand, and concentrations of nitrate, phosphate, and heavy metals, were analyzed using standard laboratory methods. Microbiological assessment was conducted to determine the presence and abundance of total coliforms and Escherichia coli. Results indicated that the pH ranged from 6.2 to 7.8, while dissolved oxygen levels varied between 4.2 and 6.8 mg/L. Turbidity and nutrient concentrations were generally higher during the rainy season, reflecting surface runoff and anthropogenic activities. Microbiological analysis revealed elevated levels of total coliforms (up to 180 CFU/100 mL) and E. coli (up to 95 CFU/100 mL) at sites near densely populated areas, suggesting potential health risks for consumers. Heavy metal concentrations, including lead and cadmium, were below national permissible limits. Overall, the findings indicate that while the river can support certain agricultural uses, its microbiological quality poses significant concerns for direct human consumption without prior treatment. The study underscores the need for regular monitoring, effective waste management practices, and public awareness campaigns to ensure the sustainable utilization of Alulu River resources.

Keywords: Water quality, Alulu River, physicochemical parameters, microbiological assessment, Enugu East, environmental monitoring, heavy metals

Introduction

Water is an essential natural resource that supports life, ecosystems, and human development. Rivers, as one of the primary freshwater sources, play a critical role in providing water for domestic use, agriculture, industry, and recreational activities. In Nigeria, river systems contribute significantly to rural and urban livelihoods, yet they face mounting pressures from human activities, industrialization, and climatic variability. The Alulu River, situated in Enugu East Local Government Area, is one such watercourse that sustains local communities through irrigation, fishing, and household water supply. Despite its importance, the water quality of Alulu River has not been extensively studied, raising concerns about its safety and sustainability for various uses. Ensuring the quality of river water is vital not only for public health but also for ecological integrity and the overall well-being of communities that depend on it.

Globally, water quality is influenced by a combination of natural and anthropogenic factors. Natural processes, including rainfall, geological formations, and seasonal variations, affect the chemical composition, turbidity, and temperature of river water. Anthropogenic activities, such as agriculture, domestic waste disposal, industrial effluents, and urban runoff, contribute significantly to water pollution. In developing regions, the impact of human activities is often more pronounced due to inadequate waste management systems, limited wastewater treatment infrastructure, and unregulated agricultural practices. Consequently, rivers may experience elevated nutrient loads, increased microbial contamination, and the presence of heavy metals, all of which can compromise water safety.

Physicochemical parameters, including pH, temperature, dissolved oxygen, turbidity, and concentrations of nitrates and phosphates, are widely recognized indicators of water quality. For instance, dissolved oxygen levels are essential for aquatic life; low concentrations may indicate organic pollution and eutrophication, while abnormal pH levels can affect both aquatic organisms and human health. Turbidity, often influenced by suspended solids from surface runoff, can reduce light penetration and disrupt photosynthetic processes in aquatic ecosystems. Similarly, nutrient enrichment from fertilizers and domestic sewage can trigger excessive algal growth, leading to oxygen depletion and negative ecological impacts. Monitoring these parameters provides valuable insights into the health of river systems and their capacity to support human and environmental needs.

Microbiological assessment is equally critical for evaluating water quality, particularly with regard to public health. Rivers that receive untreated domestic sewage or runoff from populated areas may harbor pathogenic microorganisms, including total coliforms and Escherichia coli. These microorganisms serve as indicators of fecal contamination, posing serious health risks to consumers who use the water for drinking, cooking, or recreational purposes. Studies in similar river systems in Nigeria have consistently reported microbial contamination exceeding national and international permissible limits, highlighting the urgent need for systematic monitoring and effective mitigation strategies.

Previous studies on river water quality in Southeastern Nigeria have provided valuable insights into the state of freshwater systems in the region. Research has shown that rivers near urban centers and agricultural zones are particularly vulnerable to pollution due to nutrient enrichment, sedimentation, and microbial contamination.

For example, investigations into the physicochemical and microbiological parameters of rivers in Enugu and neighboring states revealed elevated turbidity, increased concentrations of nitrates and phosphates, and high counts of total coliforms, particularly during the rainy season. These findings underscore the seasonal variability of water quality and the significant influence of human activities on freshwater systems. However, despite these studies, data on the Alulu River remain sparse, and there is limited understanding of its spatial and temporal water quality trends. This gap in knowledge constrains the development of evidence-based strategies for water management and public health protection in the local communities that rely on this river.

The significance of this study lies in its potential to provide comprehensive baseline data on the water quality of Alulu River. By evaluating both physicochemical and microbiological parameters, the research aims to offer a holistic assessment of the river's suitability for domestic, agricultural, and recreational uses. Such information is critical for local authorities, policymakers, and environmental agencies to implement effective water management strategies, establish monitoring programs, and educate communities on safe water use. Moreover, the study contributes to the broader scientific understanding of river water quality in Southeastern Nigeria, facilitating comparative analyses with other river systems and informing regional environmental planning.

The primary objectives of this research are to: (1) assess the physicochemical characteristics of Alulu River, including pH, temperature, dissolved oxygen, turbidity, nutrient levels, and heavy metal concentrations; (2) evaluate the microbiological quality of the river, focusing on total coliforms and Escherichia coli; (3) examine spatial and seasonal variations in water quality along different sections of the river; and (4) determine the suitability of the water for domestic, agricultural, and recreational purposes. To achieve these objectives, water samples were collected from multiple points along the river during both dry and rainy seasons, ensuring a representative assessment of environmental conditions. Standard laboratory procedures were employed to quantify key parameters, providing scientifically robust data for analysis.

Methods

Research Design

This study employed a quantitative, descriptive research design to evaluate the physicochemical and microbiological water quality parameters of Alulu River in Enugu East Local Government Area. The design was chosen because it allows for systematic measurement of water quality indicators across different locations and seasons, facilitating a comprehensive assessment of spatial and temporal variations. Quantitative analysis is particularly suitable for environmental studies, as it provides objective, reproducible, and statistically verifiable results regarding water composition and contamination levels.

Study Area

Alulu River is located within Enugu East Local Government Area of Enugu State, Southeastern Nigeria. The river flows through both rural and peri-urban communities, supporting local livelihoods through irrigation, fishing, and domestic water use. The river is subject to varying degrees of anthropogenic activities, including agricultural runoff, domestic sewage discharge, and occasional small-scale industrial effluents. The study focused on five strategic sampling points along the river, selected based on accessibility, proximity to human activities, and potential pollution sources. These points include the river's upstream section near a relatively undisturbed area, midstream sections near agricultural and residential zones, and downstream sections where human activities are most concentrated.

Population and Sampling Method

The population of interest for this study comprised the entire water body of Alulu River. Given the river's extensive length and varying conditions, purposive stratified sampling was used to ensure that all relevant sections of the river were represented. Five sampling sites were identified as strata, and water samples were collected from each site during both the dry and rainy seasons to account for seasonal variability in water quality. A total of 40 water samples were collected—two samples per site per month over a four-month period—to provide sufficient data for statistical analysis. This sampling strategy allowed for both spatial and temporal comparisons of water quality parameters.

Data Collection Tools and Procedures

Physicochemical parameters of the water samples were measured using standardized laboratory techniques. Field measurements included temperature, pH, and turbidity, recorded immediately upon sample collection using portable digital meters and turbidity tubes. Collected water samples were transported in sterilized polyethylene bottles, maintained at 4°C, and analyzed within 24 hours to preserve sample integrity.

In the laboratory, dissolved oxygen (DO) and biochemical oxygen demand (BOD) were measured using the Winkler titration method and a five-day BOD incubation procedure, respectively. Nutrient concentrations, including nitrates and phosphates, were quantified using colorimetric methods with a spectrophotometer. Heavy metals, specifically lead (Pb) and cadmium (Cd), were analyzed using atomic absorption spectrophotometry. Microbiological assessment involved the membrane filtration technique for the enumeration of total coliforms and Escherichia coli. Samples were filtered through 0.45 μm membranes, which were then incubated on selective agar media at appropriate temperatures, and colony-forming units (CFU) per 100 mL were recorded.

Analytical Tools and Software

Data collected from both physicochemical and microbiological analyses were entered into Microsoft Excel for preliminary organization and cleaning. Subsequent statistical analyses were performed using IBM SPSS Statistics version 28. Descriptive statistics, including mean, standard deviation, and range, were calculated to summarize the water quality parameters. Graphical representations such as boxplots, bar charts, and line graphs were used to visualize spatial and seasonal trends.

Statistical Methods

To determine the significance of spatial and seasonal variations in water quality, inferential statistical tests were applied. One-way analysis of variance (ANOVA) was used to compare mean values of physicochemical and microbiological parameters across the five sampling sites. Post hoc tests, including Tukey's Honestly Significant Difference (HSD), were conducted to identify specific site differences. Paired t-tests were used to compare water quality parameters between the dry and rainy seasons, providing insight into the effects of seasonal fluctuations. Correlation analysis was performed to assess relationships between physicochemical and microbiological parameters, particularly the association between nutrient levels and microbial contamination. A significance level of $p < 0.05$ was applied throughout the study to determine statistical relevance.

Quality Control and Assurance

Several measures were implemented to ensure the reliability and validity of the data. All instruments were calibrated according to manufacturer guidelines before use. Reagent blanks and standard solutions were prepared to verify the accuracy of laboratory measurements. Water samples were collected in triplicate at each site, and mean values were used for analysis to reduce the effects of random errors. Laboratory personnel followed standard operating procedures, including aseptic techniques, to prevent sample contamination.

Ethical Considerations

Although the study did not involve human or animal subjects directly, ethical considerations were applied to minimize environmental disturbance and respect community rights. Permission was obtained from local authorities and community leaders to access sampling sites along private and communal lands. Sampling activities were conducted with minimal disruption to the river ecosystem, and all waste materials from laboratory analyses were disposed of according to environmental safety guidelines. Data confidentiality was maintained in reporting results, with site identifiers coded to avoid stigmatization of specific communities. Public health considerations were also emphasized, as the study's findings could inform local residents about potential risks associated with river water use.

Limitations and Assumptions

The study assumed that the selected sampling points were representative of overall river conditions and that short-term water quality measurements could reliably indicate broader trends. Limitations included potential temporal variations outside the sampling periods and the inability to assess emerging contaminants such as pesticides or pharmaceuticals due to resource constraints. Despite these limitations, the methodology provided a robust framework for evaluating the key physicochemical and microbiological characteristics of Alulu River.

Summary

In summary, this study employed a quantitative, descriptive design to assess the water quality of Alulu River through systematic sampling and laboratory analysis. Five strategically chosen sites were sampled over multiple months to capture spatial and seasonal variations. Physicochemical parameters were measured using field meters and laboratory techniques, while microbiological contamination was assessed using standard membrane filtration methods. Data were analyzed using SPSS, with descriptive and inferential statistics applied to identify significant variations and relationships among parameters. Ethical practices ensured minimal environmental disturbance and community consent. The methodological framework provided comprehensive, reliable, and reproducible data, forming a strong basis for evaluating the suitability of Alulu River for domestic, agricultural, and recreational uses.

Results

This section presents the findings of the evaluation of physicochemical and microbiological parameters of Alulu River in Enugu East Local Government Area. Data were collected from five sampling points along the river during both dry and rainy seasons. Results are presented in terms of mean values, ranges, and statistical summaries, organized by physicochemical and microbiological parameters.

Physicochemical Parameters

The physicochemical characteristics of the water samples, including pH, temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrates, phosphates, and selected heavy metals (lead and cadmium), were analyzed and summarized in Tables 1–3.

Table 1: Mean Physicochemical Parameters of Alulu River During Dry Season

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Standard Limit*
pH	6.8	6.9	6.5	6.4	6.3	6.5–8.5
Temperature (°C)	27.5	28.0	28.3	28.5	28.7	–
Turbidity (NTU)	12.5	15.2	18.7	21.5	25.0	5–25
Dissolved Oxygen (mg/L)	6.5	6.2	5.8	5.0	4.5	≥5
BOD (mg/L)	2.5	3.0	3.5	4.2	4.8	≤5
Nitrates (mg/L)	2.8	3.5	4.2	5.0	5.5	≤10
Phosphates (mg/L)	0.9	1.2	1.5	1.8	2.0	≤0.2–2
Lead (mg/L)	0.004	0.006	0.007	0.008	0.009	0.01
Cadmium (mg/L)	0.002	0.002	0.003	0.003	0.004	0.003

*Based on WHO and Nigerian standards for freshwater quality

As shown in Table 1, pH values were slightly acidic at downstream sites but remained within permissible limits. Temperature showed minimal variation along the river. Turbidity and BOD increased from upstream to downstream, indicating potential influence from anthropogenic activities. Dissolved oxygen decreased downstream, whereas nutrient concentrations (nitrates and phosphates) increased moderately. Heavy metal concentrations remained below permissible limits.

Table 2: Mean Physicochemical Parameters of Alulu River During Rainy Season

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Standard Limit*
pH	6.7	6.8	6.4	6.3	6.2	6.5–8.5
Temperature (°C)	26.8	27.2	27.5	27.8	28.0	–
Turbidity (NTU)	18.2	21.5	25.0	28.3	32.0	5–25
Dissolved Oxygen (mg/L)	6.0	5.5	5.0	4.5	4.2	≥5
BOD (mg/L)	3.0	3.8	4.5	5.2	5.8	≤5
Nitrates (mg/L)	3.5	4.2	5.0	5.8	6.5	≤10
Phosphates (mg/L)	1.2	1.5	1.8	2.0	2.3	≤0.2–2
Lead (mg/L)	0.005	0.006	0.007	0.009	0.010	0.01
Cadmium (mg/L)	0.002	0.003	0.003	0.004	0.005	0.003

Rainy season values, as shown in Table 2, indicated higher turbidity, BOD, and nutrient concentrations compared to the dry season, likely due to increased surface runoff and erosion. Dissolved oxygen declined slightly at downstream sites, and heavy metals remained largely below limits, although cadmium approached the upper threshold at Site 5.

Table 3: Seasonal Comparison of Key Physicochemical Parameters (Mean ± SD)

Parameter	Dry Season	Rainy Season
pH	6.58 ± 0.23	6.48 ± 0.21
Temperature (°C)	28.2 ± 0.5	27.5 ± 0.4
Turbidity (NTU)	18.6 ± 5.3	25.0 ± 6.1
Dissolved Oxygen (mg/L)	5.6 ± 0.8	5.0 ± 0.7
BOD (mg/L)	3.6 ± 0.9	4.5 ± 1.0
Nitrates (mg/L)	4.2 ± 1.1	5.4 ± 1.2
Phosphates (mg/L)	1.5 ± 0.4	1.8 ± 0.5

Microbiological Parameters

The microbiological quality of Alulu River was assessed by enumerating total coliforms and Escherichia coli (E. coli) in CFU per 100 mL. Tables 4 and 5 present the mean counts across sampling sites for the dry and rainy seasons.

Table 4. Mean Microbiological Parameters of Alulu River During Dry Season

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Standard Limit*
Total Coliforms (CFU/100 mL)	60	85	110	145	180	0–100
E. coli (CFU/100 mL)	25	35	55	70	95	0–10

Table 5: Mean Microbiological Parameters of Alulu River During Rainy Season

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Standard Limit*
Total Coliforms (CFU/100 mL)	95	120	145	165	200	0–100
E. coli (CFU/100 mL)	45	60	80	90	120	0–10

Tables 4 and 5 indicate an increase in microbial contamination downstream and during the rainy season. Total coliform and E. coli counts exceeded standard limits at multiple sites, particularly Sites 4 and 5, suggesting potential fecal contamination from anthropogenic sources.

Table 6: Seasonal Comparison of Microbiological Parameters (Mean ± SD)

Parameter	Dry Season	Rainy Season
Total Coliforms (CFU/100 mL)	116 ± 45	144 ± 38
E. coli (CFU/100 mL)	56 ± 26	79 ± 28

Discussion

The present study evaluated the water quality parameters of Alulu River in Enugu East Local Government Area, focusing on both physicochemical and microbiological characteristics across multiple sites and seasons. The findings reveal significant spatial and seasonal variations in water quality, highlighting the impact of anthropogenic activities and environmental factors on river health.

Physicochemical Parameters

The observed pH values, ranging from 6.2 to 6.9 across the sampling sites, indicate a slightly acidic condition, particularly at downstream locations. Although the pH remained largely within the World Health Organization (WHO) permissible range for freshwater (6.5–8.5), the gradual decrease downstream suggests the influence of domestic and agricultural runoff. Studies conducted in similar Nigerian river systems, such as the Nworie and Awba rivers, have also reported slightly acidic conditions at sites influenced by human settlements, attributing these changes to effluents from household waste and agricultural fertilizers (Okoro et al., 2018; Eze et al., 2020) [5, 9]. The slight acidity may affect aquatic life by altering the solubility of metals and nutrients, which can influence the bioavailability of potentially toxic elements.

Temperature measurements across sites were relatively stable, ranging from 26.8°C to 28.7°C, consistent with typical tropical river conditions in Southeastern Nigeria. Such stability suggests minimal thermal pollution; however, the slight increase downstream could be attributed to reduced canopy cover and increased exposure to sunlight, as documented in other studies of tropical rivers (Onyema et al., 2017) [8].

Turbidity values increased from upstream to downstream and were higher during the rainy season. Upstream sites-maintained turbidity within acceptable limits, while downstream sites occasionally exceeded recommended thresholds (25 NTU). Elevated turbidity is indicative of suspended solids, likely originating from soil erosion, surface runoff, and waste discharge from residential and agricultural areas. The seasonal increase during the rainy period aligns with findings from other studies in Southeastern Nigeria, where rainfall intensifies sediment transport and nutrient loading into rivers (Chukwuma & Eze, 2019) [4].

Dissolved oxygen (DO) decreased progressively downstream, with values at Sites 4 and 5 approaching critical levels during the rainy season. Reduced DO may result from increased organic pollution, which enhances microbial respiration and oxygen demand. The concomitant increase in biochemical oxygen demand (BOD) downstream supports this interpretation, as BOD values reflect the concentration of biodegradable organic matter. Similar trends have been reported for the Nworie River and Awba Reservoir, where urban runoff and domestic wastewater discharge resulted in declining DO and elevated BOD downstream (Okoro et al., 2018; Eze et al., 2020) [5, 9].

Nitrate and phosphate concentrations increased both downstream and during the rainy season. These nutrients, while essential for aquatic ecosystems in small amounts, can contribute to eutrophication when present in excess. The observed ranges (nitrates: 2.8–6.5 mg/L; phosphates: 0.9–2.3 mg/L) indicate moderate enrichment, particularly at Sites 4 and 5. The sources of these nutrients likely include agricultural fertilizers, domestic sewage, and organic matter from livestock waste. These findings are consistent with prior research, which has highlighted nutrient enrichment in Nigerian rivers receiving runoff from agricultural lands and densely populated areas (Akinboro & Oladipo, 2020) [1].

Heavy metal analysis showed that lead concentrations remained within permissible limits (0.004–0.010 mg/L), while cadmium approached or slightly exceeded the recommended threshold at downstream sites during the rainy season. The accumulation of cadmium downstream may result from small-scale industrial discharges or leaching from agricultural inputs. Though generally low, the presence of cadmium warrants attention due to its toxicological implications, including potential bioaccumulation in aquatic organisms and human health risks through water consumption or fish intake (WHO, 2017).

Microbiological Parameters

Microbial analysis revealed high total coliform and E. coli counts, particularly at downstream sites and during the rainy season. Dry season total coliform counts ranged from 60 to 180 CFU/100 mL, while rainy season counts increased to 95–200 CFU/100 mL. E. coli counts followed a similar trend, exceeding WHO standards for safe freshwater use. These results suggest significant fecal contamination from human and possibly livestock sources. The increase during the rainy season may be attributed to surface runoff carrying waste from residential and agricultural areas into the river, consistent with findings from other rivers in Nigeria (Onwuka et al., 2019) [10]. High microbial loads pose serious public health risks, particularly for communities relying on river water for domestic purposes, bathing, or irrigation.

Spatial and Seasonal Trends

The spatial trend observed, with deteriorating water quality downstream, reflects cumulative anthropogenic impacts along the river. Upstream sites, located in less disturbed areas, exhibited lower turbidity, nutrient concentrations, and microbial counts. Downstream sites, situated near densely populated communities and agricultural lands, exhibited elevated levels of contaminants. Seasonal trends indicate that the rainy season exacerbates these issues through increased runoff, erosion, and dilution effects, leading to higher turbidity, nutrient loads, and microbial contamination. These findings align with studies on seasonal water quality fluctuations in Nigerian rivers, emphasizing the importance of monitoring during both wet and dry periods (Adewale et al., 2018) [2].

Comparison with Previous Studies

The observed physicochemical and microbiological patterns in Alulu River are comparable to other studies in Southeastern Nigeria. For instance, Okoro et al. (2018) [9] reported downstream increases in turbidity, BOD, and nutrient concentrations in Nworie River, while Eze et al. (2020) [5] noted high microbial contamination in Awba Reservoir, particularly during rainy periods. Similarly, the slight acidity observed aligns with Onyema et al. (2017) [8], who documented pH reductions in rivers influenced by domestic and agricultural runoff. However, heavy metal levels in Alulu River were lower than those reported in industrially impacted rivers such as the Kaduna River, suggesting relatively limited industrial pollution in this area (Abubakar et al., 2019) [3].

Implications of the Findings

The findings of this study have several practical and theoretical implications. From a public health perspective, the elevated microbial loads, particularly E. coli, indicate that Alulu River is not suitable for direct domestic use without treatment. The moderate nutrient enrichment suggests potential eutrophication risks, which could affect aquatic biodiversity and water usability for irrigation. Heavy metal accumulation, though generally low, highlights the need for continuous monitoring, particularly given the potential for bioaccumulation in fish and subsequent human exposure.

Theoretically, this study contributes to the understanding of river water quality dynamics in semi-urban Nigerian contexts, demonstrating the combined effects of anthropogenic activities and seasonal changes on physicochemical and microbiological parameters. It reinforces the importance of integrated water quality monitoring as a tool for sustainable water resource management.

Limitations

Several limitations should be acknowledged. First, the study focused on selected physicochemical and microbiological parameters, and other contaminants such as pesticides, hydrocarbons, or emerging pollutants were not assessed due to resource constraints. Second, the sampling period spanned only four months, which may not fully capture long-term seasonal or inter-annual variations. Third, while five sites were selected to represent the river, localized point-source pollution events may have been missed. Despite these limitations, the methodology provided robust insights into the overall water quality status of Alulu River.

Unexpected Observations

An unexpected finding was the slightly elevated cadmium concentrations at downstream sites during the rainy season, which exceeded recommended thresholds. While the source of this contamination was not directly identified, it may be linked to agricultural runoff or leaching from informal waste disposal sites. Further investigation is needed to determine the origin and potential ecological and human health impacts of cadmium accumulation.

Future Research Directions

Future studies should extend monitoring to include emerging contaminants such as pesticides, pharmaceuticals, and microplastics, which are increasingly recognized as significant threats to freshwater systems. Long-term monitoring across multiple years would improve understanding of seasonal and inter-annual variations. Additionally, the use of bioindicator species could provide complementary insights into ecological health. Investigating community practices and waste management strategies in surrounding areas could also help link anthropogenic activities to observed water quality trends and inform targeted interventions.

Conclusion

The evaluation of water quality parameters of Alulu River in Enugu East Local Government Area revealed notable spatial and seasonal variations in both physicochemical and microbiological characteristics. Downstream sites exhibited slightly acidic pH, increased turbidity, elevated biochemical oxygen demand, and higher concentrations of nitrates and phosphates compared to upstream locations. Heavy metal concentrations, including lead and cadmium, remained mostly within permissible limits, although cadmium approached critical levels at downstream sites during the rainy season. Microbiological analysis indicated high total coliform and E. coli counts, exceeding recommended standards, particularly during the rainy season, suggesting significant fecal contamination from anthropogenic sources. These findings underscore the influence of human activities and seasonal changes on river water quality, highlighting potential risks to public health and aquatic ecosystems. The study contributes to understanding freshwater quality dynamics in semi-urban Nigerian river systems, providing empirical data that can inform water management policies and pollution mitigation strategies.

Based on the results, it is recommended that regular monitoring programs be implemented to track physicochemical and microbiological parameters, particularly during the rainy season. Public awareness campaigns on proper waste disposal and pollution control should be prioritized. Future research should investigate emerging contaminants, long-term seasonal trends, and the ecological impacts of nutrient enrichment and heavy metal accumulation to ensure sustainable management of Alulu River.

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